DEVELOPMENT OF COPPER OXIDE BASED SOLID STATE pH SENSOR

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ABSTRACT

In this paper an electrochemical pH sensor that has been fabricated using copper (ii) oxide modified glassy carbon electrode (CuO/GCE). The difference in peak potential shift while using CuO/GCE as pH sensor was measured using square wave voltammetry (SWV); and was found to be linear over the range of pH 3-9, with a sensitivity of 60 mVpH^{-1}. The sensor shows a potential drift of 1.97 –3.33 % after three hours of continuous use; and could retain 95% of its initial sensitivity after 1 week of use. The electrode was found to respond both in the presence and absence of oxygen, further expanding the potential applications to include it into de-oxygenated environments. The CuO based sensor showed good sensitivity and long term stability that may show the way to develop a low cost solid state pH sensor for a wider range of applications.

Keywords: *pH, metal oxide, electrochemistry, sensor*

1. INTRODUCTION

In electrochemical sensor, pH sensor provides a logarithmic measure of hydrogen ion concentration and are essential analytical tools in laboratories, clinics and industries . Since many biological and chemical reactions are dependent on pH level, so the reliable monitoring of the pH is extensively required (Qin et al., 2015). In addition, monitoing pH needs to be fast, accurate and reliable in various applications. Usually in pH measurement, a considerable amount of time involves for several calibration steps, as well as handling delicate pH sensors during the measurement processes (Fog et al., 1984). Therefore, natural abundant materials as solid state sensing system is always researchers are looking for.

Various metal oxide based potentiometric pH sensors have drawn much attention in past decades due to their stability against dissolutions, and independence from cationic interferences (Bezbaruah et al., 2002). Several solid sate electrodes based on metal oxide such as CuO,TiO_2, RuO_2, SnO_2,Ta_2O_3,IrOx, PtO_2, PdO, Hg_2O, HgO and Sb_2O_3 have been used to fabricate pH electrodes (Kim and Midgley el al. 1989,1990). Among these metal oxide, CuO is most promising, because it is a p-type semiconductor metal oxide having narrow bandgap ~ 1.2 eV in bulk (Moura et al. 2010). For CuO, the starting growth material is inexpensive and easy to get, and the methods to prepare these materials are of low cost and having a large surface area-to-volume ratio, high surface reaction activity and biocompatible (Song et al 2010). Among the oxide materials being studied, CuO is one of the widely used earth abudant oxide that is being used as catalyst for various applications (Kuo et al., 2007). CuO is also one of the interesting and appropriate metal oxides for biosensing applications (Wang et al. 2009). Besides owing to its exceptional electrochemical activity and the possibility of promoting electron transfer at a lower potential, as well as it's availability, stability, good morphological and structural control of the synthesized CuO nanostructures; it is a good candidate for pH sensing applications (Li et al., 2011). In 2011,

S. Zaman (Zaman et al, 2011) reported CuO nano flower as an electrochemical pH sensing materials, and showed the effect of the pH on the growth morphology of nanoflowers.

Thereby, in this work, a facile, stable and sensitive pH sensor is fabricated by synthesizing CuO nanoparticle using hydrothermal method, followed by the drop cast of the nanoparticle along with chitosan and ion exchange resin, Nafion on the surface of GC electrode. In oxygenated and deoxygenated environment the sensing abilities of the electrode were investigated in terms of static and dynamic properties, such as calibration, sensitivity, response time and stability. This method allowed the fabrication suitable for mass production and cost effective; and will open up the door to fabricate a miniaturized carbon based sensing platform, which would be suitable, both in clinical, industrial and environmental applications.

2. METHODOLOGY

2.1 REAGENTS

Cupper nitrate Cu $(NO_3)_2.3H_2O$, hexamethylenetetramine (HMT), $NH_3.H_2O$, were purchased from E.Merck, Germany. Disodium hydrogen phosphate (Na_2HPO_4), sodium dihydrogen phosphate ($NaH_2PO_4.2H_2O$), sodium bicarbonate ($NaHCO_3$), disodium carbonates (Na_2CO_3), NaOH pellets, Nafion and chitosan were purchased from Sigma-Aldrich, India. All chemicals were of analytical grade with high purity. Different pH solutions were prepared using phosphate buffer, sodium hydrogen carbonate, sodium hydroxide, sodium acetate and acetic acid.

2.2 SYNTHESIS OF CuO

For the hydrothermal synthesis of CuO nanoparticle, a mixture of hexamethylenetetramine (HMT) and $Cu(NO_3)_2.3H_2O$ were dissolved in 30 ml distilled water under continuous stirring, followed by introducing 5 ml of $NH_3.H_2O$ (5%). Once the solution became clear, 40 ml of this solution has been transferred into a teflon-lined stainless steel autoclave and heated at 160ºC for 6 h. Once the autoclave cooled down naturaly at room temperature, the black precipitated from autoclave collected, washed few times with distilled water and ethanol in order to remove the impurities. Precipitates obtained were dried at 50 ºC for 6 h in air, to get CuO nanoparticle (Zhang et al., 2011).

$$NH_3.H_2O \rightarrow NH_4^{\ +} + OH^-$$
$$2\left[Cu\left(NH_3\right)_4\right]^{2+} + 2OH^- \rightarrow CuO + NH_3 + +H_2O$$
$$Cu^{2+} + 2OH^- \rightarrow CuO + H_2O$$

2.3 FABRICATION OF CuO/GCE

A simple casting method has been used for the fabrication of CuO/GCE (Liu et al., 2013). At first, GCE was polished with 1.0 and 0.3 µm alumina powder, followed by washing with water and sonication in ethanol and water respectively. A mixture of 0.2g CuO nanoparticle, 0.1g chitosan and 0.1 mL Nafion was dropped on to the clean surface of GCE, and dried at room temperature for overnight.

2.4 MEASUREMENTS

SWV and zero current potentiometric (OCP) measurements were performed using a potentiostat/galvanostat (model: µStat 8400, DropSens (Spain). Here three electrode cells has been used, where CuO/GCE were in use as a working electrode with Ag/AgCl and Pt wire acts as reference and counter electrodes, respectively. SWV measurements were conducted using a frequency of 50 Hz, pulse width of 20 mV and step height of 10 mV. The pH of the buffer solutions were perfectly determined using an Orion 2 Star commercial portable pH meter.

3. RESULTS AND DISCUSSION

3.1 COPPER OXIDE NANOPARTICLE CHARACTERISATIONS

The morphology of the hydrothermally synthesized CuO nanoparticles was observed by SEM with a magnification of (5000X to 100,000X) (Fig. 1a-d). A flower shape CuO nanostructure can be seen with an average particle size less than 100 nm width of each rod. According to the EDX datas (Fig. 1e), the average content of copper (Cu) and oxygen (O) is 8.09% (atomic percentage) and 7.17% (atomic percentage) respectively, which confirm the copper oxide (Cu: O=1:1) component. However, C peak appeared, possibly from sample holder. Due to the higher in density of nanostructure, flower like CuO has a huge potential, as high surface area would improve the sensitivity of the current response.

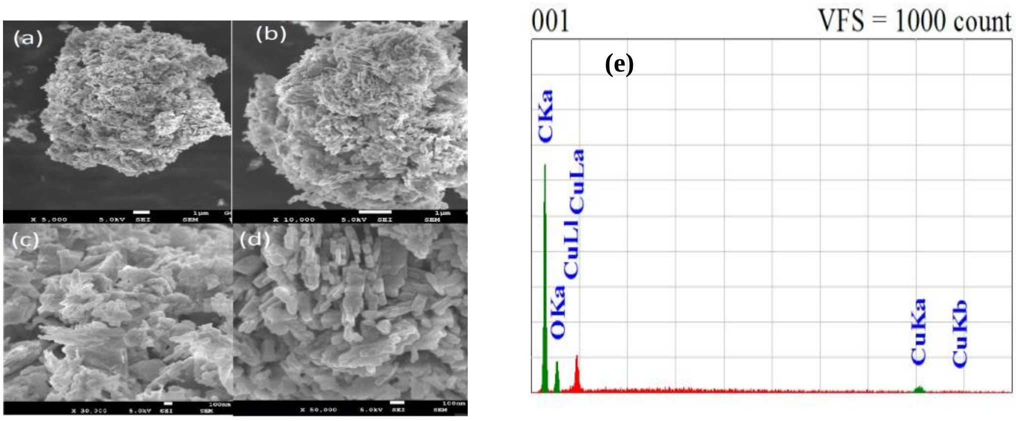


Figure 1: (a-d) Scanning electron microscopy (SEM) images of CuO nanoparticles at different magnifications (20000 to 50000X); (e) Energy dispersive x-ray spectroscopy (EDX) images of CuO nanoparticles

3.2 RESPONSE OF MODIFIED ELECTRODE TO pH CHANGES

To demonstrate the sensing application of CuO, a novel pH sensor was constructed by deposition of the aqueous dispersion of CuO on to GCE surface in the presence of chitosan and Nafion (Fig. 2). Nafion is an anionic ion exchange resin, which facilitate holding CuO on the surface of the electrode, as well as block anionic interferents. To investigate the properties of modified electrode, cyclic voltammograms (CVs) with different scan rate has been conducted with scan rates of 60-160 mVs^{-1}. On the increases of both anodic and cathodic current linearly with the scan rates, indicating that the electrochemical reaction is surface controlled. The current increases with scan rate for the sensor show no significant resistance on the electrode surface (Figures not shown here) (Zhang et al., 2011).

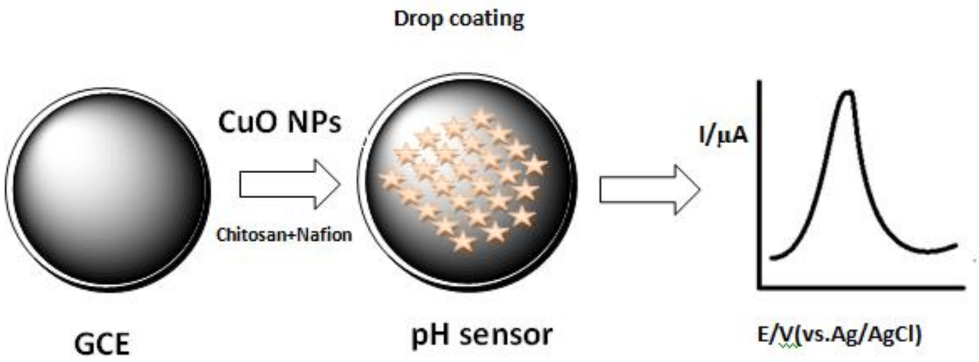


Figure 2: Schematic diagram on fabrication of pH sensor.

Since the primary focus of this paper is to fabricate and characterize the CuO/GCE as pH sensor, the SWV response in a series of aqueous buffer solutions ranging from pH 3 to 11 has been conducted. SWV is the fast, accurate and sensitive in compare to other relevant voltammograms (Harris et al. 2010). A defined peak has been obtained in every buffer solution using CuO/GCE as electrode. This sharp peak at around 0.04V at pH 7 belongs to the reduction of Cu^{2+} to Cu. However, as the pH changes from 3 to 11, the peak potential shifts from higher potential to lower potential (Fig. 3a) up to pH 9. Afterwards, the electrode shows non linear response. Therefore, in Fig. 2a, an only pH change has been shown from pH 3 to 9. This linear response with different pH solution may attributes to fewer protons available while pH increases, that speeds up the reduction of Cu^{2+} to Cu; resulted lowering the peak potential. However, we also can see the reduction of peak current, which could be due to the limiting of species that can be reduced. Possible sensing mechanism has shown in equation 1 (Kurzweil et al.2009).

$$CuO + H_2O + 2e^- \rightarrow Cu + OH^- \quad \textbf{(1)}$$

The measured potential is thus dependent on the pH and a linear relation from pH 3 – 9 has been obtained. Also due to each pH changes, potential shift around 60 mV that attributes to Nernstian behavior (Fig. 3b). According to the equation 2, the sensitivity of the sensor can in that case be obtained by the slope of the linear regression (Flavia et al., 2015).

$$E = E^0 - (2.303RT/F)\, pH = E^0 - 0.05916pH \quad \textbf{(2)}$$

Where E^0 considered as the standard electrode potential, R is considered as the gas constant, T is considered as the temperature, and F is considered as the faradays constant. In this situation, owing to the redox reaction, all space charges are formed, that indicating a good performance of the sensor. In this work (Fig. 2b), the pH sensor formed that demonstrated a mean sensitivity value of 60 ± 0.01 mV/pH which is close to the theoretical value. The correlation coefficient of R^2 values of about 0.97. This confirms the good sensitivity of the CuO/GCE to the variation of proton concentration in solution due to the redox reaction involved in the process.

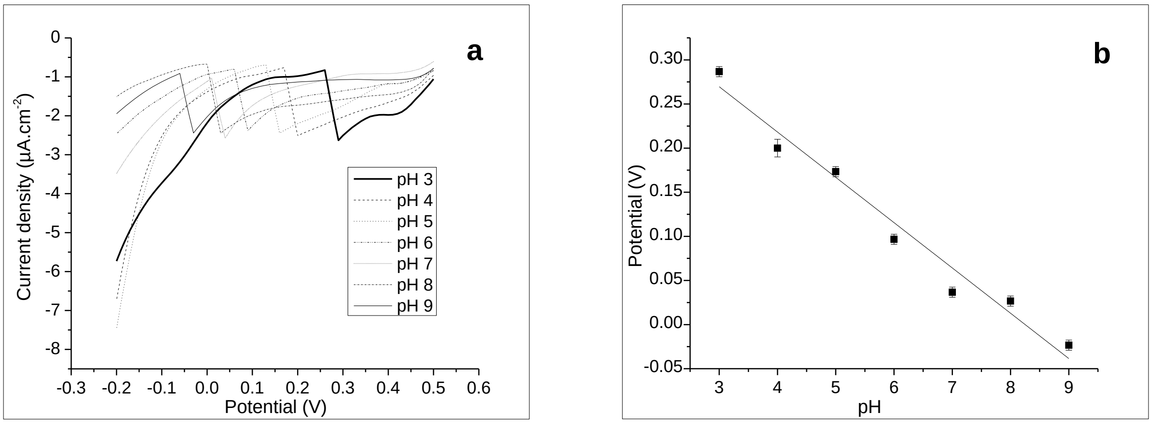


Figure 3: (a) SWV of 0.1 M buffers with different pH values (pH 3-9) on CuO/GCE (scan rate 0 .05 V/s); (b) corresponding calibration curve.

The pH sensitivity obtained using SWV has been verified using OCP. In addition, investigation of pH response has been done in both directions (pH 3 to 9 and pH 9 to 3), just to make sure electrode provides reversible behaviour and independent against pH value or direction of pH changes. It's concluded that, the potential response of the organized electrode demonstrates pH sensitivity of 60 mV/pH (Fig. 2b). As well as, it has also been found that CuO/GCE can successfully sense the pH ranging from 3 – 9 by measuring both SWV and OCP. It is needed to mention that all the experiment for pH measurement has been investigated with blank GC electrode, and no linear relation has been obtained.
Moreover, the drift of this sensor has been tested, along with oxygenated and deoxygenated environment. Sensitivity in this work compares favourably with recent reports tabulated in Table 1. To the best of our knowledge, no articles have demonstrated the use of CuO nanoparticle based GCE as sensing platform for detecting pH. We also have demonstrated stability, drift study on this system for H^+ detection. To determine the output response and the repeatability, the pH electrode was tested three to four times in a PBS buffer solution with pH ranging from 3 to 9. It was observed that the CuO/GCE showed excellent reproducibility, stable potentiometric response and good sensor stability. Similar tests have been obtained by Lidia et al. (Lidia, 2014), where author have modified gold electrode using WO_3 nanoparticle.

3.3 ELECTROCHEMICAL CHARACTERIZATION WITH AND WITHOUT OXYGEN

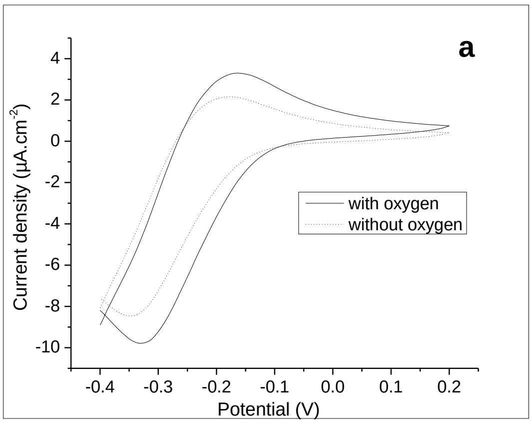
In this work, we have evaluated the possibility of the CuO/GCE to be used in both an oxygenated and de-oxygenated atmosphere. Fig. 4a shows the voltammetric response of CuO/GCE that placed in buffer solution both in the absence and presence of oxygen. As oxygen is always present in the atmosphere, therefore, it is crucial that pH electrode should be performed equally in both environments. From the comparative results, it clearly can be seen that the reductive current differences slightly increases in the presence of oxygen. However, peak potential is unaltered; that concluded that this sensor can be used to measure the pH of solutions, irrespective of the O_2 concentration.

Table 1: A comparison of different pH sensors

Electrode	Sensitivity mV/pH	Drift %	pH range	Reference
GCE/CuO	60 ± 0.01	1.9 – 3.33	3 - 9	This work
Gold /CuO NF	28	_	2-11	(Zaman, 2011)
Gold /WO_3 NPs	−56.7 ± 1.3	_	5 - 9	(Lidia, 2014)
GCE/WO_3 NPs	60 ± 0.01	2.4 – 5.0	3-11	(Irani, 2016)
AQ–Fc/AuNAE	70	1-3	2-11	(Jamal, 2013)
AQ–Fc/GCE	52	< 5	3 - 8	(Lafitpe, 2008)
AQ–CNT/GCE	51	1.4	3 - 10	(kumar, 2011)
AQ-Sulfonate/GCE	38	2 – 3	2 - 10	(Shiu, 1996)
Thick Film/RuO_2	30	_	4-10	(Glance, 2012)

3.4 DRIFT AND STABILITY MEASUREMENT

Fabricated electrode has been examined for the drift study and three buffer solutions with pH 5, 7 and 9 were chosen to determine the contribution the signal drift played. Fig. 4b showed that pH signal needed 0 – 90 minutes to stabilize, depending on the pH values. However, a good accuracy has been obtained thereafter. The drift of the potential reading in a neutral pH buffer was 0.83 mV within 3 hours. In the same way a potential drift of 1.97 mV was recorded in an acidic solution and 3.33 mV for a basic media. Largest drift has been obtained for pH 9 buffer, however, less than 4%. Stability of the electrode has been investigated, and found 95% of its initial activity after 7 days of continuous uses. The method described herein demonstrates how the CuO/GCE could be utilized as a pH sensor over a large pH range, with good stability and excellent sensitivity.



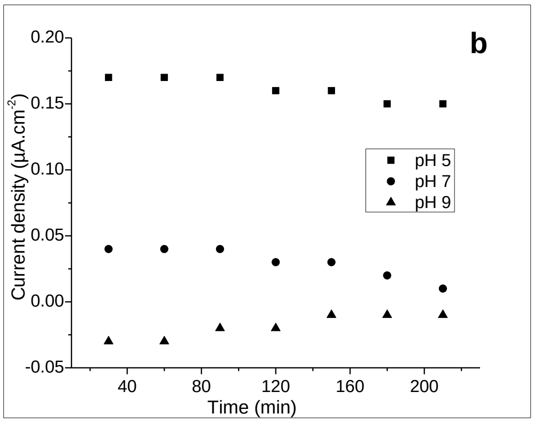


Figure 4: (a) CVs showing the response of the CuO immobilized layer to the presence and absence of oxygen in pH 6 buffer; (b) Electrode drift of CuO immobilized on the GCE; potential readings of pH 5, 7 and 9, signals have been taken every 30 min over a period of 3 hours.

3.5 REAL SAMPLE TEST

It is evident from different research works that new electrode which are proposed as pH sensor usually avoid applying them for the sensing pH in real unbuffered samples. However, in this work, we have validated our sensor against the laboratory standard glass pH electrode in the real sample: malt vinegar and antacid. Electro-analytical SWV signals gained are visible in Fig. (5a, 4b) and comparable values of pH was obtained in antacid at the pH value of 9.00 and malt vinegar at the pH value 4.00 using CuO/GCE as pH sensor. These results demonstrated that CuO/GCE showed same potential value for antacid as measured by the commercial pH sensor. Thereby, it can be concluded that our proposed pH sensor has a huge potential to be developed a solid state, cost effective, portable and reliable pH sensor.

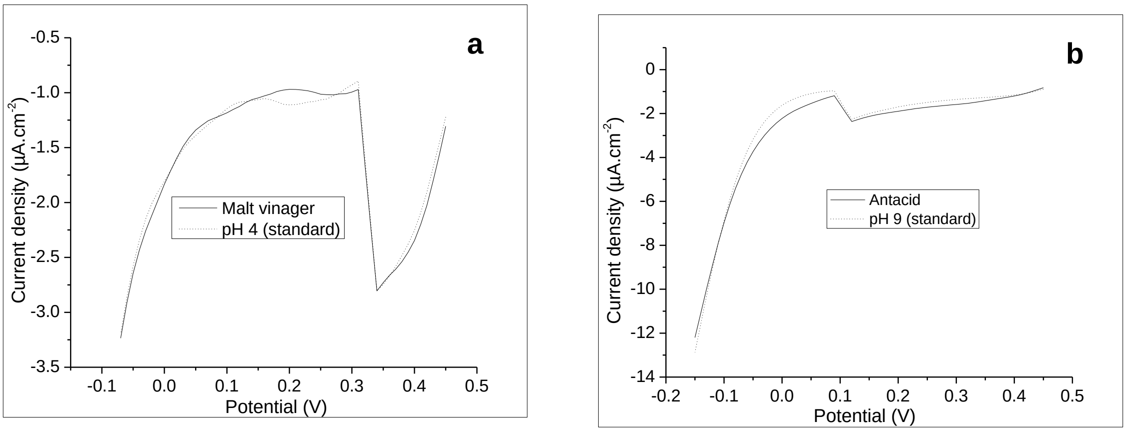


Figure 5: Electrochemical signal (SWV) obtained in “real” unbuffered samples for (a) malt vinegar; and (b) antacid using CuO/GCE.

4. CONCLUSIONS

In this study, we have developed a sensitive, selective and cost effective pH sensor using CuO modified GC electrode. Excellent linearity has been found for pH sensing using CuO/GCE. The sensitivity of CuO/GCE has been found to be 60 ±0.01 $mVpH^{-1}$ and a potential drift of 1.97-3.33% after three hours of continuous use. The sensor showed linearity range of pH 3 -9 and could retain 95% of its initial sensitivity after 1 week of use. The electrode was found to respond both in the presence and absence of oxygen, further expanding the potential applications to include de-oxygenated environments. In conclusion, the result shows that, the CuO nanoparticle is a very promising material for a stable pH sensor. The fabrication method is very cheap and easy applicable compares to the previously reported different sensing platforms. Further work is needed to improve the pH sensor, such as enhancing the stability and sensitivity, directly growth of CuO nanoparticle on different surfaces. Moreover, extensive fundamental electrochemical properties need to be investigated.

ACKNOWLEDGEMENTS

This work is financially supported by the University Grant Commission, Bangladesh.

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Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), 9~11 February 2018, KUET, Khulna, Bangladesh (ISBN-978-984-34-3502-6)

METEOROLOGICAL INFLUENCES ON ATMOSPHERIC PARTICLES IN DARUS SALAM AREA OF DHAKA CITY

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ABSTRACT

We have investigated the effect of meteorological parameters on seasonal variation of particulate matter(PM) (both $PM_{2.5}$ and PM_{10}) using a 4-year (2013-2016) monitoring data of air quality parameters from CASE project implemented by the Department of Environment (DoE). Using monthly data of the Continuous Air Monitoring Station(CAMS) of Darus-Salam, Dhaka, we performed cross correlation analysis between PM and meteorological parameters where inverse relationships of PM with temperature, rainfall and relative humidity were found. Increased space heating during low temperature period, washout effect of rainfall, wet deposition mechanism of higher humidity may be held responsible for these negative correlations. Significant seasonal variation is observed from daily data analysis of Darus Salam station and it has been found that winter PM concentrations are 4.5-5.5 times higher than monsoon PM concentrations. Seasonal cross-correlation between PM_{10} and $PM_{2.5}$ shows lower correlation during winter (December-February) and monsoon (June-September) seasons. Two possible effects can attribute to this seasonal difference: i) presence of space heating during winter which increases $PM_{2.5}$ and ii) presence of rainfall during monsoon which decreases PM_{10}.$PM_{2.5}/PM_{10}$ ratios for different months indicate the contrasting influences of different mechanisms on different sized PM particles. $PM_{2.5}/PM_{10}$ ratio is found to be higher during December-February and lower during March-September with a rise in August, which indicates the effect of 3 mechanisms: i) dilution effect of wind speed on $PM_{2.5}$ during December-February, ii) re-suspension effect of wind speed on PM_{10} during March-September and iii) more pronounced scavenging effect of rainfall on PM_{10} during August. Our study indicates the need for properly accounting the influence of meteorology for better understanding of PM variation in urban areas in Bangladesh.

Keywords: *PM, Meteorology, Cross Correlation, Seasonal Variation, $PM_{2.5}/PM_{10}$ ratio*

1. INTRODUCTION

Particulate matter (PM) is defined as a complex mixture of different sizes of airborne particles having different chemical compositions. They are mainly classified in two categories, the finer particles ranging from 0.005 µm to 2.5 µm which is called $PM_{2.5}$ and the coarser particles ranging from 2.5 µm to 10 µm which is called PM_{10}. Like other countries, particulate matter (PM) in ambient airhas become one of the major concerns in Bangladesh. According to the Global Air Report 2017, Dhaka city has become 2nd most air polluted city("State of Global Air Report," 2017). PM concentration in the air has been found to have significant correlation with diseases such as chronic respiratory illness, cardiovascular morbidity etc.(Dockery et al., 1993; Pope et al., 2002)To fully understand the processes responsible for this distribution of particulate matters, analysis of the meteorological condition and detailed study on their influence on PM concentration are required. Different studies have shown that particulate matters are highly dependent on specific meteorological parameters(Dayan et al., 2005; DeGaetano et al., 2004). It has been reported that wind speed, precipitation, relative humidity, temperature, time of day, atmospheric stability etc. arethe major factors to drive the PM_{10} concentration(Gietl et al., 2009). Several studies have been performed to evaluate the extent of urban pollution in the major cities of

Bangladesh(Begum, 2016; Begum et al., 2014). Although the relationship between meteorology and PM has been investigated, we still have very little information about the dependence of urban aerosol on atmospheric parameter in the major cities of Bangladesh. In this study, we attempted to determine the inherent relation between PM and meteorological parameters in Dhaka city using common statistical techniques. The aim is to obtain a deeper understanding of the processes involved in the variation of PM concentration over time.

2. METHODS AND DATA ARCHIVING

2.1 Data Collection

Under the Clean Air and Sustainable Environment (CASE) project, the Department of Environment (DoE) monitors realtime PM_{10} (24hr), $PM_{2.5}$ (24hr) as well as ambient temperature (1hr), rainfall (1hr), relative humidity (1hr), through 11 Continuous Air Monitoring Stations (CAMS) throughout Bangladesh. We have collected air quality and meteorological data of CAMS-3 (Darus Salam, Dhaka, with longitude of 23˚46'42.35" and latitude of 90˚21'44.54") (Figure 1) and CAMS-8 (Red Crescent Campus, Sylhet) for the year of 2013-2016. However, we have used data of CAMS-3 (Darus Salam, Dhaka) for our analysis.

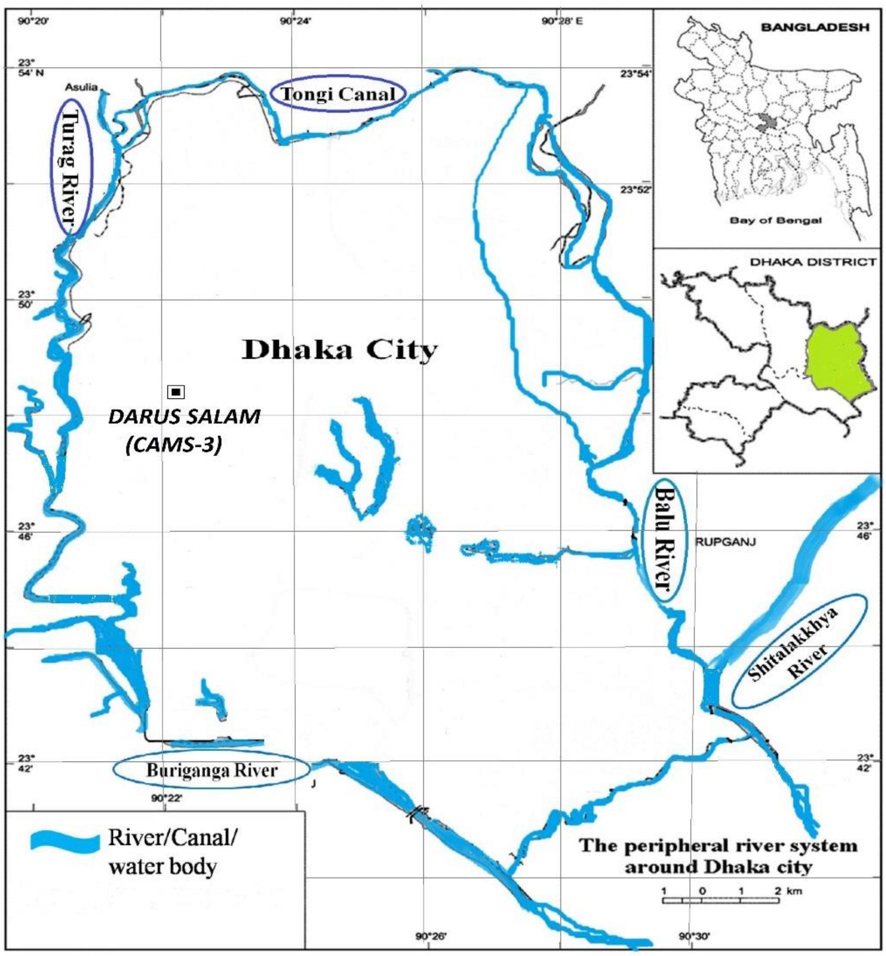

Figure 1: Latitude and longitude of CAMS-3, Darus Salam, Dhaka

2.2 Approach for Analysis

We used multiple linear regression model to quantify the correlation between $PM_{2.5}$ and PM_{10} with meteorological parameters. The regression equation is in the form of

$$y=\beta_0+ \beta_1 x+ \varepsilon \quad (1)$$

In equation (1), y is the concentration of $PM_{2.5}$ or PM_{10}, x is the meteorological parameters (Temperature, Rainfall, Relative Humidity and Solar Radiation), β is the regression coefficients and ε is the error term, where $\varepsilon= (y_i-\hat{y})$, y_i=observed $y$values, $\bar{y}$ = mean value of series y and $\hat{y}$= $y$values given by the equation.The coefficient of determination r^2 measures how related the PM concentration is with response to these meteorological parameters.

$$r^2 = \frac{S_t\text{-}S_r}{S_r} \quad (2)$$

Here, S_t=Total Sum of Squares = $\sum_{i=1}^{n}(y_i-\bar{y})^2$, S_r= Error Sum of Squares =$\sum_{i=1}^{n}(y_i-\hat{y})^2$

$$\text{Adjusted } r^2=1\text{-}\left(1\text{-} r^2\right)* \frac{m\text{-}1}{m\text{-}p\text{-}1} \quad (3)$$

Here, m is the number of elements in a series and p is the number of independent variables. Besides, we have performed cross correlation analysis between PM and meteorological parameters. Since the PM variation and meteorological parameters both vary with time, time dynamic analysis of cross correlation would be the best way to represent the actual relationship between PM and weather parameters through a lead-lag relationship.Basic cross correlation formula we have used is written below:

For $k\geq 0$, $C_{xy}=\sum_{t=1}^{T\text{-}k}\frac{1}{T}[\{x(t)\text{-}\bar{x}\}*\{y(t+k)\text{-}\bar{y}\}]$

For $k\leq 0$, $C_{xy}=\sum_{t=1}^{T\text{-}k}\frac{1}{T}[\{y(t)\text{-}\bar{y}\}*\{x(t\text{-}k)\text{-}\bar{x}\}]$

Here, $x(t)$ is the concentration of PM at time t, $y(t+k)$ is the respective meteorological parameter at time $(t+k)$, k is the lag between two time series x and y, T is the total number of elements in series x and y. In order to standardize the correlation value we have calculated the cross correlation coefficient which is given by:

$$r_{xy}(k)= \frac{C_{xy}(k)}{S_x*S_y} \quad (4)$$

In equation (4), $S_x= \sqrt{C_{xx}(0)}$ and $S_y= \sqrt{C_{yy}(0)}$

3. RESULTS AND DISCUSSIONS

3.1 Average PM Concentration and Meteorological Conditions in Bangladesh

In Bangladesh, the year can be divided into four different seasons: Winter (December-February), Premonsoon (March-May), Monsoon (June-September), Postmonsoon (October-November) (Begum et al., 2014). The climate of Bangladesh experiences prominent variation in weather during different seasons. It endures cold and dry air in winter as well as hot and humid air during the other three seasons. However, high temperature and high humidity is observed for most of the year. Precipitation shows marked distinction between seasons, maximum rainfall occurs in the monsoon and a minimum in winter. During winter, dry soil condition, scanty rainfall and low relative humidity prevails. During premonsoon, rainfall becomes moderately strong and relative humidity increases. During monsoon, moist air condition and high relative humidity prevails. Besides, the amount of rainfall also remains at its highest during this season. In the post monsoon, the amount of precipitation starts to decrease and so does the relative humidity.

Figure 2 shows the daily 24 hr average concentration for $PM_{2.5}$ and PM_{10} spanning for the year of 2013-2016. The average $PM_{2.5}$ and PM_{10} concentrations during the study period are found to be91.03µg/m^3 and 161.69 µg/m^3, respectively. To understand the PM variation throughout the entire year, seasonal and annual mean are calculated for the entire study period and the results are shown in Table 1.

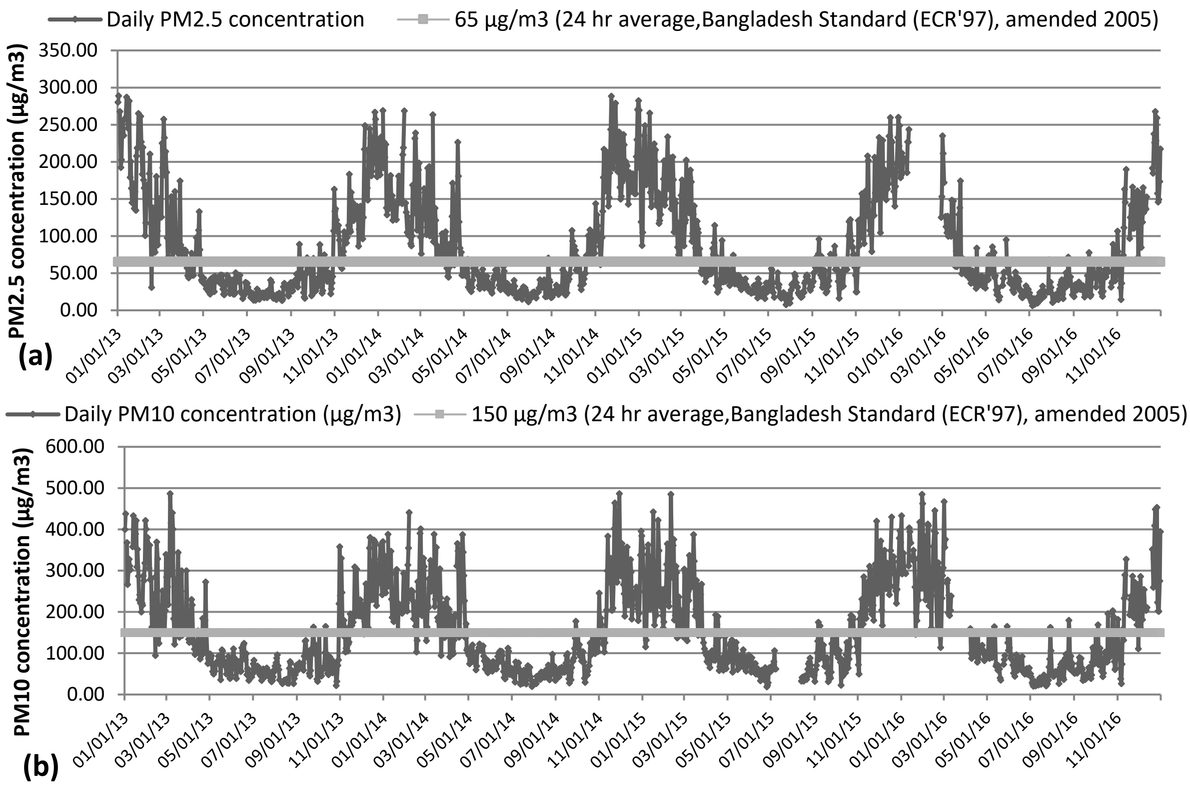

Figure 2: Daily average PM concentration with corresponding Bangladesh National Ambient Air Quality Standard (BNAAQS) for (a) $PM_{2.5}$ and (b) PM_{10}

Winter PMconcentration is found to be considerably higher than the Bangladesh National Ambient Air Quality $PM_{2.5}$ Standard of 65 µg/m^3 (daily 24hr average) and PM_{10} Standard of 150 µg/m^3 (daily 24hr average). For the year of 2013-2016, respectively 172, 194, 174 and 161 daily PM concentrations, corresponding to 48%, 53%, 48% and 44% of the sampling days exceeded the BNAAQS $PM_{2.5}$ limit value. Similarly, for this four-year period, respectively 42%, 44%, 40% and 43% of the sampling days exceed the BNAAQS PM_{10} limit value. From the above statistics, it is evident that $PM_{2.5}$ concentration is more prone to exceed the limit value compared to PM_{10}. Performing the analysis on seasonal basis, the exceedance is found to be highest for winter season (99.45% for $PM_{2.5}$ and 95.85% for PM_{10}) and lowest for monsoon season (4.5% for $PM_{2.5}$ and 1.23% for PM_{10}), while exceedance during other seasons are moderate.

Significant monthly variation has been obtained for both PM fractions. The winter to monsoon ratio of $PM_{2.5}$ and PM_{10} concentration during 2013-2016 were 6.09, 5.56, 5.04 and 6.2 as well as 4.22, 4.54, 4.11 and 4.95, respectively (Table 1). Comparing with other studies, our observations of the difference between PM concentration of winter and monsoon season have been found very high. For example, the winter to monsoon PM ratio has been found to be 2.9 for PM_{10} and 2.2 for $PM_{2.5}$ in India (Kulshrestha et al., 2009) whereas winter to summer ratio of 2.14 for PM_{10} has been found in Egypt(Elminir, 2005). In Bangladesh, during winter, higher atmospheric stability as well as dry weather condition favors suspension of particulate matter in the air. Along with it, brick kilnsremain operational at the same time. On the other hand, during monsoon, aerosol concentration remains low due to scavenging effect of precipitation and the brick kilns also remain closed during that season. Thehigh winter to monsoonPM ratio occurs due to the dual effect of atmospheric condition and brick kiln operation.Besides, the higher winter to monsoon ratio for PM_{10} indicates that this scavenging effect is more pronounced on PM_{10} compared to $PM_{2.5}$.

Table 1: Average PM concentrations, their seasonal ratio and annual exceedance from Bangladesh National Ambient Air Quality Standard (BNAAQS)

Year	$PM_{2.5}$ Average Concentration	PM_{10} Average Concentration	$PM_{2.5}$ Win./ Mon. ratio	PM_{10} Win./ Mon. ratio	Annual $PM_{2.5}$ exceed-ance from BNAAQS (%)	Annual PM_{10} exceed-ance from BNAAQS (%)
2013						
Winter	187.41 ± 57.37	277.24 ± 84.43				
Premonsoon	78.96 ± 52.17	155.22 ± 96.12				
Monsoon	30.77 ± 14.68	65.68 ± 28.22	6.09	4.22	47.12	41.87
Postmonsoon	78.69 ± 40.88	136.94 ± 80.05				
Annual	89.61 ± 73.62	152.31 ± 108.65				
2014						
Winter	168.98 ± 47.93	260.55 ± 68.95				
Premonsoon	89.28 ± 52.55	175.58 ± 89.83				
Monsoon	30.42 ± 11.55	57.34 ± 20.35	5.56	4.54	53.15	43.53
Postmonsoon	117.76 ± 69.83	181.72 ± 117.00				
Annual	95.11 ± 70.50	159.63 ± 108.53				
2015						
Winter	173.48 ± 46.14	258.45 ± 76.65				
Premonsoon	72.89 ± 43.28	139.16 ± 81.85				
Monsoon	34.39 ± 16.11	62.92 ± 30.21	5.04	4.11	47.67	40.5
Postmonsoon	93.32 ± 46.09	169.04 ± 85.18				
Annual	88.32 ± 65.34	148.13 ± 100.82				
2016						
Winter	188.28 ± 34.84	301.96 ± 76.72				
Premonsoon	69.70 ± 43.59	151.52 ± 77.20	6.20	4.95	44.11	43.01
Monsoon	30.38 ± 14.91	61.06 ± 28.68				
Postmonsoon	79.14 ± 48.10	148.32 ± 78.37				

3.2 Seasonal PM Concentration Prevalence

Figure 3 shows frequency distribution of $PM_{2.5}/PM_{10}$ ratio for all seasons which is divided into nine categories starting from <0.2 to <1. Here, during high PM prevailing season i.e. in winter, $PM_{2.5}/PM_{10}$ ratio curve shows a symmetric pattern with its peak at 0.6-0.7 (above 40% of the cases). It indicates that, this ratio fits normal distribution during winter and the contribution of $PM_{2.5}$ remains higher. Similarly, during low PM prevailing season i.e. in monsoon, symmetric pattern is also observed with peak at 0.4-0.5 (above 35% of the cases), which indicates that this distribution too follows normal distribution.However, for premonsoon and postmonsoon season, the distribution is skewed to the right with peak at 0.4-0.5, which indicates that during these seasons, contribution of $PM_{2.5}$ concentration starts to decrease after winter. High $PM_{2.5}/PM_{10}$ ratio during winter indicates that significant portion of particulate matter responsible for air pollution fall under the size distribution of $PM_{2.5}$.

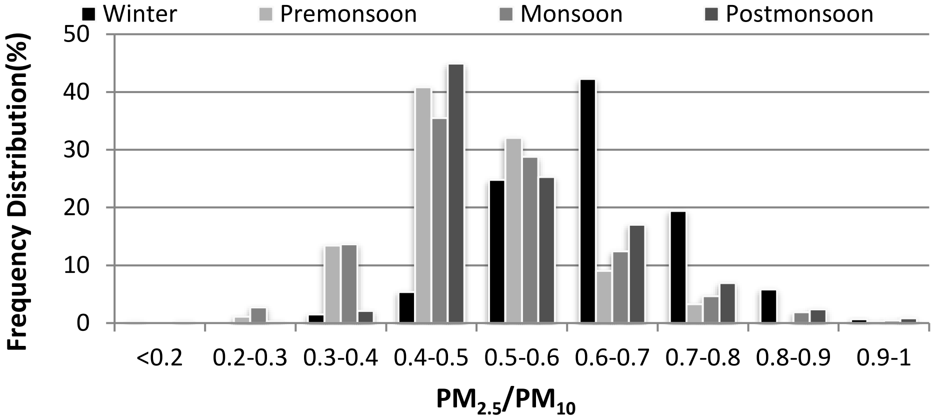

Figure 3: Frequency distribution of $PM_{2.5}/PM_{10}$ ratio

3.3 Relationship between Wind Pattern and PM concentration

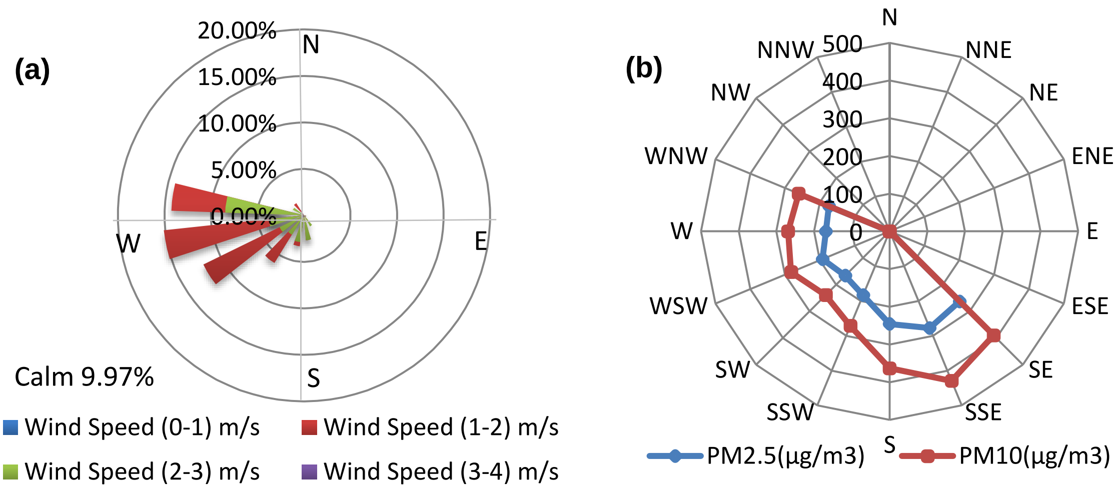

Figure 4: Winter wind rose (a) and radar plot (b) showing $PM_{2.5}$ and PM_{10} concentration at various wind direction for the year of 2013-16 at CAMS-3 (Darus Salam, Dhaka)

To understand the effect of wind mechanism on PM, the data set for winter season is analyzed because the major contributions of PM from regional transport, emission from brick kiln etc. are more dominant during winter season. Wind rose diagram (Figure 4a) show the directional distribution of wind in winter seasons near Darus Salam area. Surface wind directions are divided into 4 major categories: [North (N, WNW, NW, NNW)], [East (NNE, NE, ENE, E)], [South (ESE, SE, SSE, S)], [West (SSW, SW, WSW, W)]. For each direction, the corresponding days are calculated in which the wind flows from the specific direction. Then the PM concentrations of those days are identified and the radar plot in Figure 4b shows the average PM concentration corresponding to the respective wind directions. The percentage frequency of wind direction is in order of West (60.44%)> South (38.46%) > East (1.1%) > North (0%) during the winter season for the year of 2013-2016, which corresponds to average $PM_{2.5}$ concentration of 192.47, 169.15, 206.52 and 0.00 μg/m^3 and average PM_{10} concentration of 306.84, 259.34, 346.04 and 0.00 μg/m^3, respectively. Therefore, near Darus Salam area, a large contribution of PM comes from the western direction. Contribution of brick kiln emissions from the Amin Bazar, Gabtoli area, which are located west of the CAMS-

8 station, are likely causing high PM concentrations.There are also kilns located on southeastern side of the CAMS station which may be contributing to high PM concentrations corresponding to that direction during the winter season, although the frequency of wind direction from the southeastern side is not as dominant as that from the western side.

3.4 Meteorological Parameters Influencing PM Levels

As the dispersion condition of atmosphere is primarily responsible for the accumulation of PM particle in air, in our study we have primarily focused on the role of temperature, relative humidity and precipitationfor the variation of PM levels. The results of the correlation analysis between meteorological parameters and different sized PM particles are shown in Table 2. A significance level of 5% (p=0.05) has been chosen to be the threshold for determining the significance of correlation analysis.

Temperature is found to have strong negative relation with particulate matters ($r_{x\text{-}corr}$= -0.825at lag 0, r^2_{SLR}= -0.681 for $PM_{2.5}$; $r_{x\text{-}corr}$= -0.752at lag 0, r^2_{SLR}= -0.566 for PM_{10}). This represents the fact that, when temperature becomes lower i.e. during winter season, formation of stagnant air condition occurs and simultaneous space heating and coal burning activities increases in the kilns, which gives rise to the particulate matter concentration. Wind speed is found to be second highest influencing parameter ($r_{x\text{-}corr}$= -0.511 at lag 0, r^2_{SLR} = -0.286 for $PM_{2.5}$; $r_{x\text{-}corr}$= -0.494 at lag 0, r^2_{SLR} = -0.266 for PM_{10}). High negative correlation between wind speed and PM particle indicates that, higher wind speed induces higher dilution of particulate matter. As a result, particulate matter in the ambient air becomes dispersed and its concentration gets reduced at higher wind speed conditions.The correlation coefficient between air pollutants and relative humidity is found to be significant ($r_{x\text{-}corr}$= -0.494 at lag 0, r^2_{SLR}= -0.244 for $PM_{2.5}$; $r_{x\text{-}corr}$= -0.6428 at lag 0, r^2_{SLR}= -0.413 for PM_{10}). High humidity indicates higher precipitation events with in cloud scavenging, reduction in the formation of OC (Organic Carbon) and EC (Elementary Carbon), higher moisture absorption and subsequent settling down of particles, all of which eventually result in low concentration of particulate matters.

Table 2: Cross correlation and multiple linear regression analysis results between PM concentrations and meteorological variables

Predict-ion Variable (CAMS 3)	Using Monthly Data (n=48)			
	X Correlation (X-Corr)	Pearson's Correlation (SLR)		
	r(lag)	r^2	Adjusted r^2	Error Sum of Square
$PM_{2.5}$				
Temperature	-0.825(0)**	-0.681**	-0.674**	57763
Wind Speed	-0.511(0)**	-0.286*	-0.270*	129500
Rainfall	-0.376(0)*	-0.141	-0.123	155600
Humidity	-0.494(0)*	-0.244*	-0.228*	136990
Solar Radiation	-0.482(0)*	-0.232	-0.215	139210
PM_{10}				
Temperature	-0.752(0)**	-0.566**	-0.556**	178320
Wind Speed	-0.494(0)	-0.266*	-0.250*	301360
Rainfall	-0.396(0)*	-0.157	-0.138	346130
Humidity	-0.643(0)**	-0.413*	-0.401*	240850
Solar Radiation	-0.362(0)*	-0.131	-0.112	356600

Statistical significance indicators are as follows: **, p < 0.001; *, 0.01>p > 0.001, otherwise 0.05>p>0.01

Correlation analysis between PM concentration and rainfall is also carried out and weak negative correlation is found between these two parameters ($r_{x\text{-}corr}$= -0.376 at lag 0, r^2_{SLR}= -0.141 for $PM_{2.5}$; $r_{x\text{-}corr}$= -0.3959 at lag 0, r^2_{MLR}= -0.157 for PM_{10},). However, a strong negative correlation has been reported between average monthly PM and rainfall in Sylhet. (r= -0.731 for $PM_{2.5}$; r= -0.732 for PM_{10},) (Table 3). In Dhaka, amount of rainfall is low compared to Sylhet where consistent rainfall is a distinct feature (in Northeastern part of Bangladesh). In Bangladesh, rainfall is caused by the influence of the Southwest monsoon (Hossain et al., 2013). Total precipitation in Dhaka in 2016 is 462.02 mm with highest rainfall recorded in July (157.74mm) and total precipitation in Sylhet in 2016 is 1606.8 mm with highest rainfall recorded in the month of April (567.4mm) (https://www.wunderground.com). Therefore, lower correlation in Dhaka may occur due to the long interval of consistent rainfall occurring in this area. Relative humidity and precipitation has been found to have slightly higher correlation with coarser particle. This is because the wash out effect of humidity and precipitation is more profound for the case of coarser particles.

Table 3: Annual cross correlation coefficients between PMand other meteorological parameters (Rainfall & Temperature) at CAMS-3 and CAMS-8

Meteorological Parameters	**CAMS No.**	**$PM_{2.5}$**		**PM_{10}**	
		n	**[a]Correlation Coefficients**	**n**	**[a]Correlation Coefficients**
Temperature					
	CAMS-3(Dhaka)	48	-0.825**	48	-0.752**
	CAMS-8 (Sylhet)	47	-0.855**	48	-0.862**
Rainfall					
	CAMS-3 (Dhaka)	48	-0.340*	48	-0.396*
	CAMS-8 (Sylhet)	47	-0.731**	47	-0.732**

[a]Cross correlation coefficients at zero lag. Statistical significance indicators are as follows: **, p < 0.001; *, 0.01>p > 0.001, otherwise 0.05>p>0.01

3.5 Global Comparison of Correlation Coefficients

A comparative analysis has been conducted between this study and other literature values, based on the calculated correlation coefficients for $PM_{2.5}$ and PM_{10} with meteorological parameters and is presented in Table 4. From Table 4, it is evident that, our results show similarity with the analyses conducted in India, Turkey and Egypt, whereas contradictory relationship has been observed for studies conducted in Greece, Germany and USA.

Negative correlation for temperature with PM has been observed for Bangladesh, India, Turkey and Egypt whereas, positive correlation has been obtained for Greece, Spain, Germany and USA. This variation mainly occurs due to the difference in weather condition and chemical composition of particulate matters all over the world. Weather patterns are similar for Bangladesh, India and Turkey, since all of them fall under the subtropical region. Space heating and biomass burning activities during winter season contribute to the higher concentration of PM. During low temperature period, particulate matter concentration becomes high and thus inverse relationship is formulated between PM and temperature. However, considering USA, Greece and Germany, high temperature is favorable for atmospheric chemical reaction. Hence, secondary particle formation is favored by temperature increase which produces positive correlation between PM and temperature.

Considering Relative humidity (RH), high humidity condition leads to higher moisture absorption and subsequent settling down of particles in the subtropical region. Therefore, negative correlation occurs for RH with PM in Bangladesh, India and Turkey, whereas around the European countries i.e. in USA, Greece and Germany, ultrafine particulate formation is found to be positively affected in the presence of high humidity thus resulting in positive correlations between particulate matter and relative humidity.

Table 4: Pearson's correlation coefficients between PM_{10} and meteorological parameters in different regions

Reference	Country	Temperature	Relative Humidity	Wind Speed	Precipitation
$PM_{2.5}$					
(Galindo et al., 2011)	Spain(yearly)	-0.016	0.048	-0.496	--
--	Bangladesh	-0.681	-0.244	--	-0.141
(Tai et al., 2010)	USA(yearly)	0.4-0.7	(-0.1)-(-0.15) 0.05-0.14	(-0.05)-1.0	--
(Bhaskar et al., 2010)	India(yearly)	-0.64	--	-0.53	-0.01 -0.74
(Akyuz et al., 2009)	Turkey(winter)	-0.324	-0.108	-0.350	--
(Chaloulakou et al., 2003)	Greece(winter)	0.46	--	-0.54	--
PM_{10}					
(Elminir, 2005)	Egypt(yearly)	-0.48	0.252	--	--
(Galindo et al., 2011)	Spain(yearly)	0.601	0.189	-0.334	--
--	Bangladesh	-0.566	-0.413	--	-0.157
(Hien et al., 2002)	Germany(yearly)	0.17	-0.15	-0.49	-0.38
(Akyuz et al., 2009)	Turkey (winter)	-0.155	-0.237	-0.409	--
(Bhaskar et al., 2010)	India(yearly)	-0.34	-0.44	-0.17	-0.53
(Chaloulakou et al., 2003)	Greece(yearly)	0.39	--	-0.43	--

3.6 Relationship between Different PM Size Fractions

Table 5: Cross correlation analysis results between $PM_{2.5}$ and PM_{10} concentrations

$PM_{2.5}$ \ PM_{10}	Winter	Premon-soon	Monsoon	Postmon-soon	All Data
Winter	0.792(0)**				
Premonsoon		0.922(0)**			
Monsoon			0.812(0)**		
Postmonsoon				0.954(0)**	
All Data					0.944(0)**

Statistical significance indicators are as follows: **, $p < 0.001$; *, $0.01 > p > 0.001$, otherwise $0.05 > p > 0.01$

The relationship between fine particles $PM_{2.5}$ and coarse particle PM_{10} is studied using cross correlation coefficients and the results are presented in the Table5.Winter and monsoon correlation coefficients have been found to be lower than the coefficients of other seasons. These differences between the coefficients are due to meteorological conditions those drive the PM concentration to change. It is linked to the seasonal changes of the weather conditions. During winter, there are major natural sources of PM, such as the space heating and coal burning activities, fossil fuel burning form vehicles and burning of agricultural soil and clays in the brick kilns. These activities produce significant amount of fine particles i.e. $PM_{2.5}$. Therefore, the contribution of fine particles becomes much higher in winter. Besides, during monsoon season, significant reduction in PM_{10} occurs by the wet deposition mechanism of continuous precipitation. Thus, increase in $PM_{2.5}$ in winter and decrease in PM_{10} in monsoon leads to the reduction of correlation coefficients between $PM_{2.5}$ and PM_{10} during these seasons. During other seasons, the contribution of abovementioned sources, which mainly enriches $PM_{2.5}$, becomes low. As a result, the obtained coefficients are higher for other seasons compared to winter.

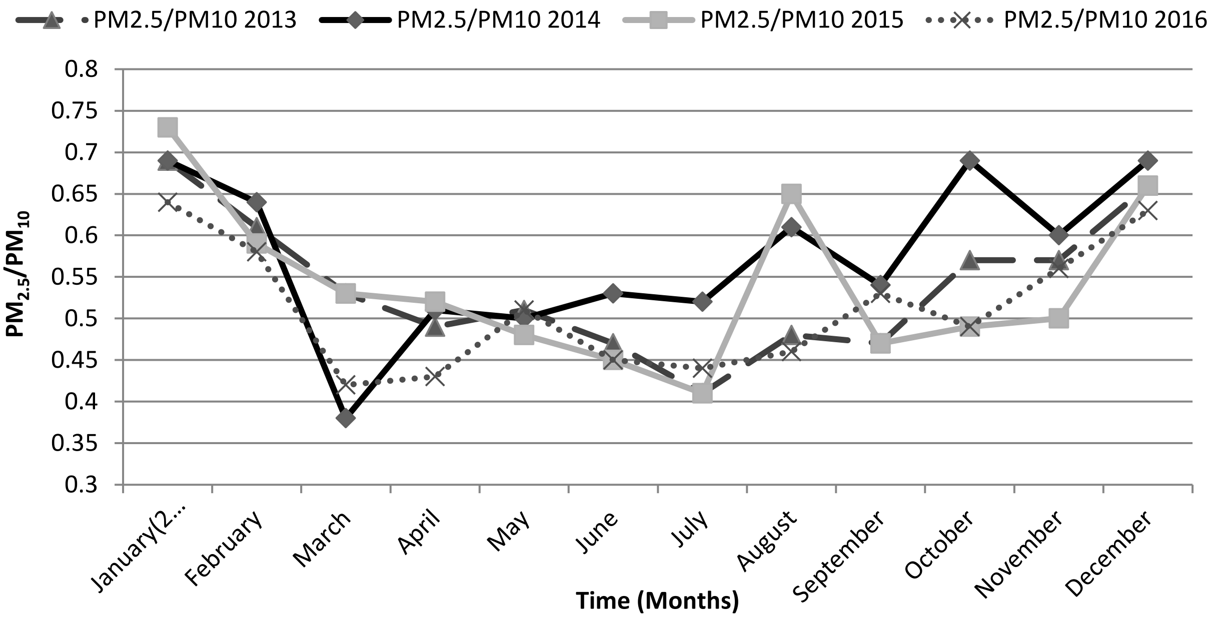

Figure 5: Annual variation of $PM_{2.5}/PM_{10}$ for the years of 2013, 2014, 2015 and 2016

We have examined annual $PM_{2.5}/PM_{10}$ variability from 2013 to 2016 and found that the ratio remains low during the period of March to September i.e. premonsoon-monsoon season (Figure 5). During this period, wind speed remains at its maximum which induces the re-suspension effect of PM_{10}. Therefore, the concentration of PM_{10} becomes higher in the atmosphere compared to $PM_{2.5}$. Besides, a distinct rise of $PM_{2.5}/PM_{10}$ ratio can be observed in August. During August, rainfall remains at its maximum, which induces scavenging mechanism that works more effectively on PM_{10}. As a result, average concentration of PM_{10} drops more compared to $PM_{2.5}$, resulting in a distinct rise in $PM_{2.5}/PM_{10}$ ratio. Therefore, this figure is indicative of 3 mechanisms: i)dilutioneffect of wind speed on $PM_{2.5}$ during December-February, ii) re-suspension effect of WS on PM_{10} during March-September and iii)more pronounced scavengingeffect of rainfall on PM_{10} during August.

4. CONCLUSION

We have examined the influence of meteorological parameters on seasonal variation of particulate matter (PM) using a 4-year (2013-2016) monitoring data of air quality parameters. Using monthly-data of the Continuous Air Monitoring Station (CAMS) of DarusSalam, Dhaka, we performed cross-correlation and Pearson's correlation analysis between PM and meteorological parameters. Inverse relationships of PM with temperature, rainfall and relative humidity have been found. Increased space heating during low temperature period, washout effect of rainfall, dry and wet scavenging effect of higher humidity may be held responsible for these negative correlations. Significant seasonal variation is observed and it has been found that winter PM concentrations are 4.5-5.5 times higher than monsoon PM concentrations. $PM_{2.5}/PM_{10}$ ratios for different months indicate the contrasting influences of different mechanisms on different sized PM particles. An analysis on seasonal variation of PM, will act as a guiding assistance to formulate a comprehensive interpretation of the extent of particle pollution over the highly polluted urban areas in Bangladesh as well as to take actions to reduce exposure to air pollution. Further research in this field i.e. study on the relationship between particulate matter and meteorology may provide meaningful information to get insight about any possible association of PM concentration with climate change.

ACKNOWLEDGEMENTS

The authors would like to thank the Department of Environment (DoE) for providing the background air quality and meteorological data.

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Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), 9~11 February 2018, KUET, Khulna, Bangladesh (ISBN-978-984-34-3502-6)

AN ASSESSMENT ON WATER SUPPLY, SANITATION AND WASTE MANAGEMENT IN SLUMS OF DHAKA CITY

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ABSTRACT

A slum is an adjoining settlement which grows haphazardly in an unwholesome condition and where the residents are characterized as having inadequate housing and basic services. Cities are being flooded with people looking for a job and a decent income. The City of Dhaka is not an exception to it. The paper reports on the condition of basic services such as water supply, sanitation and waste management in slums of Dhaka City. A vast majority of people having no other places to go, then ends up in the squatter settlements and slums sprawling within the City. This study was undertaken to assess the present scenario of the number, structure and housing condition of slum, nature of slum people, income patterns, and water supply at community or household level, thorough behavioral practices in sanitary and waste disposal systems in the slums of collected sample from selected locations. The study was conducted to get an external evaluation of the effectiveness of the basic services-water supply; sanitation practice and waste management system of slums are situated in Dhaka city. For this, 10 slums of Dhaka city has been represented in this paper by analyzing the census and survey report. The conditions of the slums are analyzed using T -test, F-test and Z-test and nonlinear regression analysis. The study ends up with the decision that the conditions of the service facilities are not adequate in the slums of Dhaka city and a lot of works need to be done to improve the facilities for making the slums in shape for the dwellers habitation.

Keywords: *Dhaka, Regression analysis, Slum, Sanitation, Water supply, Waste Management*

1. INTRODUCTION

Dhaka is the largest city of Bangladesh. Slum population has beenlargely increased in Bangladesh over the last three decades along with the expansion of cities and towns. Urban population of Dhaka city are continuing to increase, especially poor sections of the population, mostly girls and women who seek jobs in garment factories, the Dhaka Export Processing Zone (CEPZ) and other industries ending up living in slums. Water supply and sanitation facilities in terms of quality and quantity are utmost necessary for assessing the living environment of the slum. In many areas the sanitation coverage is much below than that of the national coverage figure, According to Center for Urban Studies it's only 13.5% in metropolitan slums(Town, 2009).Waste management in different slums is very poor indeed.

Environmentally sound waste management must go beyond the mere safe disposal or recovery of wastes that are generated and seek to address the root cause of the problem by attempting to change unsustainable patterns of production and consumption. This implies the application of the integrated life cycle management concept, which presents a unique opportunity to reconcile development with environmental protection. Each day Dhaka city is producing over 3000 tons of households waste (Islam K. H., 2001).On the other hand Dhaka City Corporation collects almost less then half of it(Chowdhury, 2006). The rest remains on roadsides, open areas. So, most of urban bodies are finding it very difficult to keep pace with the demand for adequate solid waste management. It will become very difficult to find sites to bury the waste as the city expands, and transport costs to transfer the waste will increase.The volume of needs to be reduced to a sustainable level.

This need have also provided a window of opportunity for cities to find solutions.

- ❖ Involving the community and private sector.
- ❖ Involving innovate technologies and disposal methods.
- ❖ Involving behavior changes and awareness rising.

Some private and community based organizations prove it that ”trash can be cash”. So, all it need to rethinking, organizing and planning about handling waste. It is obvious that the current approach for waste disposal that is focused on municipalities and uses high technology, to move more towards waste processing and waste recycling, and minimization. All these things involves public–private partnerships, community level awareness and participation, and using low energy / low technology resources.
Solid waste is any garbage, refuse, sludge, or other discarded material, including solid, liquid, semi-solid or contained gaseous material resulting from industrial, commercial mining, or agriculture operations or from community activities. (Islam, 2001) Each month, the plant produces 3 tons of bio-fertilizer, which sells for about $0.04 per kilogram (Hai, 2002).
The revenue is enough to make the operation self-sustaining, covering production costs and providing well-paying jobs to employees.Wastes of slums can also be reduced.
The key activities and role for managing solid wastes of Dhaka city are performed by several groups of people.The four main types of actors in this process are:

- ❖ The Municipal Government(DCC).
- ❖ The Formal Private (Commercial) sector, in their role as potential solid waste function contractors like, Waste Concern, Bangladesh.

Almost 15 percent (i.e., more than 467.65 tons) inorganic fraction of the waste is recycled in Dhaka City (Enayetullah, 2002)

The overall objectives is to assess the condition of 10 slums of Dhaka city are

- ❖To assess the selected slums for basic services- water supply, sanitation practice and waste disposal system.
- ❖To compare the assessed condition with the same from literature data.
- ❖To analyze the conditions of the slums statistically using T-test, F-test, Z-test and nonlinearregression analysis
- ❖To find a way of reducing the environmental pollution by comparing the collected data

Essential goal of the study is to investigate the water supply, sanitation facility and waste disposal system of Dhaka City Corporation slums. It is an effort to understand these basic facilities and the overall environmental condition in different slums of Dhaka city in these days. This information can also play an important role to carry out of development program activities and improving the living condition of slums in future.A case study methodology is conducted to examine the general environmental scenario of 10 slums of Dhaka, port city of Bangladesh between 2016 and 2017. The slums under the study were chosen randomly from different study reports.

2. METHODOLOGY

A case study methodology is conducted to examine the general environmental scenario of 10 slums of Dhaka city of Bangladesh between 2016 and 2017. The slums under the study were chosen randomly from different study reports.

2.1. Data Collection System

The following flow-chart summarizes the research methodology that was followed for this thesis:

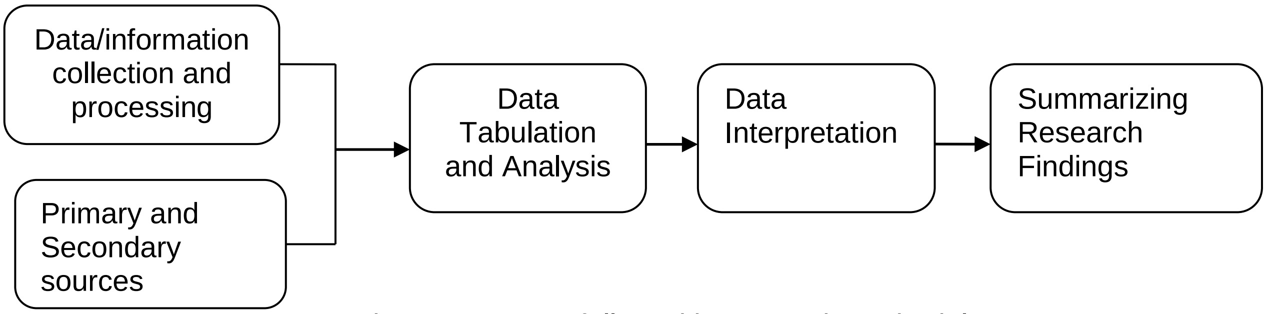

Figure 1: Stages followed in research methodology.

2.2 Scenario of Slums in Dhaka City

Total 10 numbers of slums are studied and the detailed scenario of the slums of Dhaka city parameters can be considered as follows:

3.1 Name Of The Studied Slums

1) Hazaribagh
2) kawnia Colony
3) Coloni Bosti
4) Tejgaon Bosti
5) Rishipara
6) Diyabari
7) Komlapur Bosti
8) Bou Bazar
9) Balurmat Colony
10) Kalunogor Bosti

3.2. Condition of Water Supply Facility

The classification of water sources in the slums of Dhaka city is shown below in figure 2

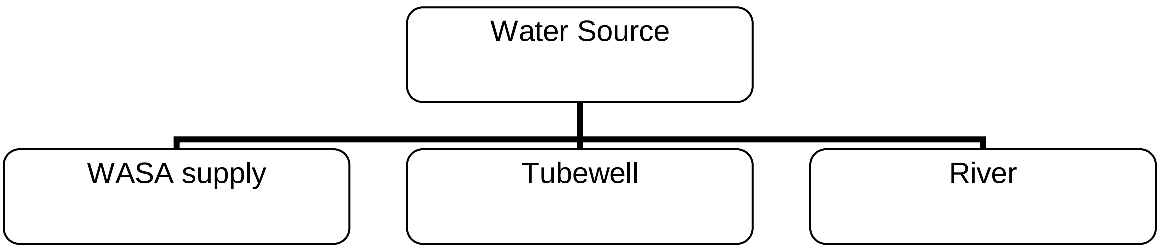

Figure 2: Classification of water source

3.3 Condition of Sanitation Practice

For the detailed and corresponding condition of slum sanitation practice, the pattern of sanitation as
Single, Communal, Hanging and Open sanitation practice in slum areas is shown in Figure 3

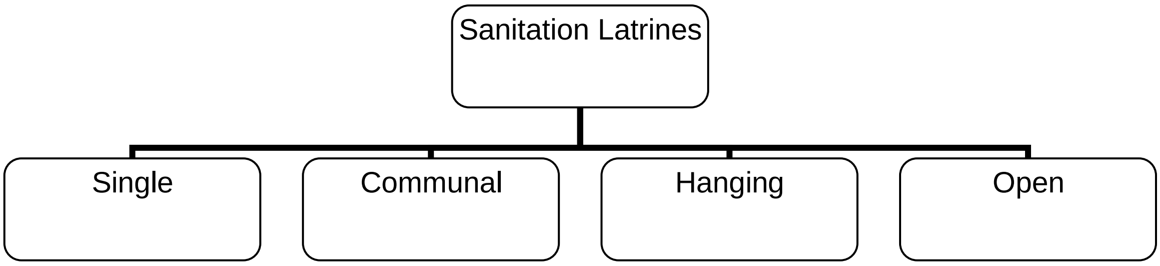

Figure 3: Pattern of sanitation facility

3.4 Condition of Waste Management System

Collected data of available waste disposal patterns categorized according to as Dustbin, Open space, Ditch and Community is shown in Figure 4

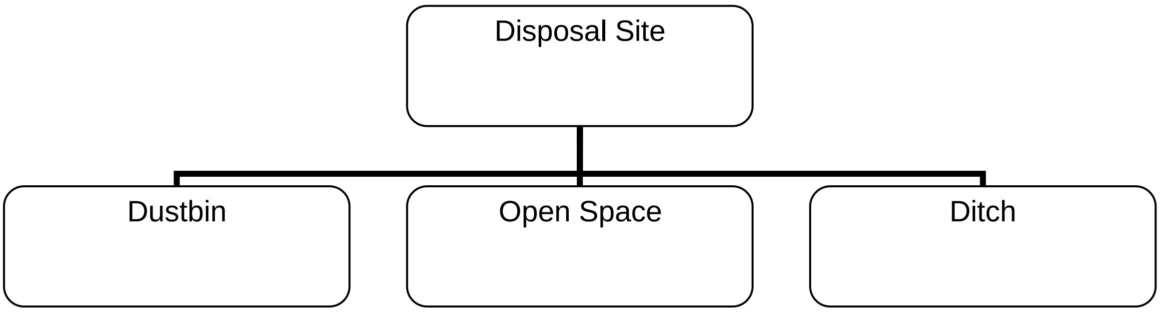

Figure 1 : Waste disposal pattern

3.5 Housing Condition

The quality of housing is one of the most basic indicators characterizing slum settlements. The majority of slum houses (56%) in the six cities were of very poor quality (weak and temporary structures or kutcha units), while another 42.4 percent were semi-pucca type (Star, June 2009). A very small proportion (1.1%) was dilapidated older buildings, while only 0.5 percent was good quality homes.

3.6 Food Consumption Pattern & Health Condition

Consumption pattern of slum dwellers depict that rice, potato, vegetable and edible oil are consumed on daily basis. Food composition sometimes is only rice with potato or peas or fish which are cheap to them. Protein energy intake is widely low in urban slums. Though, a large number of households can manage fish in weekly basis, but the quality of fish is relatively low. Inadequate access to safe water and sanitation leads millions of our people to various health problems. Water and vector born diseases like diarrhoea, dysentery, typhoid, worm infestation and polio, malaria, hepatitis A and E are too common in the slums. Many people are reported sick due to different types of water-borne diseases.67% of affected people have been reported as suffering from diarrhoea(Solid & Management, n.d.). It is said that nutritious food prevents chronic disease as it helps children to recover disease quickly like diarrhoea. But majority of households cannot afford healthy food items like protein food, not even in weekly basis.

4. RESULTS AND DISCUSSIONS

4.1. T-Test (Interpretation of Correlation Coefficients)

T-test has been conducted between population with available water source, sanitation and waste management scenario respectively to understand the sufficiency compared to it. Comparing population with available water source: Here for ten slums we represent the water source by X and population by Y and the sum of X, Y, X^2, Y^2, XY is 69, 56200, 735, 443740000 and 378800 respectively.

$$we\ know, r = \frac{XY - \frac{\sum X \sum Y}{N}}{\sqrt{(\sum X^2 - \frac{(\sum X)^2}{N}) * (\sum Y^2 - \frac{(\sum Y)^2}{N})}} = 0.049 \ldots (1) \quad Now, t = \frac{r\sqrt{(n-2)}}{\sqrt{(1-r^2)}} = 0.138 \ldots (2)$$

From two tailed T-table analysis if the degree of freedom is (10-2) = 8, t must be at least 2.306 to reach p<.05. But calculated t is 0.138, so there is no statistical relation between Population and Available Water Source. But if the no. of water source increases, significant relationship can be established between these two criteria. In other words, no. of water source is insufficient compared to the population in these slums. Comparing population with available sanitation facility: Here for ten slums we represent the sanitation system by X and population by Y and the sum of X, Y, X^2, Y^2, XY is 633, 56200, 61079, 444000000 and 5023600 respectively.

$$we\ know, r = \frac{XY - \frac{\sum X \sum Y}{N}}{\sqrt{(\sum X^2 - \frac{(\sum X)^2}{N}) * (\sum Y^2 - \frac{(\sum Y)^2}{N})}} = 0.893 \ldots (3) \quad Now, t = \frac{r\sqrt{(n-2)}}{\sqrt{(1-r^2)}} = 5.61 \ldots (4)$$

From two tailed T-table analysis if the degree of freedom is (10-2) = 08, t must be at least 2.306 to reach p<.05. But calculated t is 5.61, so there is statistical relation between Population and Available Sanitation Facility. In other words, available sanitation facility is sufficient compared to the population in these slums. Comparing population with available waste management facility: Here for ten slums we represent the waste management by X and population by Y and the sum of X, Y, X^2, Y^2 and XY is 13, 56200, 29, 443740000 and 105000 respectively

$$we\ know, r = \frac{XY - \frac{\sum X \sum Y}{N}}{\sqrt{(\sum X^2 - \frac{(\sum X)^2}{N}) * (\sum Y^2 - \frac{(\sum Y)^2}{N})}} = 0.812 \ldots (5) \quad Now, t = \frac{r\sqrt{(n-2)}}{\sqrt{(1-r^2)}} = 3.93 \ldots (6)$$

From two tailed T-table analysis if the degree of freedom is (10-2) = 8, t must be at least 2.306 to reach p<.05. But calculated t is 3.93, so there is a statistical relation between Population and Available Waste Management Facility. In other words, Available Waste Management facility is sufficient compared to the population in these slums.

4.2. F-Test to Understand the Relationship among the Studied Services Provided in the Slum

Here for ten slums we represent the water supply X1, sanitation facilities X2 and waste management X3 and the sum of X1, X2, X3, X12, X22, X32 is 69, 633, 13, 735, 61079, 29 and the sum of n is 30
Grand Total (GT) =69+633+13=715

$$Correction\ factor\ (CF) = \frac{GT^2}{n} = \frac{715^2}{30} = 17040.83 \ldots (7)$$

$$Total\ Sum\ of\ Squares, SS_T = \sum (X_1{}^2 + X_2{}^2 + X_3{}^3) - CF$$
$$= \left(\sum X_1{}^2 + \sum X_2{}^2 + \sum X_3{}^3\right) - CF \ldots (8)$$
$$= 735 + 61079 + 29 - 17040.83 = 44802.17$$

$$Here, n_1 = 10, n_2 = 10, n_3 = 10, and\ K = 3$$

$$Sum\ of\ Squares\ between\ samples\ SS_b = \left[\frac{(\sum X_1)^2}{n_1} + \frac{(\sum X_2)^2}{n_2} + \frac{(\sum X_3)^2}{n_3}\right] - CF \ldots (9)$$
$$= 40561.9 - 17040.83 = 44802.17$$

$$Sum\ of\ Squares\ within\ Samples\ SSw = SS_T - SS_b = 21281.1 \ldots (10)$$

Total Degree of Fredom=n-1=30-1=29

Degree of Freedom between Samples = K – 1= 3 – 1 =2

Degree of Freedom within Samples = n –K = 30 – 3 = 27

$$Mean\ of\ Sum\ of\ Squares\ between\ Samples\ MSSb = \frac{SSb}{k-1} = 11760.535 \ldots (11)$$

$$Mean\ of\ Sum\ of\ Squares\ within\ Samples\ MSSw = \frac{SSw}{n-k} = 7882.263 \ldots (12)$$

$$F = \frac{MSSb}{MSSw} = 1.49 \ldots (13)$$

From T-table (α = .05) for degree of freedom df1=2 & df2=27, F ratio must be 3.35. But the calculated F value is less than that. So studied services in slums are not equally available. This means the facilities provided in these slums are not sufficient enough in each other's comparison. To lead a better life these services are yet to be improved. These facilities are related to each other to such an extent that improving one is not going to recover their situation. These facilities need improvement equally and at the same time too otherwise all the efforts will be in vain.

4.3 Z-Test (Test Significance of Difference Between Two Sample Proportions)

Then,

$$Z = \left| \frac{P_1 - P_2}{\sqrt{[P(1-P) * \{\frac{1}{n_1} + \frac{1}{n_2}\}]}} \right| \ldots (14)\ \text{Here, } P = \frac{n_1 P_1 + n_1 P_2}{n_1 + n_1} \ldots (15)$$

$$Hypothesis: \pi_1 = \pi_2; no\ difference\ exists;$$

$$\pi_1 \neq \pi_2; difference\ exists\ between\ samples.$$

Water Supply Scenario of Studied Slums with Respect to Balurmat colony: For example, In Rishipara slum, Population, N1 = 6000 and No. of water source, X1 = 8 In Kawnia Colony slum, Population, N2= 3200 and No. of water source, X2= 4

$$Here, P_1 = \frac{X_1}{N_2} = \frac{7}{510} = .0013 \text{ and } P_2 = \frac{X_2}{N_2} = \frac{11}{12000} = .00125; Here, P = \frac{N_1P_1 + N_2P_2}{N_1 + N_2} = .00128$$

$$Z = \left| \frac{P_1 - P_2}{\sqrt{[P(1-P) * \{\frac{1}{n_1} + \frac{1}{n_2}\}]}} \right| = .0638$$

Table-1 : Water Supply Scenario of Studied Slums with Respect to Balurmat Colony.

Name of Slum	Population	Water Source	Ratio ,P=X/N	Total Ratio	Z	Error 5%	Decision
Rishipara	6000	8	0.0013	0.00128	0.0638	1.96	Huge Difference Between Two Slums
Kawnia Colony	3200	4	0.00125				

5.CONCLUSION

The Aim Of This Thesis Is To Determine The Overall Condition Of The Slums In Dhaka City Including Water Supply, Solid Waste Management, Sanitation System Etc. The Study Was Conducted By The Direct Interview Of Slum Dwellers And The Observation Of The Conditions Of Slums. The Study Shows That The Facilities Available In The Slums Are Not Sufficient For The Huge Number Of Slum Dwellers. Development Projects Should Be Implemented. Increasing Public Awareness Is Also Important. We Have To Include Some Recommendations That Can Be Applied For The Future Development Of The Slum. Out Of The Studied Slums, Condition Of Komlapur Bosti, Tejgaon Bosti, Bou Bazar And Kalunogor Are The Worst. So Far From Studied Survey, We Can See That The Value Of F Which Indicates The Relationship Among The Studied Services Provided In The Slums Is 1.49 Which Is Far Less Than The Standard Value That We Get From The F-Table. Also From The Z-Test We See That There Is Huge Difference Between Two Slums. So We Should Clearly Mention That Our Studied Slums Are Not Provided Sufficient Facilities. We Should Imply Safer And Healthier Water Source For The Domestic Uses Of The Slum Dwellers. Scattered Waste Is The Main Reason For The Sickness Of The Slum Dwellers, So We Should Stablish At Least 2-3 Nos Municipal Communal Bin In Every Slums. From Our Observation, Diyabari And Hazaribagh Slums Are Comparatively Good Condition Among The Ten Surveyed Slums. The Surrounding Of These Slums Is Quite Clean And Dwellers Are Provided Better Sanitation Facilities And Good Water Supplies From Wasa Or Shallow Tube Wells. Waste Management System Is Quite Good And Uniform In These Slums. Though People Are Not Fully Happy About Their Condition But The Condition Is Far Better Than Previous Slums.

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Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), 9~11 February 2018, KUET, Khulna, Bangladesh (ISBN-978-984-34-3502-6)

ENVIRONMENTAL HEALTH IMPACTS ASSESSMENT DUE TO BRICK KILNS: A CASE STUDY ON BADARGANJ UPAZILA UNDER RANGPUR DISTRICT IN BANGLADESH

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ABSTRACT

Brick is one of the most important and available construction material in Bangladesh but Brick kilns are orange-A category industry in Bangladesh. Brick kiln operating in northern part of Bangladesh is known as a leading cause of air pollution. The main objective of this study is to assess the effect of brick kilns on human health. This study is conducted at Badargong upozila. This upazila has 80 brick kilns and all brick kilns use low technology. Thus it produces so much CO_2, CO, NO_2, SO_2 and hydrocarbon around the area and some respiratory related diseases are occurred. Different methods were used for data collection, such as Household Environmental Interview Survey (HIS), Focus Group Discussion (FGD) and Health Examination Survey in different primary school. Three schools were selected these from most affected areas (Ghatabil primary school), moderately affected areas (Kalirdanga primary school) and less affected areas (Jugipara primary school). Most of the interviewee replies that smoke related diseases are much more around brick kilns area. People affected 7.5% more during brick kilns operating period than brick kilns not operating period.

Key word*: Northern part of Bangladesh, air pollution, human health, brick kiln, Badargonj*

1. INTRODUCTION

Recently development works have been increasing day by day so the demand of bricks has also been increasing continuously. Because of increasing demand of bricks people establish much more brick kilns. As a result burning of coal, gas and wood was automatically increased and emission rate of CO_2, CO, N_2O, NO, Hydrocarbon, SO2 etc. was also increased. When any local area produces so much of CO_2, CO, N_2O, NO, Hydrocarbon, SO_2 etc. then it directly affects to the environment and human health. It creates environmental pollution. It is the exposure of much smoke related disease like asthma, respiratory problem, tonsillitis, acute pharyngitis and even cancer. It is also affected the agricultural production. All brick kilns in these study area are situated at the Centre of the agricultural land. Production from these agricultural lands has decreased during brick kiln operating period than brick kiln not operating period.

In the North Dhaka cluster, brick kilns are the city's main source of fine particulate pollution, accounting for nearly 40 per cent of total emissions (Biswas et al., 2009). The impacts of brick kilns were increased as per the increasing of brick kilns. So this study is conducted to assess the impact of brick kilns on human health. This study may give a clear identification about the impacts on health due to brick kilns. Most of the brick kilns in the Badarganj upazila operate from the month of November till April. Day by day the environmental condition and health condition becomes worse because of unplanned construction of brick kilns. Where one brick kiln has established people want to reconstruct another one on this spot to get agglomeration of economics. For this reason many brick kilns have established in one location and it causes pollution blooming in that surrounding locality. This pollution is mainly affected human health and environment According to World Bank in 1996, the main contributing sources for total suspend particles (TSP) in the valley are cement factory (36%), brick kilns (31%), domestic fuel combustion (14%), road re-suspension (9%) and vehicle exhaust (3.5%).

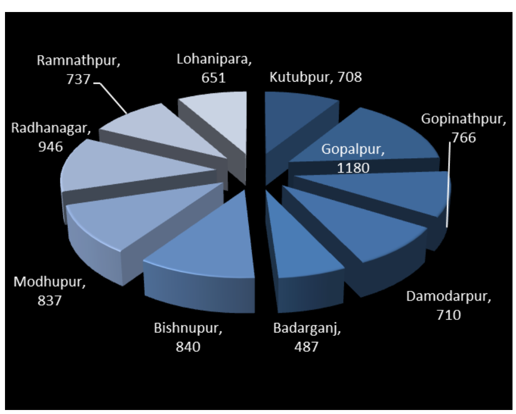
This study can help to realize the present situation in analytically & future trend of brick kilns on these area. In Bangladesh many research have been done already about Brick kilns but their work is being held on CO2 emission, laws of Brick kiln, manufacturing process of brick etc. But the researchers were not concerned about health impacts due to emission from brick kilns. In Bangladesh, there is no research which has mentioned about health impacts due to brick kilns. So, it is the first research which mention about the relation between health impacts due to brick kilns. It may help to the Govt. to take necessary steps in taking decision to permit for construction of brick kilns in rural area.

The aim of this research is to assess and analyze health condition due to emission from brick kilns. Badargonj upazila has been selected as study area under Rangpur district. 80 brick kilns were founded in these area and various classes of people were affected due to brick kilns. For this reason these areas have been selected as study area. The study may help to understand the effects of brick kilns on human health. This study also provides the spatial distribution of brick kilns and vulnerable zone of brick kilns which may help to analyze future trends.

The selected objectives of the research are given below-
- To observe the existing situation of brick kilns in the study area.
- To assess the effect on human health due to brick kilns in the study area.
- To provide some guidelines to reduce the negative impacts of the brick kilns in that locality.

2. STUDY AREA PROFILE

Badarganj is located at 25°40′N 89°03′E. It has 44029 households and total area of 301.29 km². As of the 1991 Bangladesh census, Badarganj has a population of 213431. Males constitute 51.28% of the population, and females 48.72%. (Wikipedia, 2017)



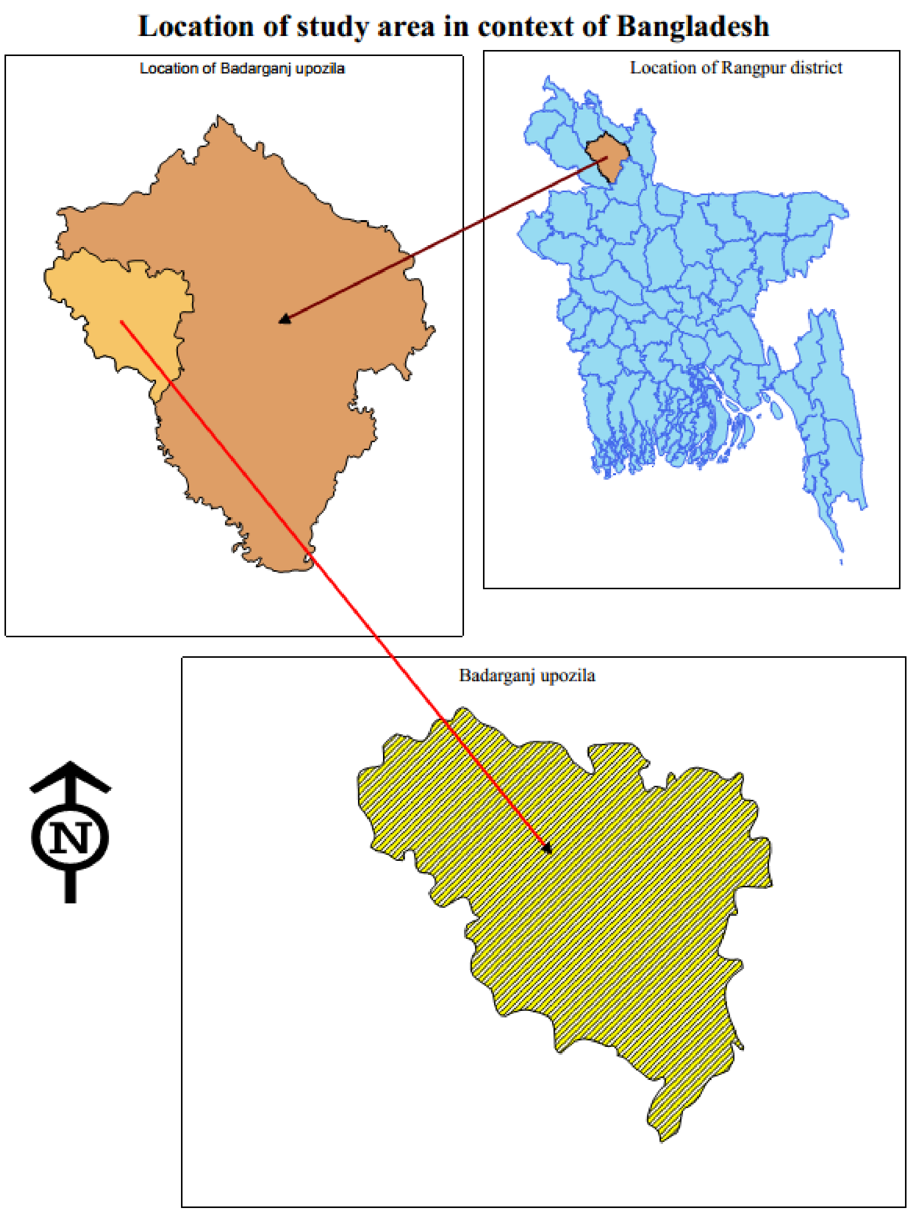
Source: BBS, 2011 and Author

Figure 1: Union wise population density (Per sq. km)

2.1 Economic condition of the study area

Main sources of income of the area are Agriculture 69.54%, non-agricultural laborer 3.32%, industry 0.48%, commerce 13.8%, transport and communication 2.25%, service 4.58%, construction 0.75%, religious service 0.2%, rent and remittance 0.07% and others 5.01%. Ownerships of agricultural land Landowner 41.42%, landless 50.58%. Main crops are Paddy, jute, wheat, potato, mustard seed, tobacco, vegetables etc. (Wikipedia, 2017)

2.2 Location of the study area in context of Bangladesh



Source: Compiled by the Author, 2017

Figure 2: Location of the study area

3. METHODOLOGY OF THE STUDY

This study was conducted at Badarganj upazila. Badarganj upazila has total 80 brick kilns and it is identified that most affected areas are Modhupur union and Ramnathpur union, moderately affected areas are Damodurpur union and Bishnupur union and rest other unions are less affected area. The study uses both primary and secondary data. After collection the data were analyzed using various types of analytical tools like Geographic Information System (GIS 10.3), Microsoft excel, SPSS, Auto cad etc. After that the impacts on health due to brick kilns were identified and recommendations were provided to reduce the negative impacts of brick kilns. The methodological approaches are divided into several parts which are as follows

3.1 Primary sources of data collection

3.1.1 Household Interview Survey (HIS)

Badarganj upazila has total 44029 households among them for the restriction of time and financial cost 2% (880) of total households is sampled for survey. Data were collected from most affected areas (Modhupur union and Ramnathpur union), moderately affected areas (Damodurpur union and Bishnupur union), less affected areas (rest other union) separately. A sequential questionnaire was prepared to gather information from households like how many people live within a family and what are their ages and occupations, smoking habit, asthma, respiratory problem, tonsillitis, acute pharyngitis have or not etc.

3.1.2 School health examination

This survey was conducted at three schools one from most affected areas named as Ghatabil primary school, one from moderately affected areas named as Kalirdanga primary school and another from less affected area which named as Jugipara primary school. The three schools were chosen from same socio-economic conditions. By this survey it is tried to collect attendance sheet of six month (Brick kilns operating period and non-operating period) from the three schools and find out the causes of absent. It is also tried to know how many times a student was sick in a month during Brick kiln operating and non-operating period and by which diseases they were affected?

3.1.3 Focus group discussion (FGD)

Several Focus group discussion has been arranged in the selected sites (i.e. Modhupur union Ramnathpur and Damodurpur union) participation of local political leader, manager of brick kilns, respected person from different professional and social groups like teacher, UP chairman and members, and conscious people who are residing for more than 10-12 years in the study area. It is tried to evaluate the perception of local people through the focus group discussion.

3.1.3.1 Survey Considerations

- How to reduce the impacts on agricultural production and human health due to Brick kilns?
- How can be stabilized the increasing rate of Brick kilns in the study area?
- What initiative should be taken to improve environmental, social and economic conditions?
- Is it safe for pregnant women and children to live in the most affected area?
- How many people were affected and what are the initiatives for them?

3.1.4 Physical observation

This survey was conducted at the problem arising point (i.e. Modhupur union, Ramnathpur union, Damodorpur union and Bishnupur union) in the study area to find out the main scenario and causes of existing impacts due to emission from brick kilns. Mainly it is observed that how many brick kilns are situated in the study area and which unions are the most affected which are moderately affected and which are less affected.

3.2 Secondary sources of data collection

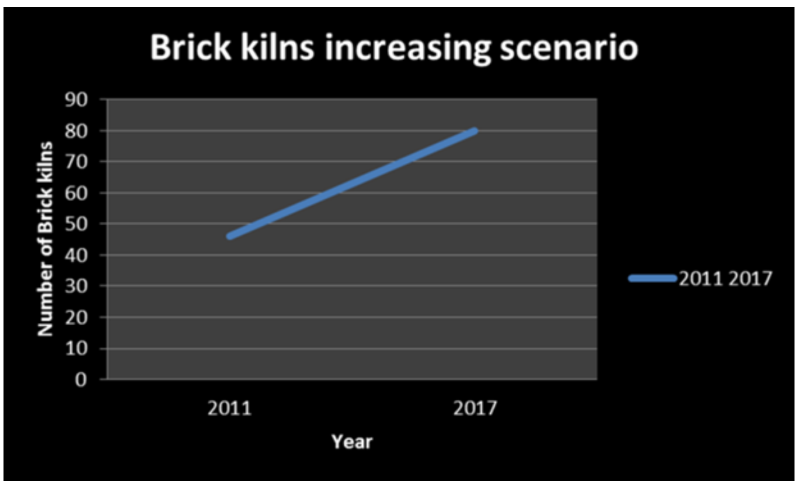
Secondary data were collected from different secondary sources like conference papers, books, journal paper etc.

3.3 Result and discussion

From existing condition analysis and the survey result the impacts on health and agriculture have been identified and some guidelines have been provided to reduce the associated problems due to brick kilns in the study area.

4. RESULT AND DISCUSSION

4.1 Existing condition of Brick kilns in the study area



Source: BBS, 2011 and the Author, 2017

Figure 3: Brick kilns increasing scenario in the study

BBS (2011) reported that Badarganj upozila has total 46 Brick kilns and according to local people it was not more than 10 in 1990 and also not more than 20 in 2000. But in 2017 it reaches at 80 in number it indicates huge change in last 17 years.

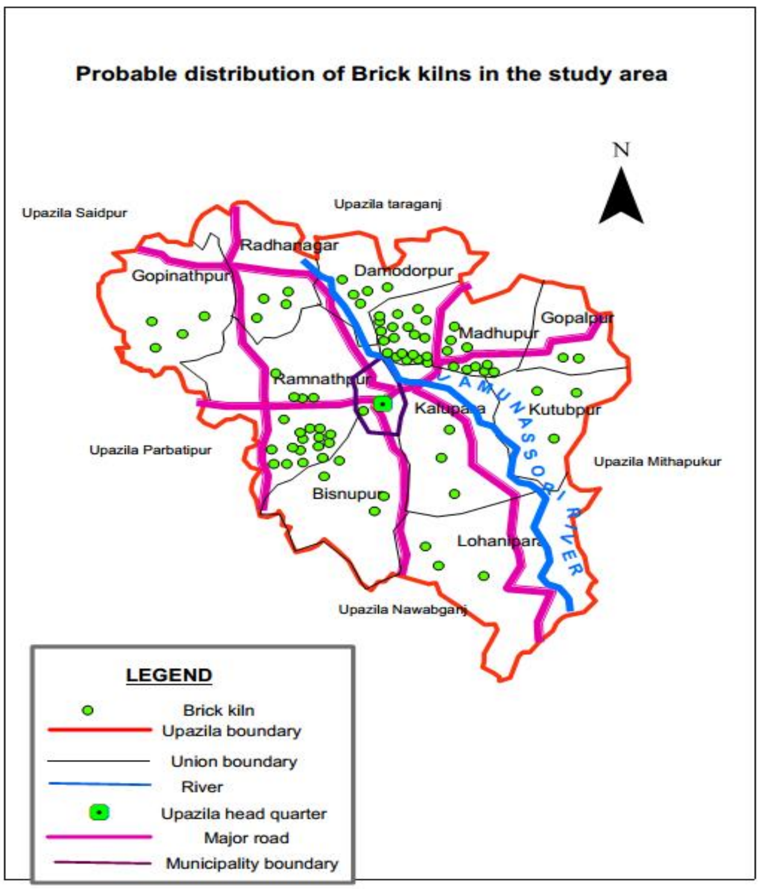
Table 1: Number of brick kilns in the study area

Location (Union under Badarganj Upazila in Rangpur)	**Number of Brick kilns**
Modhupur	30
Ramnathpur	21

Damodorpur	5
Radhabagar	4
Gopinathpur	4
Gopalpur	2
Kutubpur	3
Bisnupur	5
Kalupara	3
Lohanipara	3

Source: Field survey, 2017

The table shows that the study area has total 10 union among them modhupur union has 30 brick kilns and ramnathpur union has 21 brick kilns. Damodorpur union, Bishnupur union have also 5 brick kilns. Furthermore there was no single union which hasn't more than one brick kilns. Among all union modhupur and ramnathnathpur unions are identified as the most affected unions.



Source: Field survey, 2017

Figure 4: Probable distribution of Brick kilns

4.2 Effects on agriculture

All brick kilns are situated at the center of the agricultural land in the study area. That's why agricultural productivity decreases as brick kilns increases. A small brick kiln needs 10 to13 acre lands and a large brick kilns needs 16 to 20 acre lands. So every brick kilns needs average 15 acre lands. That's why 1200 acre (15 acre*80) agricultural lands had lost due to establishment of brick kilns. So it is a direct effect on agricultural productivity. Besides 11,000 cubic feet top soil are used to produce every one lakh bricks. Every brick kiln produces average 35 lakh bricks per season (November to April). So 80 brick kilns were used 11,000*35,00000*80=3,08,00000 cubic feet top soil per season. So it is also a direct effect on agricultural productivity. It has also some indirect effects on agriculture through different ways like coal burning, dust producing, decreasing fertility etc.

4.3 The effects on human health

Table 2: Existing situation of brick kilns in the study area

Height of the chimney	Validity license	Certificate from DoE	VAT Certificate
65 Feet=1 (M.M.B) 100 Feet=1 (R.B.C) 85 Feet=1 (U.B.B.L) 62 Feet=2(U.B.L, A.U.B) 129 Feet=1 (S.B.B) 133 Feet=1 (B.B.L) 130 Feet=4(R.B.B, C.B.L, R.B.B and M.B.L) 120 Feet=69(Rest other brick kilns in the Badarganj upazila)	License had till 2014 35% Don't have any license till 2017	Have only 3 these are M.B.C (Kutubpur), A.S.B.L (Kutubpur) and M.B.C.2 (Lohanipara)	VAT Certificate had till 2014 35% Don't have any certificate till 2017

Source: Field survey, 2017

The table shows that the height of the chimney is not satisfactory in the study area. Only 5 Brick kiln's chimney height is environmental friendly. These brick fields are B.B.L, R.B.B, C.B.L, R.B.B and M.B.L. The all 5 brick kilns are situated at Ramnathpur union. So the rest 75 Brick kilns have problem in chimney height it is a main reason for surroundings air pollution that's why respiratory related diseases were increased.

No brick kilns have validity license till 2017 only 35% had license till 2014. Without license these brick kilns runs because they have political power and Govt. is not concerned about it. One brick kiln owner has more than three or more brick kiln in the same area. For example R.B.B, R.B.B.2 and R.B.B.3 are situated in Ramnathur union owned by the same person.

Only three brick kilns have a license from Department of Environment (DoE). They are M.B.C, A.S.B.L and M.B.C.2 among these three Brick kilns 2 are situated at kutubpur union and 1 at

Lohanipara union. Without environmental clearance brick kilns are established at the center of the agricultural land, besides schools and center of the villages. No brick kilns have VAT certificate till 2017 only 35% had till 2014. The students of the selected three school are as follows

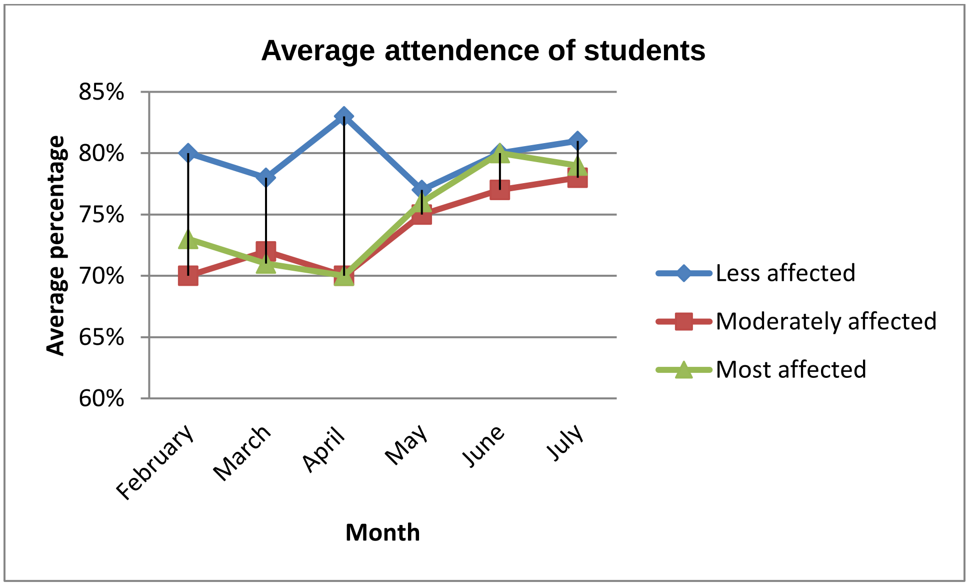
Table 3: School wise male female students

Name of the institution	Male	Female	Total
Ghatabil primary school	52	58	110
Kalirdanga primary school	90	75	165
Jugipara primary school	63	75	138

Source: Collected from school, 2017

From the school health examination survey it is observed that the three school have total 413 students among them 205 male and 208 female. All students from the same socio-economic background and their age range between 5 to 15 years. All students are also non-smokers but they have tonsillitis, asthma and respiratory related diseases.

The average attendance of the students are given below



Source: Collected from school, 2017

Figure 5: Average attendance of selected three schools

The figure shows that students from less affected areas have attended at school more than moderately affected and most affected areas. During Brick kilns operating period (November to April) but during the brick kilns not-operating period less affected, moderately affected and most affected all are same.

The main causes of absence of students in primary schools in the study area are as follows

Table 4: Causes of absent in school

Causes	Average percentage
Unconsciousness of the guardians	20%
Diseases	40%
Child labor at brick kilns operating period	25%
Playing with friends	15%

Source: Field survey, 2017

The table shows that 20% students were absent due to Unconsciousness of the guardians and 40% students were absent due to disease during brick kilns operating period and 25% students were absent due to poverty they work (reverse clay bricks to dry and earned 200 taka per day) during brick kilns operating period. 15% students were also absent due to play with friends at field as schools can't provide proper instrument to play.

From the household interview survey it is found that people affected much more during brick kilns operating period than brick kilns not operating period. This survey was conducted surrounding area of modhupur union and Ramnathpur union where more brick kilns are situated.

The results of household's interview survey are as follows
Total 880 households were sampled and conducted the survey during two period one survey was conducted at operating period and another survey was conducted at non-operating period.
During operating period 440 household were surveyed and the result are as follows

Table 5: Result of household interview survey

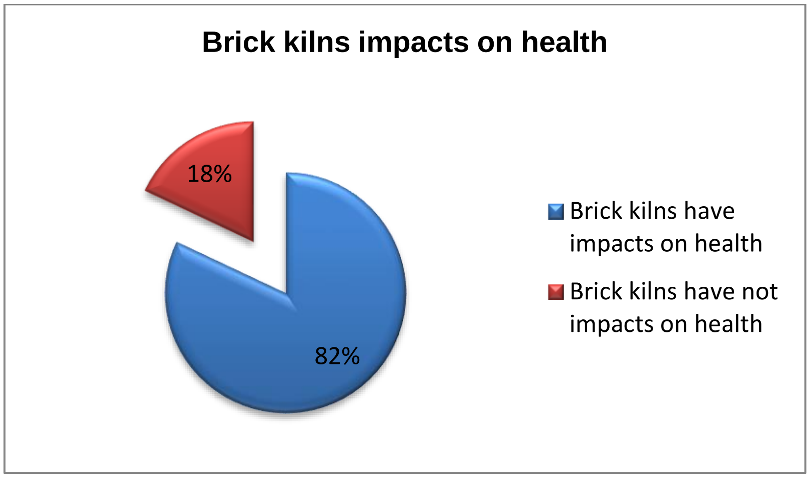
Occupation	Respiratory related diseases for non-smoker (Within 1 month)	Specific problem due to Brick kilns
1. Agriculture=65% 2. Driving=15% 3. Business=8% 4. Job=7% 5. Others=5%	12.5%.(February) Total 55 people affected among them 35 were children and 12 women	Road condition fatally destroy and lack of free air

Source: Field survey, 2017

The table shows that the main occupation in the study area is agriculture is 65%. From the household interview survey it is found that total 12.5% (55) people have respiratory related diseases who are totally non-smokers among them 35 are children and 12 women.

But at non-operating period,
Respiratory related diseases for non-smokers (Within 1 month) are 5% (June). So, it is clear that 7.5% people are affected due to emission from brick kilns.

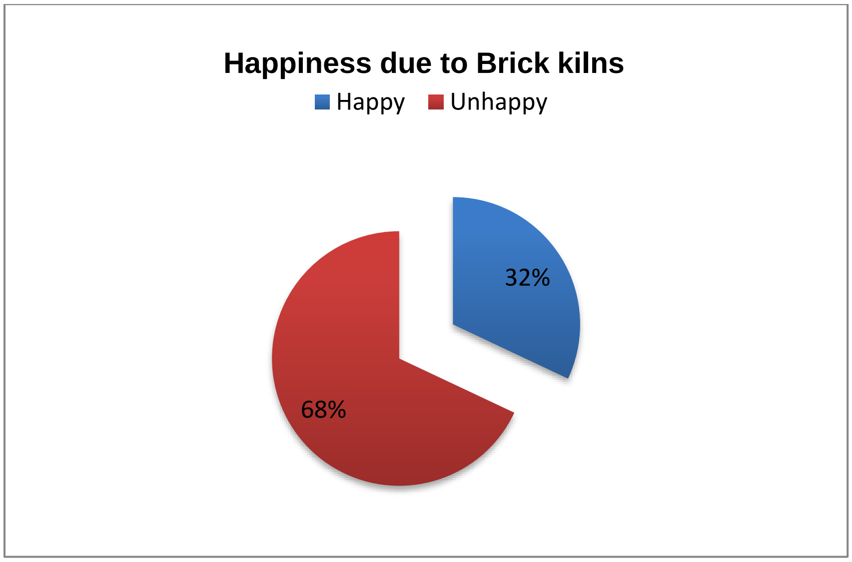
From household interview survey it was tried to know from local people's perspective wheather Brick kilns have impacts on human health or not, the result are as follows-



Source: Field survey, 2017

Figure 6: Brick kilns impacts on health

From 880 people total 82% (722) replied that Brick kilns have impacts on human health and 18% (158) replied that Brick kilns have not impacts on human health but only destroying our environment.



Source: Field survey, 2017

Figure 7: Happiness due to brick kilns

The above figure shows that 68% people are unhappy due to brick kilns because it is the main contributor of outdoor air pollution, contributor to the respiratory related diseases, destroying natural environment, degrading top soil, loosing land fertility, decreasing agricultural productivity, destroying road network for transporting soil etc.

32% people are happy due to brick kilns because it provides job opportunity (November to April) and availability of bricks.

5. RECOMMENDATION

Some recommendation and guideline are provided to reduce the negative impacts of brick kilns these are as follows

- Height of the chimney should be 130 feet for every brick kilns because 130 feet chimney height is environmental friendly.
- Every brick kilns should use CO_2 purifier at top of the chimney.
- Every brick kilns must have certificate from Department of Environment (DoE).
- Expired Brick fields should be stopped as soon as possible.
- Most affected area (Modhupur and ramnathpur union) must be restricted to construct new brick kilns.
- One brick kiln owner will not be permitted to construct more brick kilns in that locality.
- Government should take proper steps to control the excessive increasing rate of brick kilns in the study area.
- Nine brick kilns in Ramnathpur union are situated besides two schools (Ghatabil girls high school and Ghatabil primary school). Among them R.B.B, R.B.B.2 and R.B.B 3 Brick kiln's boundary and school boundary are same. In these two schools the health condition of students result and their attendance is not satisfactory because the students don't get environment to learn. So these schools or brick kilns must be shift to another place

6. CONCLUSIONS

Brick kilns industry is Orange-A category industry its severity is much more than Green categories industry and Orange B categories industry so it has a great impact on human health and environment. After completion of all survey it is found that 7.5% people are affected due to emission from brick kilns. Among them 64% are children 22% are women. 82% (722) people think that Brick kilns have negative impacts on human health and only 18% think that Brick kilns have no adverse impacts on human health. In the study area 65% people are engaged with agriculture. The area provides paddy all over the country (Rangpur, Dinajpur) so 80 Brick kilns in one upazila is impending disaster for the villagers. So Government should take proper steps to control the increasing rate of Brick kilns in Badarganj upazila and it also should be ensured that all brick kilns must have renewable license, VAT certificate, certificate from DoE and adequate height of the chimney.

7. SCOPE FOR FURTHER RESEARCH

- ✓ Causes and consequences of land degradation due to Brick kilns: A case study on Badarganj upozila.
- ✓ Effectiveness of Brick burning law in Bangladesh: A case study on Badarganj upozila.
- ✓ Overuse of soil resources causes poverty: A case study on Modhupur union, Badarganj upozila under Rangpur districts.
- ✓ Correlation between top soil and agricultural productivity: A case study on Badarganj upozila.
- ✓ Is agricultural land perfect place for establishing Brick kilns: Perspective of farmer and Brick kilns owner
- ✓ Brick kilns are the main contributor of outdoor air pollution: A case study on Badarganj upozila.
- ✓ Criteria for selecting location for Brick kilns: A case study on Badarganj upozila.

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A STUDY ON PLASTIC WASTE RECYCLING PROCESS IN KHULNA CITY

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ABSTRACT

Municipal Solid Waste Management (MSWM) has emerged as one of the greatest challenges facing environmental protection in least developed Asian countries like Bangladesh. This study is covered the plastic waste recycling in Khulna city, Bangladesh. In Khulna city, the generation of MSW was found approximately 0.38 kg per capita per day. The MSW of Khulna city mainly consisted of food and vegetable (78.9%), paper & paper products (9.5%), polythene and plastic (3.1%), textile & wood (1.14%), rubber & leathers (0.5%), metal & tins (1.1%), glass and ceramics (0.5%), brick, concrete & stone (0.1%) and dust, ash and mud (3.7%), others (1.46%). Recycling has become one of the primary strategies for sustainable management MSW in the most of the countries of the world. Plastic has become an essential part of our daily life because of its durability, light weight properties and also for its low price. In this study a traditional recycling pattern of plastic in Khulna city has been investigated. Through a number of field interviews to the waste collectors, primary dealers and secondary dealers, a complete hierarchy from waste collectors to the final sellers of recycled product has been identified and the profit at each level determined. In Khulna city the plastic wastes are mainly found in the form of plastic bottle, jars, buckets and plastic bags. In Khulna city there are four industries for recycling of plastic waste material. The study reveals that about 3400kg/day plastic waste are collected and 3100kg/day are processed and recycled in Khulna city.

Keywords:*Municipal solid waste, Plastic waste, Plastic waste recycling, Influence factors*

1. INTRODUCTION

Solid waste comprises all the wastes arising from human and animal activities that are normally solid which are discarded as useless or unwanted. The term solid waste means all-inclusive, encompassing the heterogeneous mass of throwaways from the urban community as well as the more homogeneous accumulation of agricultural, industrial and mineral wastes(Tchobanoglous, Theisen,&Vigil, 1993). Solid waste can be classified into different types according to sources such as Municipal Solid Waste (MSW), Industrial Waste, Agricultural Waste, Municipal Sludge and Other Wastes. (Peay, Rowe, & Tchobanoglous, 1985)

Municipal Solid Waste refers to the materials discarded in the urban areas for which municipalities are usually held responsible for collection, transport and final disposal (Islam, Alamgir, Howlader, Kraft E,&Headrich, 2009b). Municipal Solid Wastes are the heterogeneous composition of wastes, organic and inorganic, rapidly and slowly biodegradable, fresh and putrescible, hazardous and non-hazardous, generated in various sources in urban areas due to human activities (Alamgir M. , Ahsan, McDonald, Upreti,&Islam, 2005). In present days developing countries like ours are facing serious problems due to poor waste management system of MSW. This are happening due to the rapid industrialization and urbanization. Although the municipal and industrial waste produced in developed countries are enormous in compared to that of developing countries but they can handled it through well waste management system. Solid waste management may be defined as the discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal in a manner that is in accord with the best principles of public health, economics, engineering, aesthetics and other environmental consideration and which is also responsive to public attitude (Bozkurt,Moreno,&Neretnieks, 1999).

Now a day's plastic is the most useable material in the world wide. Without it we cannot think about a single day. As we are using it in our everyday life enormous amount of waste of them are producing every day. Plastics are used in our daily life in a number of applications, such as greenhouses, coating and wiring, to packaging, films, covers, bags, containers etc. Plastic is one of the most popular building materials of modern human culture, but its widespread use brought us many problems and caused environmental dangers of unprecedented scale. For this reason the waste need to be managed in proper way one of the best means is recycling.

Khulna is one of the most beautiful city corporation in Bangladesh. Khulna is situated at the south-western part of Bangladesh near the world largest mangrove forest, Sundarbans also situated on the bank of river Rupsha andBhairab shown in Figure 1. The area of Khulna district is 4394 km^2 and the Khulna city area is 20.6 km^2 with population of 1.6 million. Most of the people in Khulna live on agriculture and fishing. But it does not have enough resources, man power or adequate system in place to treat its wastes which is generating every day. It is also one of the very cleanest city corporation in Bangladesh but the waste management process is not adequate. The amount of waste in Khulna has been increasing in recent years, due to the rapid population growth and improvement of the living standards of the residents. Therefore, the necessary of a reliable recycling system became a top priority for Khulna city. The waste are not collected properly in Khulna city. If these wastes can collected by proper grading and separately then the recycling process may be easier than present recycling management process although the process of recycling plastic is not as simple as recycling paper, glass and metals, because the greater number of steps involved for extracting dyes, fillers and other additives.

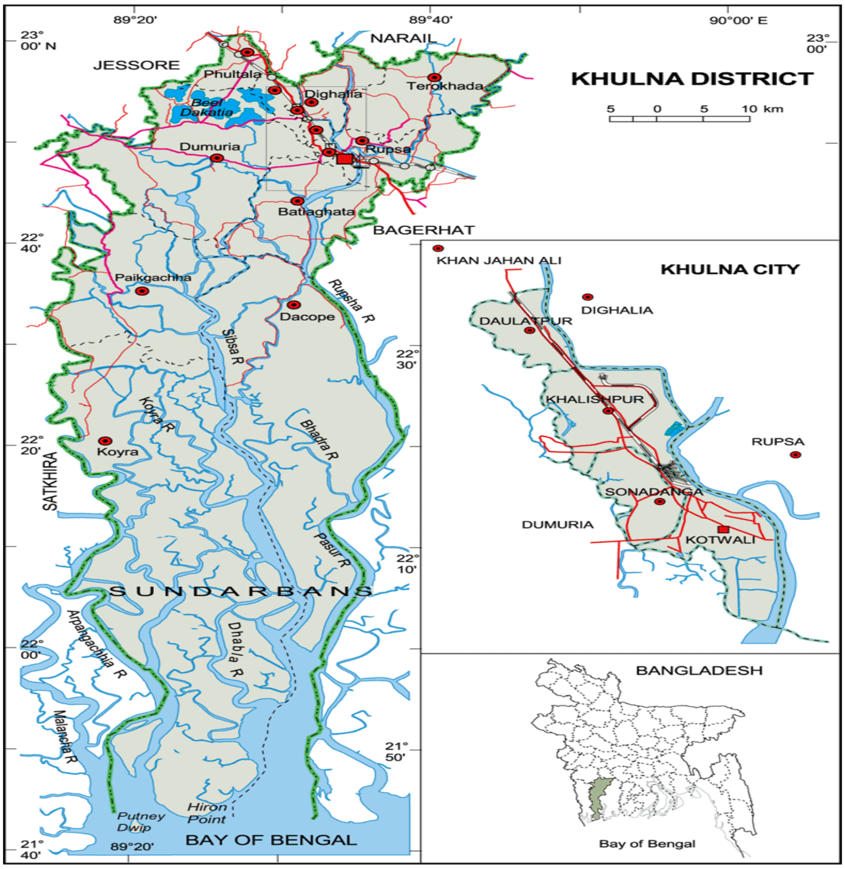

Figure 1: Map of Khulna District

Table 1 presented the components of MSW in Khulna city and characteristics of SW are presented in Figure 2(Ahmed, Hossain,&Islam, 2017).

Table 1: Composition of MSW in Khulna city.

Waste components	(% by weight)
Food and vegetable wastes	78.9
Paper and paper products	9.5
Polythene and Plastics	3.1
Textile and wood	1.14
Rubber and Leathers	0.5
Metals and tins	1.1
Glass and ceramics	0.5
Brick, Concrete and Stones	0.1
Dust, Ash, Mud	3.7
Others	1.46
Moisture content	65
Organic Content	52
pH	7.79
Volatile Solids	58
Ash Residue	46
Bulk Density	1000-1066 kg/m^3

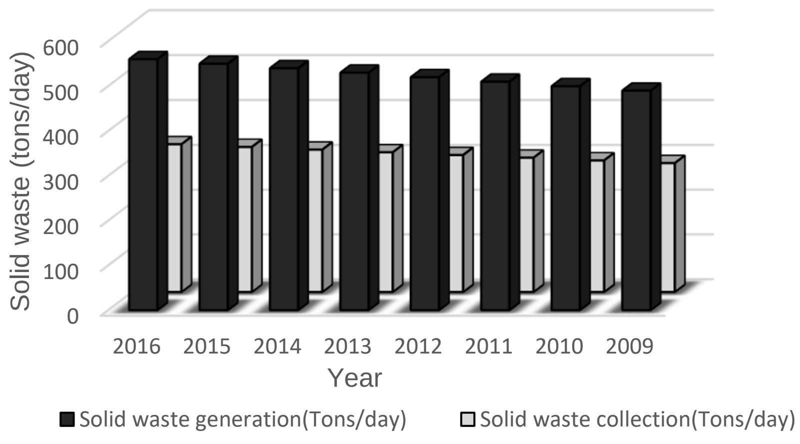

Figure 2: Characteristics of solid waste in Khulna city

2. METHODOLOGY

In present days the population of Khulna city has been increasing day by day. With the increase of population peoples everyday life leading pattern is also changed. For this reason the people used more materials than previous and the result is excess generation of solid waste is making serious problem for the Solid Waste Management System (SWMS). According to the recent report of Khulna City Corporation’s Conservancy Department the current actual collected waste per day is 35% only whereas WG rate is 0.40 Kg per capita per day. In the other hand, the rapid population growth rate and urbanization cause the significant fluctuations of waste generation in this city which consequently results many problems for SWMS.

2.1 Waste Collection

To know about the existing waste collection, storage and recycling pattern in Khulna city, a detailed questionnaire survey and field observation are carried out among the Waste collector (Feriwala/Tokai), Primary dealer (Vangari shop), Secondary dealer and Industry owner. The person who buys the Recyclable Solid Waste (RSW) from household and sells them to the primary dealer as well as secondary dealer is generally known waste collector. The person who buys RSW only from the feriwala and sells them to the secondary dealer and recycling industry is known primary dealer and the secondary dealer buys RSW from both feriwala and primary dealer and sells only to the recycling industry. Generally secondary dealer shops are relatively large compared with the primary dealers. The recycling industries generally collect their recyclable paper, plastic and glass as raw materials from theprimary dealers as well as the secondary dealers. The number of feriwala, primary dealers, secondary dealers & recycling industries in different places of Khulna city are given in Table 2. Two photographs of a feriwala and a primary dealer shop are shown in Figure 3 and Figure 4 respectively.

Table 2: The number of Feriwala, Primary dealers, Secondary dealers & Recycling industries in different places of Khulna city.

Places	**Freiwala (No's)**	**Primary dealer (No's)**	**Secondary dealer (No's)**	**Industriesa (No’s)**
Fulbarigate	05	02	00	00
Daulatpur	07	06	02	01
Khalishpur	9	04	04	01
Sheikhpara	11	03	03	00
Sonadanga	10	05	03	00
Lobonchora	16	8	05	02
Total	57	28	17	04

Figure 3: A Feriwala in Khulna city

Figure 4: A Primary dealer shop in Khulna city

3. RESULTS AND DISCUSSION

The main purpose of this study was to find out the total amount of recyclable plastic wastes produced and the actual amount of recyclable plastic wastes that are recycled daily in Khulna city. The process of recycling plastic which follows in Khulna city recycling industries was also observed. The buying and selling price of the recyclable plastic waste and the plastic after recycle were also a part of this study. The profit of each stages were also find out in this study.

After collecting the recyclable plastic waste by recycling industries send them to the worker for sorting.Sorting of recyclable plastics are done by manual methods in Khulna city. They are generally done by eye inspection. Generally, clear PET (Polyethylene terephthalate) and HDPE (High-density polyethylene) bottles are positively identified and separated out of the stream. They are generally sorted as hard, soft and rubber and shoe. Sorting is also done according to their colour. The financial efficiencies of recycling process mainly depend on this step. More perfection of this process will increase the workability of recycling process as well as the financial profit. When sorting is done send them for cutting. This is the process in which the sorted plastics are reduced to a desired size by a cutting machine. This machine is provided with a motor and a cutter inside. It also has a half conical shape basket from which it is supplied with plastics. After the cutting process have been done the small pieces of plastic are then put into a machine named washing machine. The washing process is also done by hand. Then the cutting plastic are placed to the open place for drying. Drying process is generally done manually. Small pieces of plastics that has been washed by washing machine is dried under sun for natural drying. But in the rainy season they are dried by electric fan. Afterthat molding is done. This is the last step of recycling. In this process the plastics are put into a molding bag and molded manually to get a desired shape. Figure 5 represents the flow diagram of recycling of plastic in Khulna city. The typical photographs of sorting, cutting machine, washing, drying and molding of plastic recycling process are shown in Figure 6, Figure 7, Figure 8, Figure 9 and Figure 10 respectively.

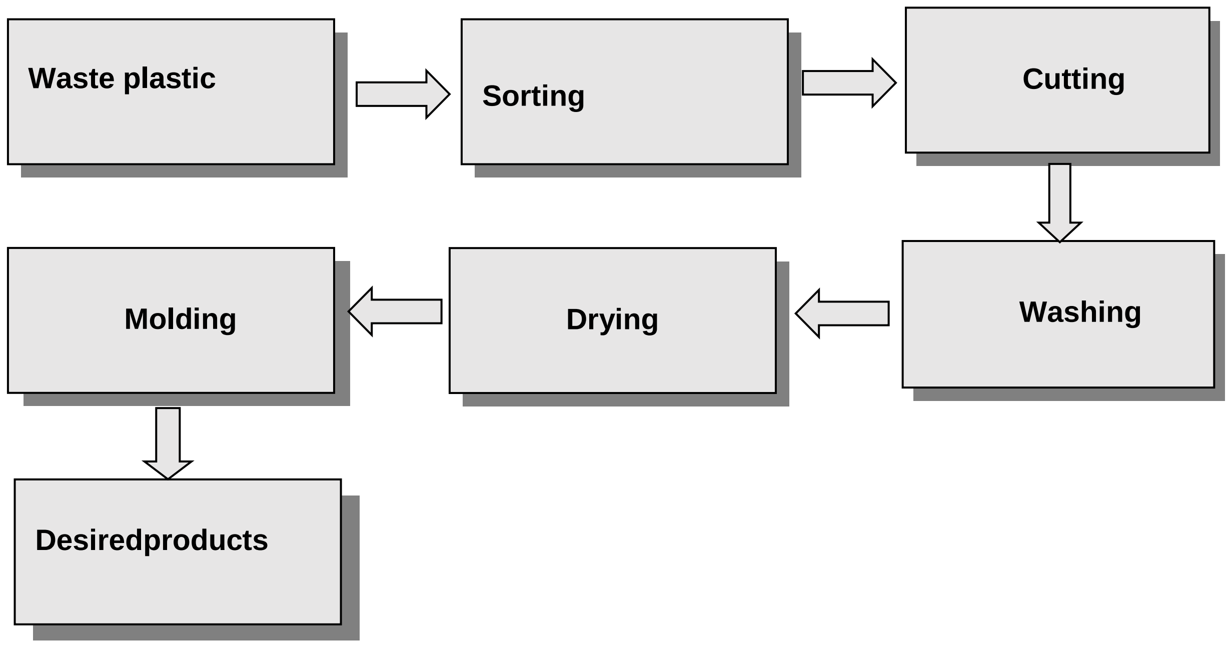

Figure 5:Flow diagram of recycling of plastic in Khulna city.

Figure 6: Sorting

Figure 7: Cutting machine

Fi

Figure 9: Drying

Figure 10: Molding

Total quantity of recyclable plastic wastes in different shops and Tokai are presented in a tabular form. The table shows the quantity of different type recyclable plastic waste collection per day, their buying and selling price. The source and the destination of solid waste are also shown in the table. The working hours of the workers per day and their daily income are also given below the table. Table 3 represents the daily collection of recyclable plastic waste from house to house by a Feriwala. Table 4, Table 5 and Table 6 are also represent the daily collection, buying and selling price, source and destination of recyclable plastic waste of primary dealer shop, secondary dealer shop and recycling industry respectively.

Table 3: Quantity, price, source and destination of collected plastic waste according to Feriwala.

Types of Recyclable Plastic waste	**Amount of collection (Kg/day)**	**Price (Tk./day)**		**Source and Destination of Plastic Waste**
		Buying	**Selling**	
Soft	15-20	15	20	Collected : From houses Destination: primary and secondary dealers
Hard	15-22	25	28	
Rubber/ Shoe	20-23	5	7	

Total amount of collected plastic waste by a Feriwala is 60 kg/day in which 55 kg is recyclable. Total number of feriwala is 57. So Total amount of recyclable plastic waste collected by all Feriwala = 57 x 55 = 3135 kg = 3.1 ton/day.

Table 4: Quantity, price, source and destination of collected plastic waste according to Primary dealer shop.

Types of Recyclable Plastic waste	**Amount collection (Kg/day)**	**Price (Tk./day)**		**Source and Destination of Plastic waste**
		Buying	**Selling**	
Soft	25-35	20	26	Collected: from feriwala Destination: Higher industry
Hard	30-35	30	35	
Rubber/ Shoe	35-40	7	10	

Daily working hours for the workers in a primary dealer shop is 8am to 6pm and the monthly income of every worker is 2000-2200 taka. Total amount of collected plastic waste by a Primary dealer is 115 kg/day in which 95 kg is recyclable. Total number of primary dealer shop is 28. So the total amount of recyclable plastic waste collected by all primary dealer shop = 28 x 95 = 2660 kg/day = 2.7 ton/day.

Table 5: Quantity, price, source and destination of collected plastic waste according to Secondary dealer shop.

Types of Recyclable Plastic waste	Amount collection (Kg/day)	Price (Tk./day)		Source and Destination of Plastic waste
		Buying	Selling	
Soft	60-75	25	33-34	Collected: from feriwala and primary dealer Destination: Higher industry
Hard	55-70	35	45	
Rubber/ Shoe	25-40	8-9	13-14	

Daily working hours for the workers in a secondary dealer shop is 8am to 6pm and the monthly income of every worker is 2200-2500 taka. Total amount of collected plastic waste by a Secondary dealer is 170 kg/day in which 155 kg is recyclable. Total number of secondary dealer shop is 17. So the total amount of recyclable plastic waste collected by all secondary dealer shop = 17 x 155 = 2635 kg/day = 2.6 ton/day.

Table 6: Quantity, price, source and destination of collected plastic waste according to Recycling Industry.

Types of Recyclable Plastic waste	Amount collection (Kg/day)	Price (Tk./day)		Source and Destination of Plastic waste
		Buying	Selling	
Soft	300-380	32	55	Collected: from feriwala and primary dealer Destination: Higher industry
Hard	250-230	40	60-65	
Rubber/ Shoe	220-260	12-13	20-25	

Daily working hours for the workers in a recycling industry is 8am to 10pm and the monthly income of every worker is 3000-3500 taka. Total amount of collected plastic waste by a Recycling industry is 790 kg/day in which 770 kg is recyclable. Total number of recycling industry in Khulna city is 4. So the total amount of recyclable plastic waste collected by all recycling industries = 4 x 770 = 3080 kg/day = 3.1 ton/day. The approxiate net profit per day for a feriwala, primary dealer secondary dealer and recycling industry are given in Table 7. Figure 11 represents the mass balance diagram of recycling of plastic waste in Khulna city.

Table 7: Approximate net profit per day for a Feriwala, Primary dealer shop, Secondary dealer shop and Recycling industry.

Plastic waste collector	Average profit (Tk/Kg)	Amount of waste sell (Kg/day)	Net profit (Tk/day)
Feriwala	3	55	165
Primary dealer	5	95	575
Secondary dealer	7	155	1085
Recycling industry	15	770	11550

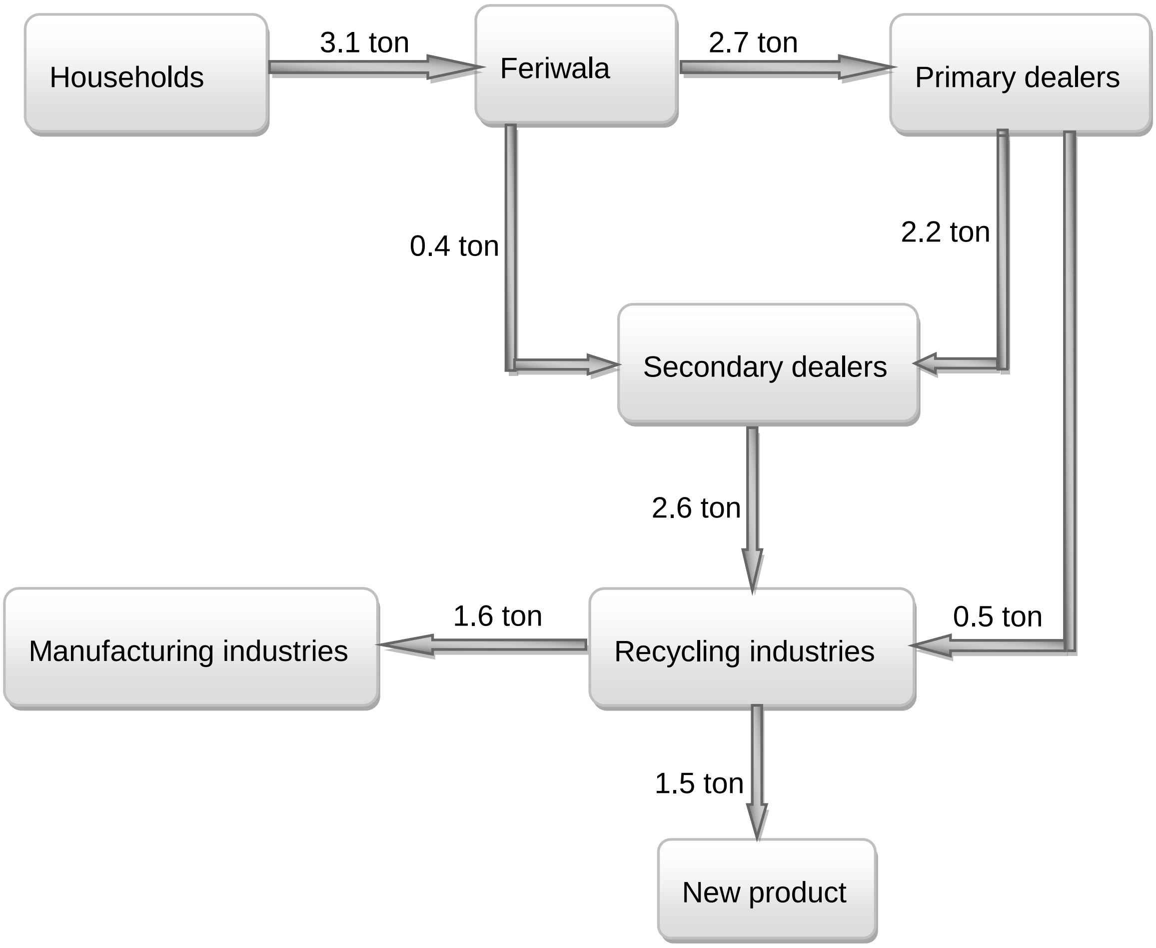

Figure 11: Mass balance of plastic waste recycling in Khulna city.

3.1 Influence Factors

The study reveals that there have some factors of solid waste management system in Khulna city which is influenced the whole system. These factors are necessary to effectively improve waste management, growth and performance, as well as to reduce the environmental degradation of the household waste. The study affirms that understaffing, lack of household education, poor supervision, lack of technological and human resources, lack of government policy and government finances are among reasons leading to poor solid waste management in Khulna Municipality. The study also found thatwaste characterization, waste collection and segregation, local recycled-material market, technology used in recycling are factors influencing solid waste recycling. The manpower in waste disposal, facilities available at the council, attitude of community towards waste disposal, funding for waste disposal programs and technology used in solid waste disposal are factors influencing solid waste disposal.

4. CONCLUSIONS

In this study the process of plastic waste recycling in Khulna city was properly observed.Based on results, it can be observed that the total amount of collected plastic waste was 3400kg/day where 3100kg/day of plastic waste was recycled. The net profit of feriwala, primary dealer, secondary dealer and recycling industry are 165tk/feriwala/day, 575tk/primary dealer shop/day, 1085tk/secondary dealer shop/day and 11550tk/recycling industry/day respectively. Finally, the mass balance of recycling plastic waste was estimated as well as the influence factors of plastic waste recycling were also identified.

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SCENARIO OF EXISTING SOLID WASTE MANAGEMENT PRACTICES AND INTEGRATED SOLID WASTE MANAGEMENT MODEL FOR DEVELOPING COUNTRY WITH REFERENCE TO JHENAIDAH MUNICIPALITY, BANGLADESH

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ABSTRACT

With an increasing population and urbanization, the solid waste management has become a major social and environmental challenge for the local authorities in developing countries all over the world. In Bangladesh in particular, the combined influence of poverty, population growth and rapid urbanization has tended to worsen the situation. Solid waste disposal, in particular has become daunting task for the municipal authorities who seem to lack the capacity to tackle the mounting waste situation. Solid waste is indiscriminately dumped on roads and into open drains, thus leading to serious health risks and degradation of living environment for millions of urban people. In response to the waste challenge many developedcountries have embarked upon ambitious environmental reforms, recording remarkable advances in best practices and sustainable management of Municipal Solid Waste (MSW). However like many developed countries, Bangladesh has faced many problems to manage MSW such as lack of manpower, awareness, knowledge of proper practices, financial capacity etc.The aim of this study is to find out the major weakness of existing system, ananalysis on solid waste management practices and to develop an integrated waste management model for Jhenaidah municipal area and for the similar environment..

Keywords:*Municipal Solid Waste, Waste Management, Environment, Jhenaidah Municipality.*

1. INTRODUCTION

Municipal Solid Waste Management (MSWM) is a challenging problem for the developing countries like Bangladesh where the trend of urbanization is very high. In Bangladesh, the municipal bodies render the solid waste management services. Though it is an essential service, it is not attaining proper priority, which it deserves and services are poor. This has caused many problems in urban environment as well as to the public health in most of the Bangladeshi cities and towns(Ahmed & Rahman, 2003).

During the last few decades, the problems associated with Municipal Solid Waste (MSW) management have acquired an alarming dimension in the developing countries. High population growth rate and an increase of economic activities in the urban areas of developing countries combined with the lack of training in modern solid waste management practices complicate the efforts to improve the solid waste management services. In developing countries, the per capita generation of the solid wastes in urban residential areas is much less compared with the developed countries; however, the capacity of the developing countries to collect, process, dispose, or reuse the solid wastes in a cost effective manner is significantly limited compared with the developed countries(Tchobanoglous, Theisen, & Vigil, 1993).Bangladesh is a developing country and is the ninth most populous and twelfth most densely populated countries in the world. In urban, the projected urban population growth rate from 2010 – 2015 is 3%. Current waste generation in Bangladesh is around 30 million tons per year or 150 kg/cap/year (Iqbal, Tasnim, Chowdhury, Islam, & Islam, 2015). The Waste Generation Rate (kg/cap/day) is expected to increase to 0.6 in 2025 (Alamgir & Ahsan, 2007). The total waste collection rate in major cities of Bangladesh is near only 35%. These trends pose a challenge to cities, which are charged with managing waste in a socially and environmentally acceptable manner. Municipal agencies spend about 10-15% of their budget on solid waste management (Iqbal, Tasnim, Chowdhury, Islam, & Islam, 2015). But it is not enough because like in most developing countries, the solid waste management has so far been ignored and least studied environmental issues.

2. METHODOLOGY

In order to achieve the objectives and to design the research paper the following research methodologies are followed:

2.1 Study Area

Jhenaidah is located in the western part of Bangladesh. The town is located on the bank of the river Nabaganga and Kumar. Jhenaidah is considered as one of the most beautiful city in Bangladesh. The area of the Jhenaidah district is 1949.62 sq km and located in between 23°13' and 23°46' north latitudes and in between 88°42' and 89°23' east longitudes. The area of Jhenaidah city is 44.33 sq km. Jhenaidah city is comprises Jhenaidah pourashava which has 9 wards. The population of Jhenaidah district is 1579490 where male 815576, female 763914; Muslim 1415379, Hindu 162808, Buddhist 835, Christian 161 and others 307 and the population of Jhenaidah municipality is 157822. In Figure 1Jhenaidah municipality map is given.

Figure 1: The map of Jhenaidah Municipality(JM)

2.2 Waste Components in Jhenaidah Municipality

Table 1 presents the percentage of components of MSW collected and analyzed in the study area. Table 1shows the percentage of food and vegetable waste components in the waste stream as 65.9%. Hot and very humid climatic conditions are considered as important causes behind the high percentage share of organic food and vegetable waste in the waste stream. It was observed that, a large volume of food and vegetable wastes were generated from the residential areas in the form of kitchen waste, garden waste and fruit waste. Wastes sources like lawns, parks, playgrounds and institutional campuses have also contributed sizeable volume of food and vegetable wastes in the waste stream. Moreover, fruits and vegetable residues from the both wholesale and retail market areas, leftover foods from the hotels, restaurants, hostels, community halls etc. have increased the percentage of food and vegetable waste to such an extent. The quantity of paper and paper products was found high about 7.6% in the total waste volume. Such types of wastes were mainly derived from covered and open drains. The percentage of polythene and plastic was found high about 6.7%. The percentage of wastes were found for rubber and leathers 3.8%, medical waste

5.4%, glass and ceramics 3.1%, brick concrete and stone 0.2%, Textile and Wood 1.02%, metal and tins 0.4% and others 5.88%.

Table 1: Composition of MSW in Jhenaidah municipality

Waste Components	(% by weight)
Food and vegetable wastes	65.9
Paper and paper products	7.6
Polythene and plastic	6.7
Rubber and leathers	3.8
Medical waste	5.4
Glass and ceramics	3.1
Brick, Concrete and Stone	0.2
Textile and Wood	1.02
Metal and tins	0.4
Others	5.88

2.3 Estimation of Waste Quantum

Table 2 presented the result of the exercise performed in the study area. The number of trips made by different vehicles for seven consecutive days and the approximate amount of waste carried to the disposal site is shown in the Table 2. From the average daily number of trips performed by each category of vehicles and the approximate load carried by these vehicles, the total quantum of MSW generated in the town was estimated. Thus, the average amount of wastes was estimated at 37.168 tones with an average amount of 0.236 kg/person/day.

Table 2: Quantum of MSW generated and number of trips conducted by the vehicles in Jhenaidah Municipality.

Vehicle Types	Load Carrying capacity (Ton)	No of vehicle in operation	Approximate average amount of load carried by each vehicle per trip	Total no.oftrips performed by the vehicles daily	Average Approximate quantity of waste carried daily in (Ton)	Total Number of Trips Performed in a week	Approximate quantum of waste carried weekly (Ton)
Mini Truck	4	4	3.80	8	30.4	56	212.8
Van	0.5-0.6	6	0.54	12	6.48	84	45.36
Trolley	0.01-0.015	8	0.012	24	0.288	168	2.016
Total	4.51-4.6	18	4.352	44	37.168	308	260.18

Average quantity of solid waste generated by each person per day in JM
=Total amount of waste generated/Total estimated population
=37168/157822 = 0.236 kg/person/day

2.4 Present Waste Management Scenario

In Jhenaidah municipal area about 37.168 tons of wastes were generated daily and to store the wastes only 42 numbers of community bins have been used. As the numbers of community bins were few and distributed haphazardly without any planning, residents have no other alternatives rather than to deposit the wastes along the road sides and in the open drains. The urban local body has used RCC bins and metallic containers to store the wastes and 144 numbers of workers were engaged to handle the waste management task. The sweeping crew collects the wastes from road sides and deposit in the nearby community bins by using tricycles. To transfer wastes three types of vehicle is used such as Mini truck, Van and Trolley. Every day, mini trucksperformed 2 trips each while the van and the trolley performed 2 and 3 trips respectively. The collected wastes were carried in open trailersand trucks for about 6.6Kilometers to the final disposal site located at Nagarbathan.The collection drive starts at 7 A.M and continued till 2 P.M in the afternoon. Collected wastes were finally disposed by simply dumping and land-filling processes. The dumping site is located about 6.6Kilometers away from the town. The final waste dumping site is about 0.0182 square Kilometers in area. Open air burning and unscientific land filling of wastes not only causes air pollution but also contamination of ground and surface water in the nearby location.

2.5 Integrated solid Waste Management System

Integrated waste management is concerned with synthesizing a range of different option to deliver an environmentally andeconomically sustainable system for a particular area. Hence, it describe an approach in which decisions on wastemanagement takes account of different waste streams, collection, treatment and disposal methods, environmental benefits, economic optimization and social acceptability. To integrate a solid waste program within a community, the program should address theneeds of the community as a whole. In other words waste generated from individual houses, apartments, public places, business, andindustries located within a community should be taken into consideration for efficient management. Enough flexibility should be built into a program so that it can protect the environment. Willing participation of the community as a whole in reducing waste isessential. Thus, apart from management practices, due consideration should be given to educating the source reduction concept coupled with proper storage, effective collection, transfer, treatment and disposal of waste.

2.6 Planning integrated solid waste management

To ensure better human health and safety there will be a need of effective solid waste management system for the urban areas. The system needs to be safe for workers and public health. Besides these requisites, the system must be environmentally sustainable and economically feasible. An economically and environmentally sustainable solid waste management system is effective if it follows an integrated approach. The planning of integrated solid waste management system has been explained below in a case study for Jhenaidah municipality.

1. Reduction of waste at source with the active participation of the community. Wastes can be reduced by changing the consumption pattern, use of recyclable materials, practice of waste segregation and refusing the use of polythene bags etc. About 20% reduction in waste generation is possible through simple housekeeping measures that require no marginal investment.
2. There are considerable benefits of increasing solid waste recycling and reuse. Source separation and recycling of waste reduces the volume of the waste considerably. Promoting recycling as an alternative to the existing forms of waste disposal may be economically gainful. Further, thousands of poor people are directly or indirectly participating in waste collection and recycling to support their families.
3. Composting seems to be a very effective measure of waste disposal in the study area as organic waste constitutes about 72% ofthe wastes stream. Composting is a form of source reduction or waste prevention as the materials are completely diverted from thedisposal facilities and require no management or transportation. Diverting such materials from the waste stream frees up dumpingspace or the materials that cannot be compost.

a. Practice of dumping of waste along the final disposal site is found to be unscientific and highly vulnerable to environmentand public health. Sanitary land fill not only reduces the risk to the environment and public health but also proper use of landfill site to the fullest extent. Therefore, adoption of sanitary land filling will be a better option for final disposal of wastes inthe study area.

b. Community participation is essential for smooth and efficient operation of solid waste management system. Performances ofsuch system depend on the meaningful participation of individuals, communities and institutions, producers, NGOs andgovernment. The key element of the community participation is involvement of the community in the decision andimplementation process. Therefore, a consistent andongoing educational program is necessary for the success of the wastemanagement system.

3. ILLUSTRATIONS

In this paper it was found that the solid waste generation rate in Jhenaidah municipality is about 37.168 ton/day and the solid waste generation rate is 0.236 kg/capita/day. The waste characteristics areslightly different with respect to geographical regions, the influence of seasonal variation, population density, habits and custom of living, lifestyles, economic conditions, climate, recycling and waste management program. But there is a little variation due to the awareness of the householders and scavengers.

3.1 Proposed ISWM Scheme for Jhenaidah Municipality

The ISWM scheme for Jhenaidah municipal area have been designed to minimize the initial generation of the wastes through source reduction, then through reusing and recycling to further reduce the volume of the material being sent to landfill sites for final disposal. Efficient management of wastes requires collection of up- to- date information for corrective measures as well as future planning. Integration and assimilation of information from various sources and levels also have been considered important in ISWM. Thus, the strategic approaches for ISWM involve integration of available data, guidelines and framework to eliminate the constraints. The main objective here is to proper storage, effective collection, transfer, processing and disposal of wastes according to the constituents present in the waste stream in a sustainable manner with the participation of the community. To maintain a healthy environment, the LGED has to adopt this approach and set goals to reduce the amount of solid waste in a cost effective manner.

3.2 Focus of the ISWM Scheme

1. Equations Segregation of wastes at source especially the household wastes through active participation of community and in separate containers and regular collection of wastes by using separate fuel efficient vehicles according to nature of the wastes. Use of compactor makes the collection drive more efficient and cost effective.
2. Improve community bins, storage containers for the storage of biodegradable and wet wastes and containers should be placed scientifically using GIS and GPS.
3. Adequate training to all the levels of staff engaged in solid waste management to handle respective functional aspects like collection, generation, storage, segregation of waste etc. and medical check-ups for municipal workers and rag pickers should be mandatory at regular interval.
4. Establishment of some transfer station for smooth operation of the SWM system at some suitable locations.
5. Composting should be done with the help of technological experts and o handle the bulk of waste generated everyday sanitary landfill site have to be set up to dispose off the rejects after composting.
6. Promotion of public participation in the SWM scheme and constitution of citizen forum in each municipal ward involving local people.
7. Developing public –private partnerships leading to privatization of some aspects of garbage collection, recovery and disposal.
8. To tackle various issues such as road sweeping, open dump, open burning, garbage collection, disposal etc. regular monitoring is necessary.
9. Garbage tax should be levied against large and small generators for the disposal of Wastes.

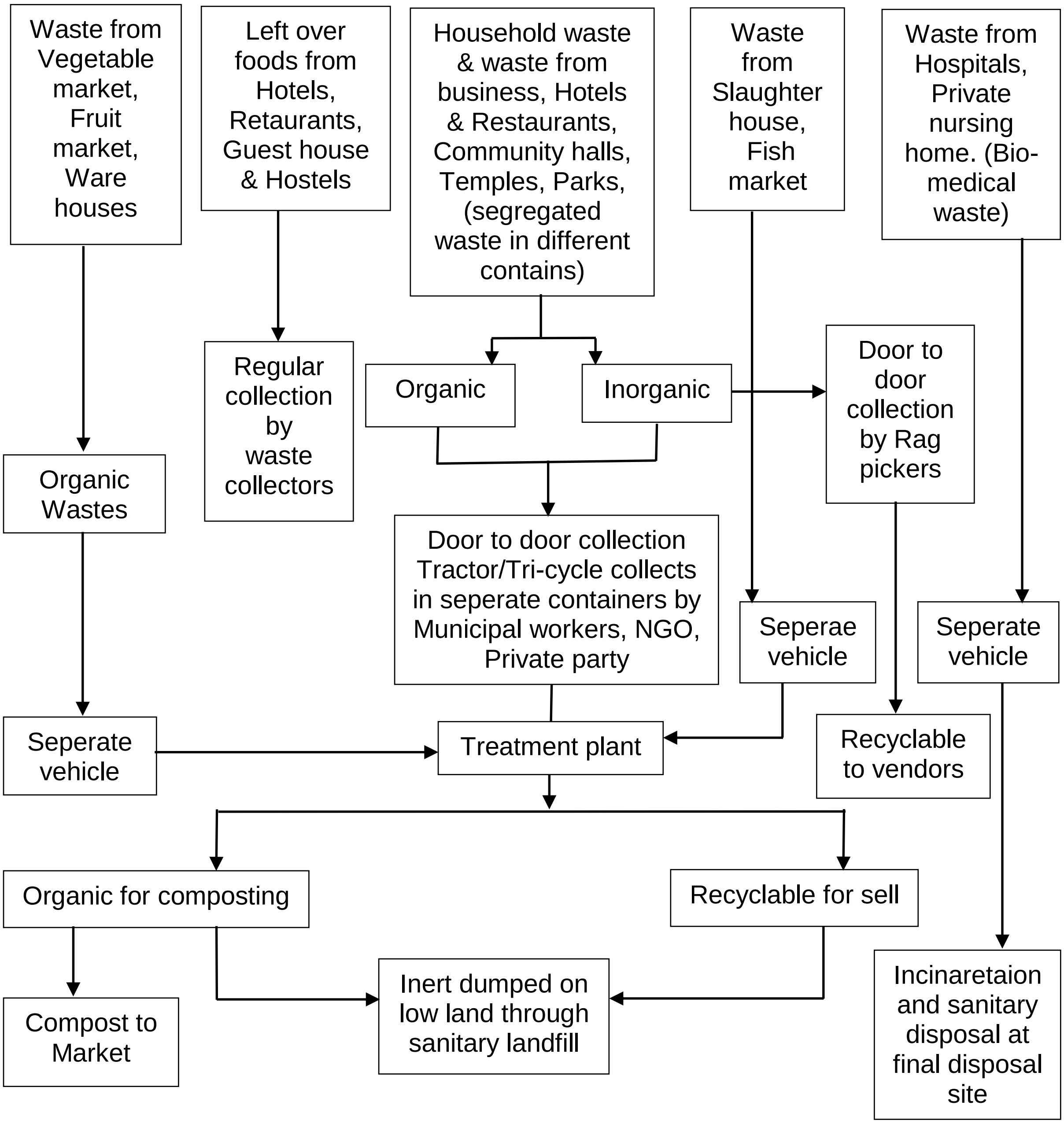

Figure 2: Integrated Solid Waste Management model.

10. Administrative restructuring of the LGED to discharge more efficiency and specific responsibilities. This requires structural changes within administration aimed at decentralizing authority and responsibilities. This also includes periodic meetings among the staff and between the executives and elected wing of the board.
11. Encouraging involvement of local NGO's in working on various environmental awareness programs and areas related to waste management including the public about the importance and necessity of better waste management.
12. Privatize solid waste management facilities or contract for waste disposal services, including recycling.

In Figure 2 the Integrated Solid Waste Management model is shown.

4. CONCLUSIONS

Mismanagement of wastes not only causes serious environmental problems but also risks to public health. Therefore, there is a shift from the traditional solid waste management options to more integrated solid waste management approaches. Waste management system in Jhenaidah municipality is traditional and needs up gradation in the areas of storage, collection, transfer, processing and disposal. Financial hurdles and lack of co-ordination and co- operation between the concerned authority and the public has created bottlenecks in improving its efficiency. The potentiality of the community participation in the waste management system has to be given more and more emphasis for smooth management of the system along with the adoption of latest spatial analytical technologies such as GPS-GIS system. However, government initiative is always necessary to make the system successful. Waste recycling can be promoted through consumer campaigns that will encourage citizen to co-operate in waste separation and to purchase recycled products. In the same time LGED should encourage composting of wastes which will not only reduce the volume of waste to dispose but also maintain a healthy environment and low risks to public health. Finally, proper monitoring of the system in every steps is utmost important for smooth functioning of the system.

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BENCH SCALE STUDY ON CO-COMPOSTING FOR ORGANIC SOLID WASTES AND FAECAL SLUDGE

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ABSTRACT

Faecal sludge has a high moisture and nitrogen content, while biodegradable solid waste is high in organic carbon and has good bulking properties (i.e., it allows air to flow and circulate). By combining the two, the benefits of each can be used to optimize the process and the product.This paper shows the variation of physiochemical characteristics in the different stages of combined treatment of faecal sludge and municipal solid waste through co-composting. The objectives of the study were to observe the extent of degradation by measuring the volatile solids, percentage carbon contents and area under temperature, determine the volume mass and height reduction and examine the temperature fluctuation for the different compost mixtures. Composting process was done in two stages by both active and passive aerobic condition for 51 days. In the compost mixture, solid waste was combined with dewatered faecal sludge in mixing ratio of 3:1 by weight. Samples were taken at the beginning and end of a stage and analyzed for percentage volatile solids, percentage fixed solids and percentage carbon content. Temperature, moisture content, height, weight and color were chosen as maturity indicators. Result showed a preference of using faecal sludge in composting process. It is clearly observed that the value of percentage volatile solids and percentage carbon were reduced to a significant amount which were almost half of the initial percentages. The output of this research can help to design the small-scale composting system for municipal solid waste management in low income countries.

Keywords: *Faecal Sludge, MSW, Organic Solid Wastes*

1. INTRODUCTION

In many countries including USA, Germany, India and Bangladesh, composting has become one of the most economic ways of solid waste treatment. It requires lower equipment and operation cost. Organic waste composting techniques have been extensively developed in recent decades in response to the increasing concern about the amount and management of wastes. It is one of the most effective and efficient way to manage organic waste and it helps to reduce the volume of waste almost 50%. With this population growth, there is an increasing problem of waste management particularly in the larger cities. The large amount of municipal, industrial and agricultural wastes have led increasing environmental, social and economic problems. For these waste disposals agricultural lands are used as landfill. The two primarily environmental concerns related to landfills are leachate generation and gas emission. The leachate produced from landfills may contain a variety of toxic and polluting components. If managed improperly, leachate can contaminate groundwater and surface water. Landfill gas which is consists of carbon dioxide and methane, small amounts of nitrogen and oxygen. Methane is a greenhouse gas and very harmful for the environment. For this reason Municipal Solid Waste (MSW) management has become one of the largest environmental concerns in recent decades (Iqbal et al., 2010). The high organic fraction in MSW makes it easy to be converted to the energy sources through composting (Jolanun and Towprayoon, 2010; Ponsá, 2010).

Compost can be used as soil conditioner that minimizes the use of chemical fertilizers and has significant environment benefits. It is made up of waste material that is generally high in either carbon or nitrogen. It improves soil water-holding capacity. Compost loosens clay soils and helps sandy soils retain water by binding soil particles together. Besides solid waste treatment, the management of faecal sludge is another concerning factor in an overpopulated country like Bangladesh. Faecal sludge, also known as bio-solids, is a by-product of faecal sludge treatment processes, which final disposal represents 50% of the total operating cost of faecal sludge treatment plants (BETTIOL and CAMARGO, 2007). Co-composting is a combined treatment of faecal sludge and municipal solid waste.

Co-composting of faecal sludge and organic solid waste allows recycling of nutrients into agriculture thereby closing the nutrient loop. The two materials compliant each other and provide missing component in inorganic fertilizer. However effective use of such compost in agriculture depends among other factors on its quality. Several authors have proposed some particular methods such as CO_2 evaluation, pH, C/N ratio, temperature, moisture and colour to determine compost maturity (Tiquia et al., 1996; Sharma et al., 1997; Lasaridiet et al., 2006). The compost product is adequately sanitized with co-composting process and can be used with reduced risk to applicator public health as well as the environment.

2. METHODOLOGY

The co-composting of solid waste and faecal sludge has performed in the laboratory of Ahsanullah University of Science and Technology. The experiment has done with a ratio 55:25:10:10 of mixed food waste, faecal sludge, saw dust and paper cutting and two types of aeration namely forced aeration and passively aeration. Food wastes consist of cooked rice, fried rice, cooked vegetables, bread, burger, noodles etc. Vegetable wastes consist of potato, cabbage, gourd, onion etc. Food wastes and vegetable wastes were collected from AUST hall and AUST canteen. Saw dust was collected from Badda saw mill and paper waste was collected from paper factory. Dewatered faecal sludge was collected from KUET waste management plant.

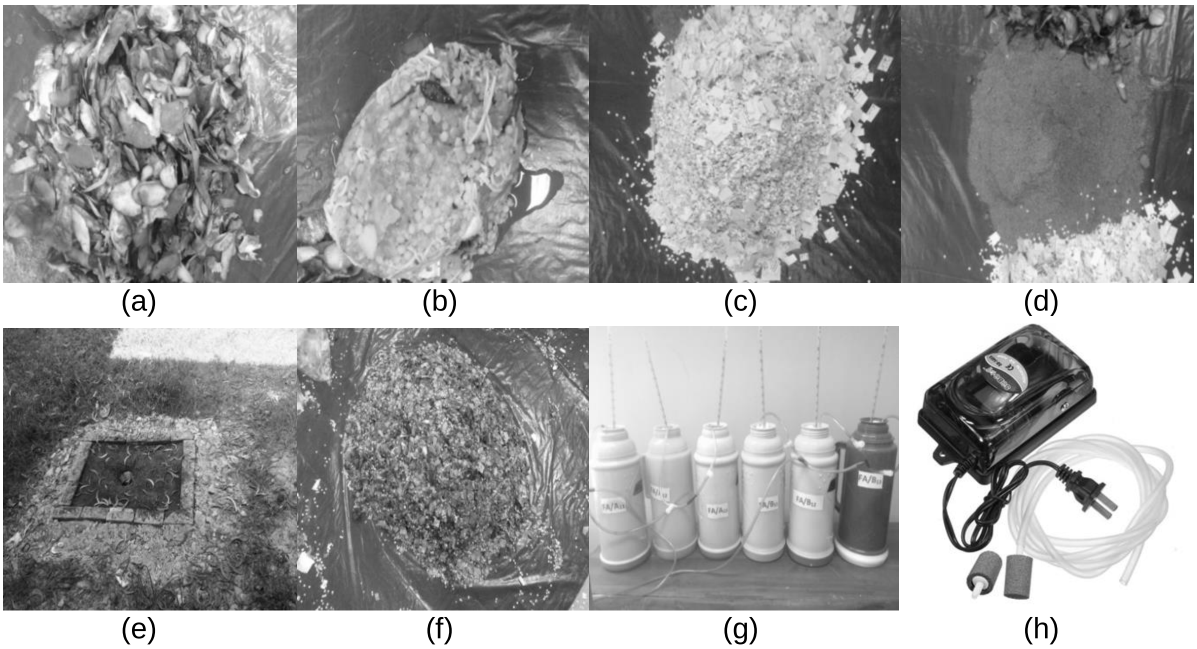


Figure 1: a) vegetable wastes, b) food wastes, c) paper cutting, d) saw dust and e) dewatered feacal sludge f) waste mixture g) reactors h) pumper

A number of equipment were required and used during the various stages of the study. In this experiment thermo flasks were used as heat insulator. The volume of each flask is 1 litre. Two types of electric balance were used in the experiment. One was normal electric balance which is not capable of measuring decimal numbers. Another was sensitive electric balance which can count up to three decimal numbers. Thermometers are used to measure temperature fluctuation and each thermometer was checked before installation whether it was working or not by using it in water at room temperature. Two plastic pipes were connected with two pumpers and then connected to the reactors. Several piping network were created from one point of the pump by using some connecting pipes. Air controller keys were used to control the air the approximately same amount of air was entered into several flasks. Air pressure of the pump was checked before installation. Normal oven and muffle furnace were used to determine the moisture content and organic content respectively. In the normal oven, the sample waste was kept for 24 hours. The temperature was maintained constantly 103 ºC to 105 ºC. In muffle furnace the temperature was maintained around 500~550 ºC.

Plastic spoon, bottle, polythene etc. were separated from the food waste because these do not decompose. In addition bones, tissue, fishbone etc. are also removed. Bones are very slow to decompose. These can also attract pests. These products can overheat the compost piles. From vegetable wastes tomato was removed as it increase the pH and toxic the compost mixture. Particle size affects the rate of organic matter breakdown. The more “surface area” available, the easier it is for microorganisms to work, because activity occurs at the interface of particle surfaces and air. Microorganisms are able to digest more, generate more heat, and multiply faster with smaller pieces of material. Although it is not required, reducing materials into smaller pieces will definitely speed the decomposition process. Larger part of bread and vegetables of food wastes and vegetable wastes were shredded into smaller pieces. Moisture content of all raw wastes was measured before mixing.

All the waste components namely food waste, vegetable waste, faecal sludge, saw dust and paper waste were taken according to predefined ratio. Then these wastes were mixed very carefully so that waste components are uniformly distributed. Composting proceeds best at a moisture content of 40-60% by weight. At lower moisture levels, microbial activity is limited. At higher levels, the process is likely to become anaerobic and foul-smelling. So we tried to keep moisture content of waste mixture 50 to 60%. To identify the moisture content the mixture is squeezed by hand. If water comes out of it, the compost is too wet. If the compost does not release water but crumbles apart when released, it is too dry. If the compost does not release water but stays compacted, it is in right condition of wetness to carry out composting process.

Before pouring the waste mixture, air pipe was placed in the reactor in case of forced aeration. The outer surface of the reactor was properly cleaned after pouring the waste mixture. Weight of reactor was taken before and after pouring of waste into it. Height of waste in reactor was measured by using scale. For both passively and forced aeration, the reactor was properly labelled and numbered before the final placement.

At the initial stage of composting, the rise of temperature was rapid. That’s why the temperature reading was taken at least two times or more in a day. To observe the reduction of volume, the height of the sample was measured after each 10 days. In every stage, the reactors were kept under both passively and forced aeration condition. The difference in temperature fluctuation occurs due to the aeration condition. It has been observed regularly whether the aerator is working properly or not. Temperature fluctuation rate decreased at the end of a stage. When the temperature became stable, the temperature change was noticed after altering the aeration condition after 2 days. At the end of each stage, physical appearance and odor, moisture content and volatile solids percentage, volume and weight loss after composting etc. were measured.

3. RESULTS AND DISCUSSION

First Stage of Co-composting

Co-composting was done by mixing of solid wastes and faecal sludge. The compost mixture contains 30% food wastes, 25% vegetable wastes, 25% faecal sludge, 10% saw dust and 10% paper waste. Co-composting was run for total 51 days and done in two stages. First stage and second stage were carried out for 26 days and 25 days respectively. Moisture content and dry solids were measured before and after the composting process. Weight loss of raw waste mixture due to composting process was calculated. Temperature reading was observed throughout the composting process. It is recommended that 55% to 60% moisture content is suitable for composting process. The optimum MC was 60% during the composting of green waste and food waste at a low C/N ratio (19.6) (Kumar et al., 2010). In Table 1 moisture content of waste mixtures is shown and the average of moisture content was found near 53% before composting. In first stage of co-composting six reactors were used. Among these reactors three reactors were forced aerated and three were passively aerated. Moisture content of waste mixtures after composting in each reactor was nearly 48%. Before started composting process moisture content of waste mixture was nearly 53% means rest 47% was in dry. So the moisture is more than dry solids before composting. During composting waste starts to degrade and moisture is reduced and dry solids is also decreased than before. As a result end of the process a reasonable amount of weight is lost in each reactor as shown in Table 1.

Table 1: Percentage weight loss, area under temperature and Moisture content before and after composting

Reactor name	Waste mixture weight (before), gm	Waste mixture weight (after), gm	Percentage weight loss	Moisture content (%) (before)	Moisture content (%) (after)	Area under temperature, °C.hr
PA11	410	283	30.97	53.76	50.88	6456
PA12	459	333	27.45	53.76	49.36	8040
PA13	430	313	27.20	53.76	51.51	7518
FA11	433	383	11.54	53.76	46.25	6948
FA12	436	308	29.35	53.76	45.83	7132
FA13	413	360	12.83	53.76	46.14	5112

FA=Forced aerated PA= Passively aerated

From the value of Table 1 it is seen that the weight decreasing rate of forced aerated reactor is higher than the passively aerated reactor. Percentage weight losses of passively aerated reactors are around 11% to 29% and forced aerated reactors are around 28%. First stage of co-composting process was continued for 26 days and the temperature measured in °C. For forced aerated reactors the area under temperature is varies between 5112 °C.hr and 7132 °C.hr. Whereas the area under temperature for passively aerated mixture varies from 6456 °C.hr to 8040 °C.hr. It indicates that the co-composting of organic solids waste requires less time to be composted than composting of organic solids waste.

Temperature which is as a result of microbial activity is an important factor in a composting process. The temperature of the composting pile expresses the breakdown of the organic matter and the quality of the compost, since the rise of temperature is the result of readily available organic matter and nitrogen compounds decomposition by microorganisms (Ros et al., 2006; Lee et al., 2007). Temperature is one of the important indices to evaluate compost efficiency (Lee et al., 2007) because it affects the biological reaction rate, the population dynamic of microbes, and the physiochemical characteristics of the compost (Hu et al., 2009).

The microbial activity and the organic matter breakdown rate decreased when the organic matter becomes more stabilized and consequently the temperature drops to the ambient temperature (Ros et al., 2006). The composting materials went through the three typical degradation phase: mesophilic, thermophilic and curing. Decomposition occurs most rapidly during the thermophilic Stage of composting (40-60°C). High temperatures destroy pathogenic bacteria and protozoa and weed seeds, which are detrimental to health and agriculture when final compost is used on the land. By the standard of best practice for temperature of a formulated compost pile, it is recommended to manage pile to achieve an average temperature greater than or equal to 65 ºC (≥65 ºC) for at least 3-7 days. Temperature profiles of forced aerated and passively aerated reactors are shown in Figure 2. It is seen that temperature rises sharply after first day and reached at thermophilic Stage and stayed about 5 days. Peak was found about 65 ºC. Temperature in excess of 60°C could reduce the activity of the microbial community as the thermophilic optimum of microorganisms is surpassed. Ambient temperature varies from 25 ºC to 27 ºC. Temperature was increased sharply within 2 days and crossed 50 ºC. The Second peak of temperature was found after 10 to 12 days. Temperature was fall near ambient temperature at the end of the Stage.

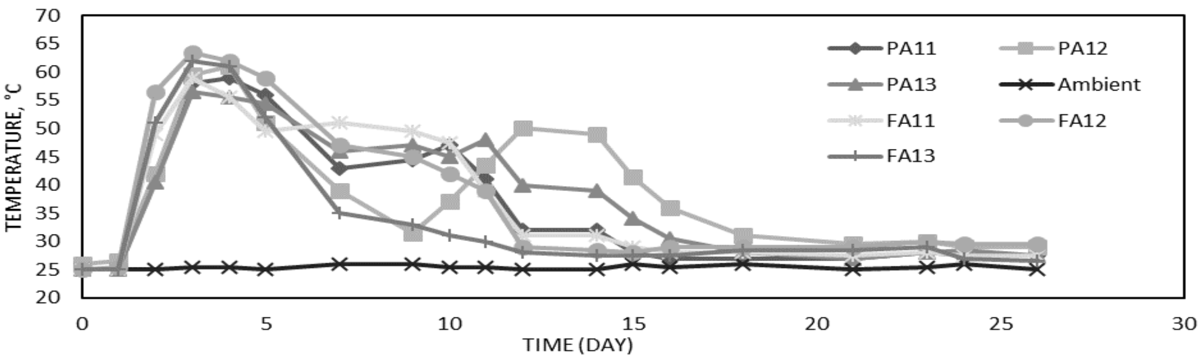


Figure 2: Temperature profile of forced aerated and passively aerated reactors in stage-1

The reduction of height of the sample mixture is very high at the initial Stage. For force aerated waste mixture the sample have gained 80% height reduction of its total reduced height at about 10 days after the first setup. But for passively aerated waste mixture, it takes up to 20 days to gain 80% height reduction of the total reduced height during Stage-1.

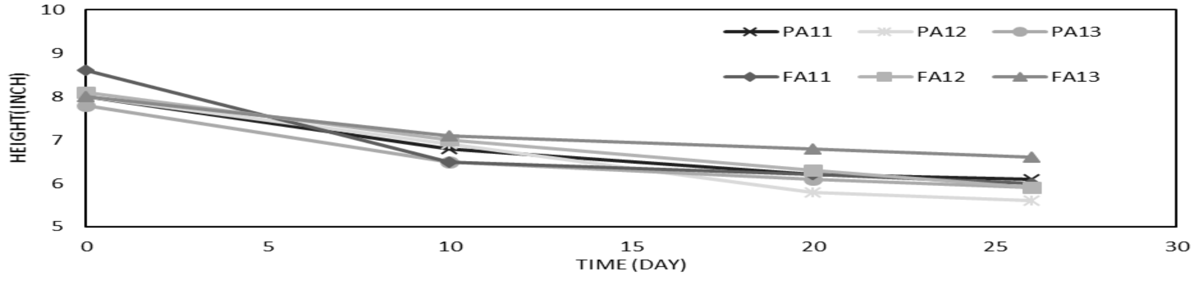


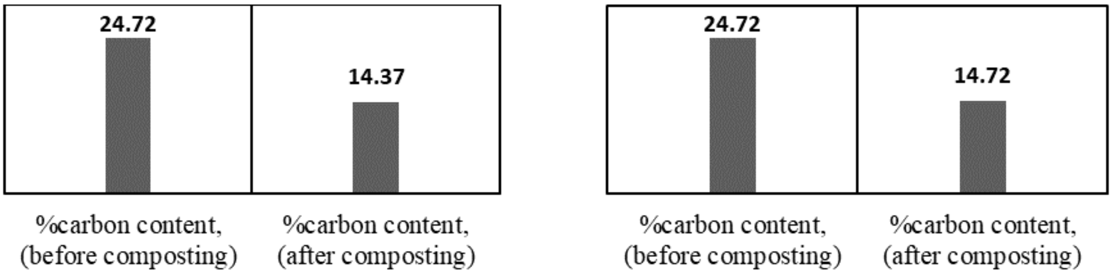
Figure 3: The height of the Compost mass vs Time graph for forced aerated (FA11, FA12, FA13) and passively aerated (PA11, PA12, PA13) test mixture at first stage of co-composting

Percentage volatile solids and carbon contents were calculated before and after co-composting as shown in Table 2. Volatile solids was determined by putting the dry solids into Muffle Furness at 550 ºC for 1 hour and then percentage volatile solids was calculated. For most biological materials the carbon content is between 45 to 60 percent of the volatile solids fraction. The formula is:

% Carbon = (% VS) / 1.8.

Table 2: % Volatile solids and % Carbon before and after composting

Sample	Average % Volatile solid (before composting)	% Volatile solids (After composting)	Average % carbon (Before composting)	% Carbon (After composting)
PA11	44.13	25.48	24.72	14.27
PA12		27.10		15.17
FA11		24.49		13.71
FA12		26.83		15.03



a) Forced aerated b) Passively aerated

Figure 4: Carbon content variation for initial and finished co-compost

In first stage of co-composting, the initial percentage carbon content of forced and passively aerated was 24.72. In the finished co-compost percentage carbon content decreased to the values of 14.37 and 14.72 respectively.

3.2 Second Stage of Co-composting

Second stage was carried out for 25 days. Moisture content, dry solids, volatile solids and percentage carbon was measured before and after the composting process. Moisture and dry solids in gm of waste mixture before and after composting are shown in Table 3. It is seen that moisture content reduced from nearly 50% to 43% in passively aerated reactors and for forced aerated reactor moisture content decreased from around 45% to 34%. Before started composting process moisture content of waste mixture was nearly 50% and 45% in passively and forced aerated reactors respectively means rest 50% and 55% was in dry. So the moisture is almost same as dry solids before composting. During composting, waste starts to degrade and moisture is reduced and dry solids is also decreased than before. As a result end of the process a reasonable amount of weight is lost in each reactor as shown in Table 3. From the value of Table 3 it is seen that the weight decreasing rate of forced aerated is higher than the passively aerated reactor. Percentage weight losses of passively aerated reactors are around 9% to 16% and forced aerated reactors are around 45% to 75%. From the time-temperature curve in Figure 5, the approximate area under temperature is calculated and shown in the Table 3. The temperature was measured in °C. In the case of forced aeration the area under temperature is 1818 °C.hr for First reactor and 5544 °C.hr for Second reactor. Whereas the area under temperature for passively aerated mixture varies from 3072 °C.hr to 4548 °C.hr, indicating the completion of co-composting process.

Table 3: Percentage weight loss, Area under temperature and Moisture content before and after composting

Reactor name	Waste mixture weight (before), gm	Waste mixture weight (after), gm	Percentage weight loss	Moisture content (%) (before)	Moisture content (%) (after)	Area under temperature, °C.hr
PA11	437	394	9.83	50.28	44.26	3072
PA12	481	404	16.00	50.28	42.18	4548
FA11	455	114	74.94	45.15	35.33	1818
FA12	454	239	47.35	45.15	36.66	5544

FA=Forced aerated, PA=Passively aerated

Temperature profiles of forced aerated and passively aerated reactors are shown in Figure 5 As temperature reached in thermophilic level at stage-1 and active phase of composting has already done, after this phase, microbial activity and organic matter decomposition rates slowed down and the temperature decreased gradually. Temperature gradually increased in passively aerated reactors. Peak temperature was found 37 ºC for passively aerated and 42 ºC for forced aerated reactors. The ambient temperature varies between 25 ºC to 27 ºC.

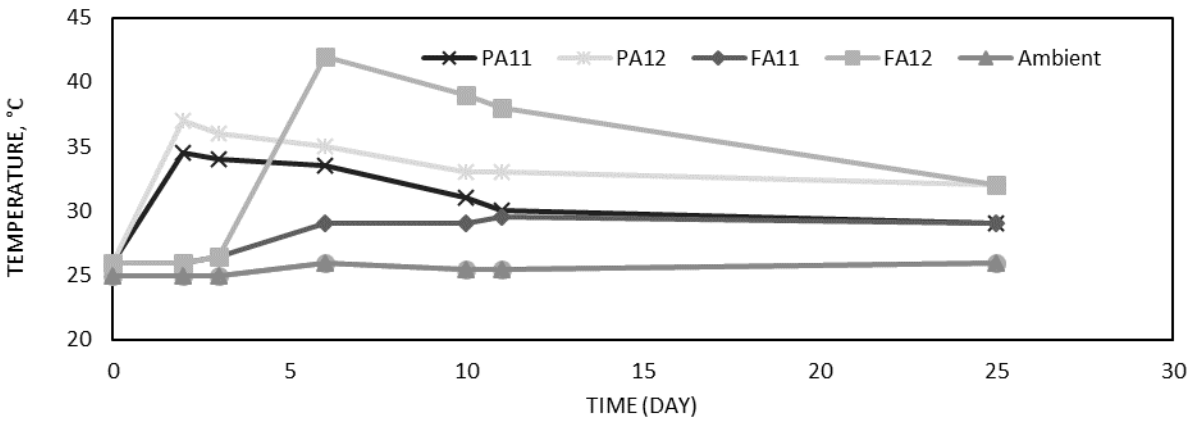


Figure 5: Temperature profile of forced aerated and passively aerated reactors in stage-2

For co-composting of faecal sludge with organic solids waste, the maximum height reduction of the waste mixture was gained at the first stage of co-composting and there was a little height reduction during the second stage. And the height of the waste mixture have become stable at about 10 days after the Second setup.

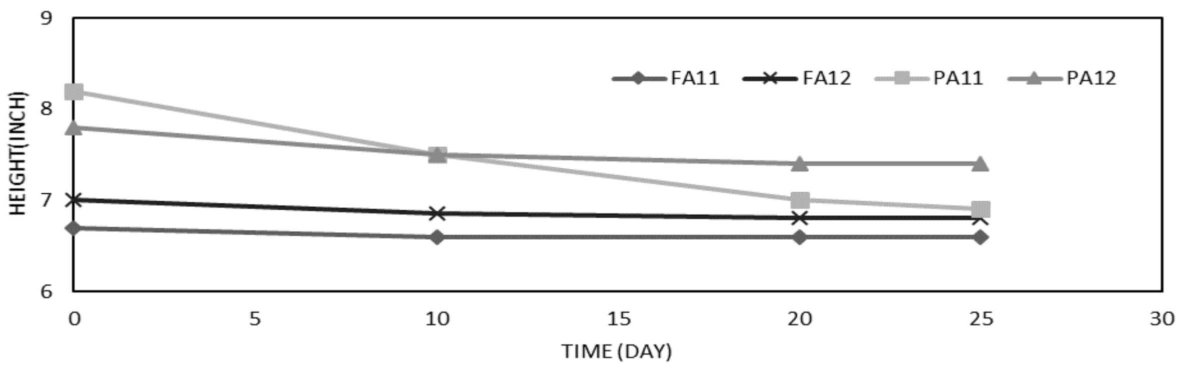
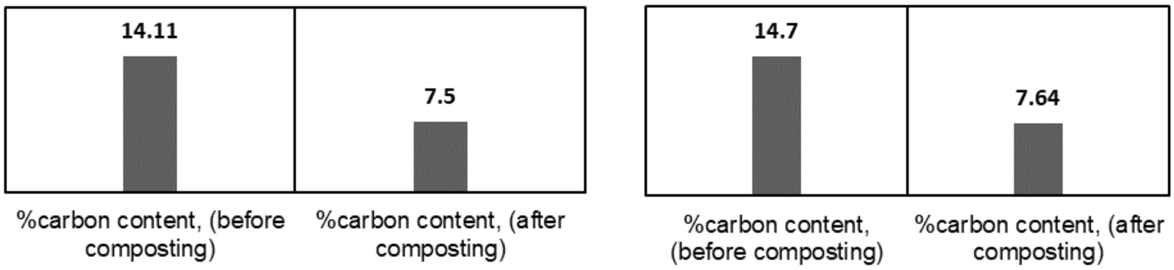


Figure 5: The height of the Compost mass vs Time for forced aerated (FA11, FA12) and passively aerated (PA11, PA12) Test mixture at second stage of co-composting.

Percentage volatile solids and carbon content were calculated before and after co-composting and are shown in Table 4. Percentage carbon was found from percentage volatile solids. In second stage of co-composting, the initial carbon content of the co-composts of forced and passively aerated were 14.11% and 14.7% respectively. In finished co-compost these values decreased to 7.5% and 7.64% respectively. According to SRDI standard the total carbon content (%) of finished co-compost should be within 10-25%. So the values of carbon are not within the standard limit.

Table 4: Percentage Volatile solids and %carbon before and after composting

Sample	Average % volatile solid (before composting)	% Volatile solids (after composting)	Average % carbon (Before composting)	% Carbon (After composting)
PA11		13.67		7.66
PA12	26.26	13.62	14.70	7.63
FA11		14.41		8.07
FA12	25.11	12.43	14.11	6.96



a) Forced aerated b) Passively aerated

Figure 6: Carbon content variation for initial and finished co-compost

4. CONCLUSIONS

The initial moisture content for test mixtures was 53%. After completing the first stage of composting process, moisture content of the waste mixture was found 50% and 46% for passively and forced aerated reactors respectively and after 2nd stage, final moisture content was found 43% to 35%. The reduction of moisture content for test mixture in forced aerated reactors is higher than the passively aerated reactors.

In stage 1 and 2, peak temperature was found 50°C to 60°C indicating the thermophilic stage. Test mixture in forced aerated reactors reached the thermophilic stage during the first stage of composting within 2 to 3 days and lasted for 3 to 5 days but it took more time to reach the thermophilic stage for passively aerated reactors.

The height of the test mixture reduced rapidly within 10 days and then slowly reduced. The total height reduction was higher in passively aerated reactors than the forced aerated reactors. It is clearly observed that the value of percentage volatile solids and percentage carbon were reduced to a significant amount which is almost half of the initial percentage.

Bulking agents (paper waste and sawdust) affected the pH profile. Its interaction with aeration ratio impacted germination index value. Waste mixture had offensive odor before composting which was disappeared in the final compost. The color of the final compost was grey and dark brown.

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EXTENT OF EFFLORESCENCE IN A BRICK MASONRY PARTITION WALL OF A GARAGE

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ABSTRACT

Efflorescence is widely recognized as an aesthetic problem of brick masonry. Till now there is no authentic solution found out for this phenomenon. Efflorescence is a crystal-like deposit, usually white, that may develop on the surface of masonry construction. On porous construction materials it may cause staining, but can sometimes specify the deterioration of internal structure by relocating and degrading of component materials especially mild steel reinforcing bar. The provided research concentrates on the efflorescence procedure and growing factors. The purpose of the test is to develop the techniques for resolution of the efflorescence risk and to evaluate the potential solutions for the problem. To continue the research a salinity affected brick masonry wall was taken into study. To understand both horizontal and vertical movement of salt, twenty-four samples including cement plaster and underlying bricks were collected from different point of the wall as well as the corresponding point of the opposite side of the wall. After chloride content test and conductivity test of samples, the result demonstrates that lower part of the wall is affected very much and upper part is less affected. The research described in the present paper aims to achieve better understanding of the relationship between chloride content and conductivity of the samples based on the laboratory test. It is also tried to figure out the factors of the unsuccessful repairs of masonry wall conducted in the past and to recommend possible alternatives to end or reduce the corrosion process based on primary research of field data and continuous observation of affected spot.

Keywords: *Efflorescence, brick masonry, chloride content test, conductivity test, repairing process*

1. INTRODUCTION

Efflorescence is a crystalline deposit on surface of masonry or concrete. It appears as a mostly white and thin, foggy salt deposit on the surface. Efflorescence has been an issue for many years. Depending on its intensity, efflorescence changes the colour impression and appreciation of the material surface and the facade as a whole (Hall, Hoff, & Nixon, 1984). In some cases, efflorescence appears directly after construction. In other cases, efflorescence starts to appear after a couple of years for taking appropriate maintenance of the façade. Most building materials contain a number of various ions which may be natural part of the material or can be additionally introduced to the pore system from the atmosphere in the form water solution (Benavente, García del Cura, & Ordóñez, 2003). Water disappears after a change of environmental circumstances and salt crystallizes either inside the pores or on the surface area (Pavlíková, Pavlík, Keppert, & Černý, 2011). The formation of salt deposition is not unidentified. For dissolving and transporting the salts, water must be present. It is required for dissolution of elements of the efflorescing salts as well as for their transportation between brick or concrete block and mortar joint, and lastly, to the brickwork surface (Brocken & Nijland, 2004). It is difficult for water to transport salts to the surface in denser materials whether it be brick, stone or concrete. Conversely, for the porous materials, transportation and deposition are very easy (Bari, Rahman, Islam, & Alam, 2016). Temperature, humidity and wind affect efflorescence mainly (Abu Bakar, Wan Ibrahim, & Megat Johari, 2011). For example, in the summer, moisture disappears so rapidly that relatively a bit of salt is introduced to the surface. Typically, in the winter when a slower rate of evaporation lets migration of salts to the surface, efflorescence is more frequent (Lee & Moon, 2006). During drying of a wall salt is migrated to the evaporation front, where it crystallizes and builds up. Generally, the evaporation front is located near the surface of the wall, i.e. the plaster, runs the maximum risk of corrosion. Even though the plaster used in recovery is usually regarded as a sacrificial part, a long service life of the plaster is pursued (B. Lubelli, van Hees, & Groot, 2006).

Groundwater in Khulna region is a vigorous source of efflorescence (Morshed, Uddin, Islam, & Linda, 2016). Efflorescence can be caused by the use of unwashed seashore aggregate (Bosunia & Choudhury, 2001). They are, for the most part, water-soluble salts that come from many possible sources like clay bricks contain the initial soluble salt content as a parameter of efflorescence (Ahl & Lü, 2007).

According to PCA (Portland Cement Association), most efflorescence can be classified as temporary. On the other hand, recurrent efflorescence indicates a chronic moisture problem. Sometimes efflorescence is removed by some treatment measures, but if it returns, it is a sign that water is entering the wall and driving the salts out. If it does not return, then the reason is initial moisture and salts at the time placing the concrete. Beginning efflorescence can be eliminated with a brush and water. Large remains may require acidity treatment of the surface of the concrete. Initiatives should be taken to appropriate the wetness issue, thereby avoiding and removing repeated efflorescence.

Since many issues influence the formation of efflorescence, it is tough to predict when it will appear: There is no approved conventional analyse means for identifying the efflorescence prospective of brickwork mortar. Numerous time, money and initiatives have been spent trying to fix troubles efflorescence produces. Many test applications have been designed and several efforts have been made to remove the efflorescence problem but none has been known as efficiently forecasting the efficiency of mortar components in real use (Barbara Lubelli, van Hees, & Groot, 2006). However, even though no certain treatment process has been found, a good deal has been found all about how efflorescence works and ways to avoid it, and if safety actions are insufficient, how to remove the efflorescence if it does appear.

This article describes the techniques of white efflorescence, how to help avoid efflorescence and to find cost-effective possible methods to remove efflorescence from new surfaces.

In this research, a brick masonry wall of a car parking of KUET campus which is affected by repeated efflorescence has been taken into consideration.

This research includes developing a low-cost solution for efflorescence problem. This research investigates the inefficiency of the repairing works regarding this problem. Moreover, being unawareness and maintenance difficulties, the number of structures affected this problem increasing at an alarming rate. An attempt has been taken to minimize this problem and providing some recommendations for sustainable use of the structure are also the goals of this research.

2. METHODOLOGY

2.1 Selection of The Affected Area

To accomplish this study, a seriously affected masonry wall was needed. For this reason, a salinity affected wall in Garage 3 situated in Khulna University of Engineering & Technology was selected. In this wall, there is no presence of water line. It is completely free of rainwater. The wall is an interior partition wall used for car parking. The spot is shown in Figure 2(a).

2.2 Observation different stages of efflorescence

For the research, it is necessary to observe whole process of efflorescence (Figure 1). There are number of reasons which directly or indirectly cause efflorescence. The study continued for year and half to find the reasons that come into play of the severe efflorescence problem.

As the older the structure the more susceptible to have this problem. For this project, it was necessary to find an old structure where change is rapid due to efflorescence in plaster.

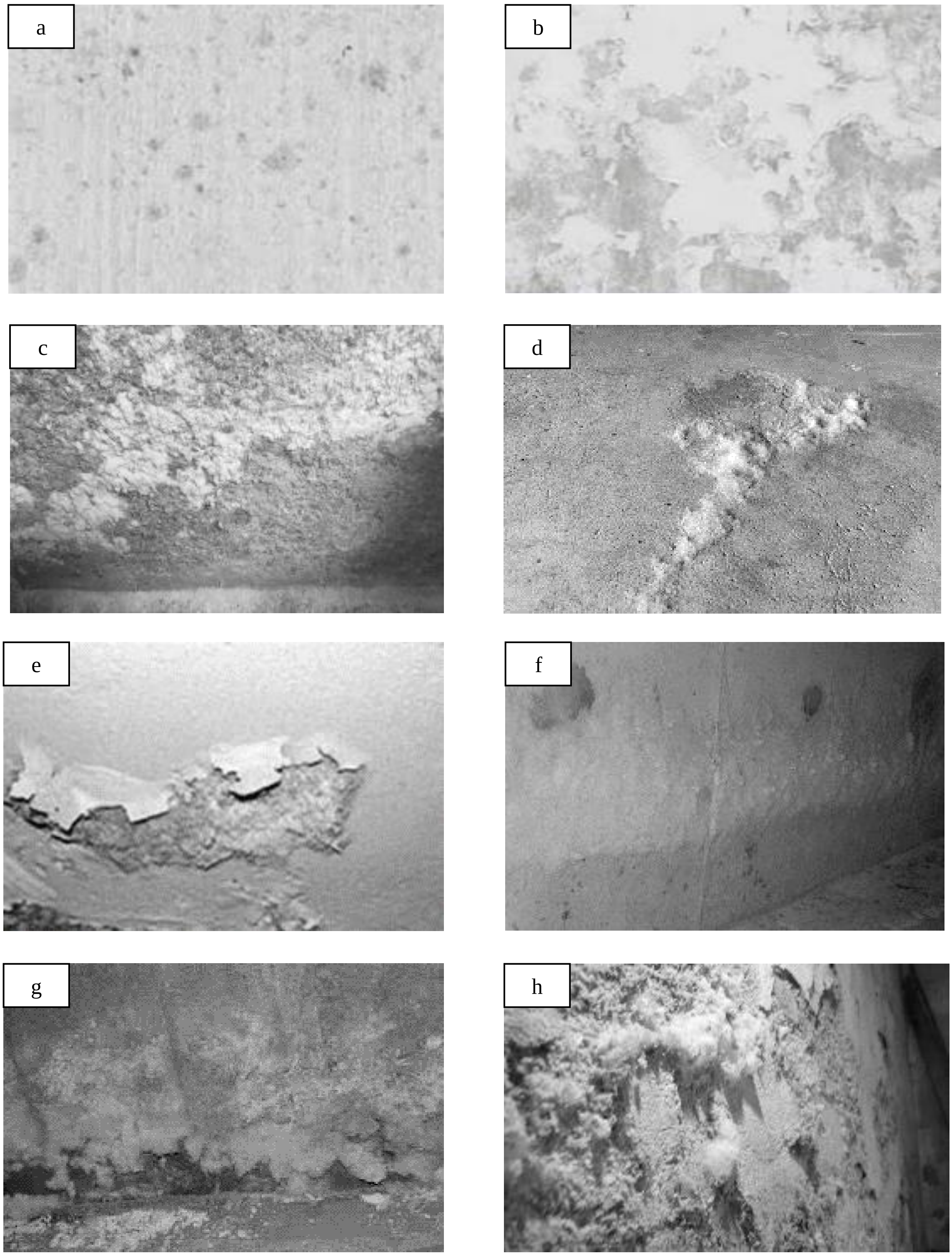

Figure 1: Different stages of efflorescence

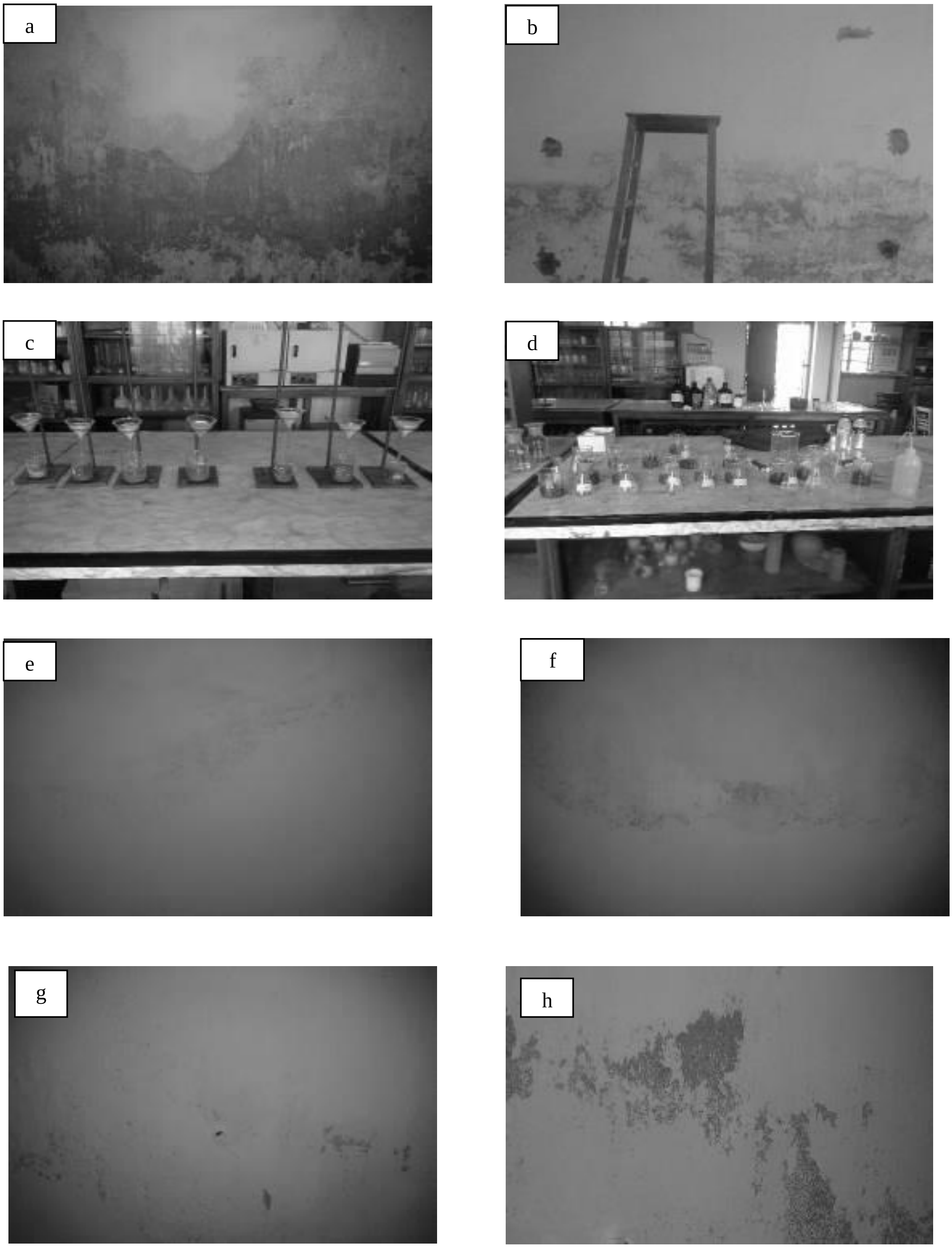

Figure 2: Stepwise procedure of this study

2.3 Collection of Cement Plaster and Brick Sample of The Affected Wall

To conduct the test and to know the severity of the efflorescence, samples including cement plaster and underlying bricks were collected from different point of the wall as well as the corresponding point of the opposite site of the wall to understand the movement of salt both horizontally and vertically. 12 cement plaster and 12 brick samples were collected (Figure 2 b).

2.4 Performing Chloride content test and Conductivity Test

To comprehend the severity of efflorescence problem, its propagation and the movement of the soluble salts, two tests were performed. For these, samples both bricks and cement plaster were oven dried. Performing conductivity test and silver nitrate titration for chloride content test. (Figure 2. c & d).

2.5 Computing the Area of The Salinity Affected Zone

The wall is 33 feet long and 15 feet in height. The efflorescence affected zone was selected very carefully. Then total area of the affected zone was calculated by dividing the length of the wall into 33 segments.

2.6 Computing the Area of The New Plastered Zone

To understand the post repairing state, the efflorescence affected area were repaired by new cement plaster. The total area of new cement plaster was also calculated.

2.7 Continuous Observation of The Affected Area

This research had been performing more than 18 months. During this period, it was under observation to identify the change which was a continuous process. The whole time was divided into three phases.

2.7.1 Before Repairing Work

First, the observation before the repairing work which is about eight months, displaying gradual propagation of efflorescence from its starting to the serious level (Figure 1). As this masonry wall is an example of severe attack of efflorescence, the gradual change is reflected significantly. Maintaining a certain time interval these images were taken to understand the change of the state of efflorescence.

2.7.2 During Repairing Work

To remove efflorescence from wall, at first wetting the walls with water and rinsing with water. Water used was pure and salt free. For repairing purpose high quality cement paste containing minimal water was used. Fly-ash was also used because adding fly-ash to cement paste binds some salts which minimize efflorescence. At the end of the remedial strategies, it was tried to ensure the least possible presence of moisture in the wall.

2.7.3 After Repairing Work

The last part started after remedial process had been completed. After some days, it was seen that the problem had not been solved totally. The severity of the problem was reduced but still the wall was attacked by efflorescence. It was noticed how the surfaces be affected by efflorescence again and the way of its duplication. These images figure 2 (e, f, g and h) were taken keeping a certain time period to comprehend regeneration process. Finally, decision was taken which ingredient or sealer should be used to diminish this problem by further treatment process and it would be the vital result of the experimental study.

3. ILLUSTRATIONS

3.1 Figures

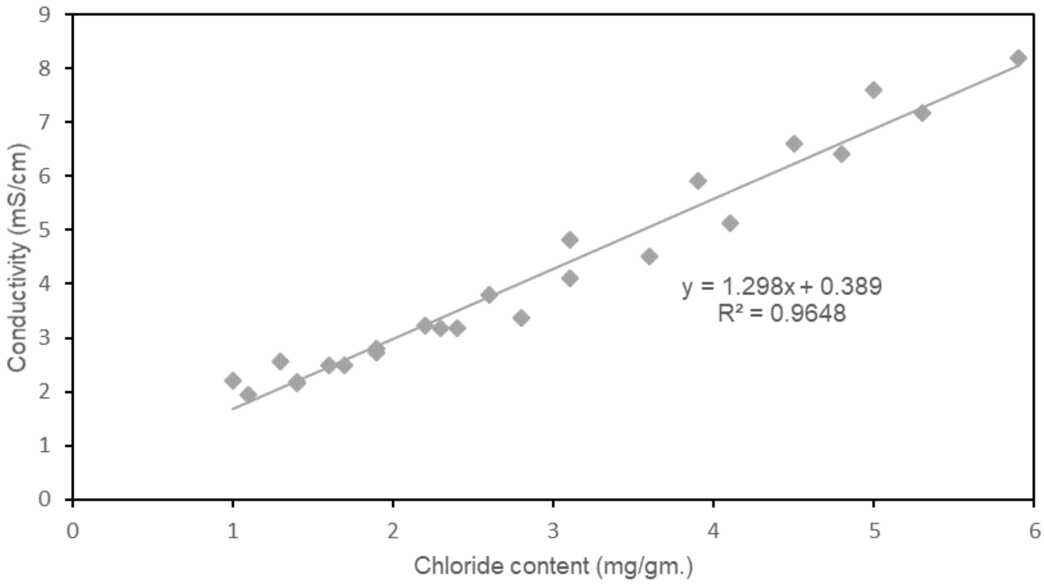

Figure 3: Variation of conductivity with respect to chloride content

3.2 Tables

Table 1: Chloride content test and Conductivity test of the brick and cement plaster

Chloride content of plaster (mg/gm)											
Wall											
Point 1						**Point 2**					
Lower Level		**Middle Level**		**Upper Level**		**Lower Level**		**Middle Level**		**Upper Level**	
West	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**
A	A'	B	B'	C	C'	D	D'	E	E'	F	F'
4.5	5.3	2.4	2.8	1.0	1.3	5.0	5.9	3.1	3.6	1.6	1.9
Conductivity of plaster (mS/cm)											
Wall											
Point 1						**Point 2**					
Lower Level		**Middle Level**		**Upper Level**		**Lower Level**		**Middle Level**		**Upper Level**	
West	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**
A	A'	B	B'	C	C'	D	D'	E	E'	F	F'
6.60	7.17	3.18	3.38	2.21	2.57	7.62	8.21	4.14	4.53	2.51	2.84

Chloride content of brick (mg/gm)											
Wall											
Point 1						**Point 2**					
Lower Level		**Middle Level**		**Upper Level**		**Lower Level**		**Middle Level**		**Upper Level**	
West	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**
A	A'	B	B'	C	C'	D	D'	E	E'	F	F'
3.1	3.9	1.9	2.3	1.1	1.4	4.1	4.8	2.2	2.6	1.4	1.7
Conductivity of brick (mS/cm)											
Wall											
Point 1						**Point 2**					
Lower Level		**Middle Level**		**Upper Level**		**Lower Level**		**Middle Level**		**Upper Level**	
West	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**	**West**	**East**
A	A'	B	B'	C	C'	D	D'	E	E'	F	F'
4.83	5.90	2.73	3.18	1.95	2.18	5.13	6.40	3.23	3.79	2.17	2.48

From the comparison of chloride content test and conductivity test (Table 1), it is found the lower part of the wall is badly affected by efflorescence and upper part is less affected and it is also seen that chloride content of a point and the corresponding point of opposite side of the wall is very close. From (Figure 3), the gradual change of conductivity with respect to chloride content is very clear. Though Khulna is situated in the coastal belt but there are some other reasons responsible for this problem. These are at first, there must be water soluble salts exist in the fired clay bricks during the construction period of the garage. Secondly, presence of sufficient moisture in the wall. Lastly and the most important is that, there must be a pathway in the wall for the soluble salts to migrate through to the surface where the moisture can easily evaporate, by this way salts are deposited which then crystallize and finally cause efflorescence. These three reasons are combinedly responsible for the severe efflorescence problem.

Table 2: Measurement of the efflorescence affected area and repaired area of the wall

Wall (west) (ft.)	**Net area of efflorescence affected zone (ft²)**	**Net area of the new plastered zone (ft²)**
1	0.7	1.3
2	1.4	2.6
3	1.1	2.7
4	0.5	2.8
5	0.3	3.1
6	0.3	3.5
7	0.5	3.7
8	1.2	3.8
9	1.3	3.8
10	0.5	3.9
11	0.4	4.1
12	0.5	4.2
13	0.6	4.0
14	0.7	4.0
15	0.8	4.1
16	0.7	4.1
17	0.7	4.2
18	0.7	4.1
19	0.7	4.2
20	0.9	4.3
21	0.9	4.3
22	0.7	4.3
23	0.4	3.9
24	0.5	3.8
25	0.7	3.8
26	0.6	3.9
27	0.5	3.8
28	0.7	3.6
29	2	3.5
30	3.1	3.4
31	1.6	2.5
32	0.4	2.2
33	0.5	2.8
Total	27.1	118.0

Net area of efflorescence affected zone = 27.10 ft^2
Net area of the new plastered zone = 118 ft^2
So, the ratio of repaired area and affected area = 118/27.10 = 4.35
Analysing the total area of affected zone by efflorescence and newly plastered area it is found that almost four and half times area is plastered corresponding to the affected area (Table 2). Apparently, it looks good for the recovery of efflorescence but the final result is not satisfactory. During the repairing process only one side of the wall (west) was plastered keeping other part of the wall (east) unrepaired. As there is a horizontal movement of the soluble salt and plenty of water-soluble salts present in the wall, the repaired wall affected by efflorescence again in a continuous process. While repairing the wall, it is urgent to renovate the wall exposed to the weather. The finest way to reduce the problem is to prevent water from infiltrating and letting outside water in.
To prevent further efflorescence, it is required to apply a concrete sealer to the surface of the affected wall. In this garage wall, film sealer can be used to protect pavers by blocking the effects of water and other contaminants. Film formers generate a barrier on the surface of the paves. Penetrant sealers can also be used. It is very effective to repel water in this condition.

4. CONCLUSIONS

- Chloride content is higher in lower portion of the masonry wall and less in the upper portion of the wall.
- There remains always a horizontal movement of soluble salts in the affected wall.
- It should be ensured that there must not be any path for the soluble salts to migrate.
- In case of fixing an efflorescence affected wall, it is necessary to renovate both the external and the internal part of the walls.
- In severe condition it is required to apply a concrete sealer on the repaired surface to reduce the problem.

It is not easy to remove the efflorescence problem completely. It will be better, if some precautionary steps are taken into consideration from the beginning of the construction process, there is less possibility of arising this problem. Low-alkali mortar for stone or brick work should be used so that alkali salts don't leach into the masonry. Mortar should be firm and free of cracks. No leak should be allowable inside the brick masonry. It is required to be sure the manufacturer of fired clay bricks has added chemicals during manufacture to make salts in them insoluble and limit efflorescence. Structures those are constructed maintaining these factors will be less vulnerable to efflorescence.

ACKNOWLEDGEMENTS

The authors are grateful to the assistants and laboratory technicians of the Engineering Materials Lab and Environment Engineering Lab for their assistance and co-operation in carrying out the study in various ways.

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AN IMPROVED METHOD OF SOLAR DESALINATION: TUBE IN TUBE TECHNIQUE

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ABSTRACT

Water is one of the quintessential elements that enable our existence on earth. However, around 97% of that water is contained by the ocean which is saline. The remaining 3% of water is fresh and is found in rivers, lakes, snow on mountain top and underground water resources which fulfills the demand of both plants and animals. With the expansion of the human civilization, scarcity of fresh water is also increasing. This ever increasing scarcity of water can be mitigated through desalination. This research makes an attempt to desalinate water with a new and improved method named "Tube in Tube" technique. The research was conducted at the terrace of a local building in Dhaka, Bangladesh. In this research three variation of Tubular technique, Tray in Tube, Tube in Tube (Jeans) and Tube in Tube (Jute) was prepared and some selected parameters were observed to compare those setups. Each setup observed in this research had the same dimension of 0.254 m in diameter and 0.914 m in length. After analyzing the acquired data it was derived thatTube in Tube (Jeans) and Tube in Tube (Jute) gave 72% and 53.5% increased distillate output and an increased temperature of 11°C and 8°C respectively than simple Tray in Tube setup. It was also observed that use of composite fibers to increase the evaporation surface area accelerates the distillate output production rate.

Keywords: *Solar Desalination, underground water, Tubular technique, potability, palatability*

1. INTRODUCTION

With the advancement of the human civilization, more and more water is required every day. This ever increasing scarcity of water can be mitigated through desalination of sea water. The systems that are used at present for desalination mostly harness non-renewable energy and are very expensive in terms of installation, operation and maintenance. Bearing that in mind, an attempt has been made to develop a system which will use renewable energy only and which can be constructed with readily available inexpensive materials. This system is extremely easy to construct and can be transported easily. This method of desalination is termed as 'Tube in Tube' technique which was first applied in Department of Civil Engineering, Ahsanullah University of Science & Technology in 2015. It is suitable for many remote and arid areas of the world that are blessed with plenty of solar desalination.

The prime objective of our work is to compare selected parameters between the different arrangements of the 'Tube in Tube' system. These parameters include temperature variation in different zones within the system, distillate collection rate and effect of composite fiber. In addition to that, salinity of the treated water is also measured in order to assess its potability and palatability.

The aim of this research is to make an attempt in solving numerous issues that arise due to salinity of water and scarcity of fresh water such as reduction in agricultural production, lack of usable water of standard quality, impact of saline water on infrastructures etc. We observe the temperature variation in different zones within 'Tube in Tube' system; evaluate the distillation output rate, cost estimation, and salinity measurement.

2. REVIEW

Several techniques have been used to desalinate water over the years. Here some of these have been studied and the outcome was observed. The techniques were divided into five categories.

a) Wick Type
b) Basin Type
c) Tubular Type
d) Humidification-Dehumidification Type
e) Enhancement to existing System

2.1 Wick Type

A paper by Karaghouli, *et al.* (1995) states that floating wick type solar still can generate a higher water production compared to basin type still and tilted wick type solar still. Also the production output doubled when tracking mechanisms were used.
In a paper published by Anand, *et al.* (1992) the authors presented that combined tubular multi wick solar still gives more output than tubular multi wick or basin type solar still.
A paper published by Mahdi, *et al.* (2010) presents that increase in the mass flow rate of feed water decreases the efficiency of the wick type solar still and if there is an increase in salinity of feed water, efficiency of the still will be reduced.
A study conducted by Bhattacharyya (2013) states Passive solar still especially the wick or capillary type seems to be an attractive choice to get water for drinking and other domestic purposes.

2.2 Basin Type

A paper published by El-Bassouni, *et al.* (1993) states that basin type units are not effective for desalination. They can be improved by increasing the incident solar radiation.
Firozuddin, *et al.* (2013) conducted a research to investigate the effect of evacuated tube on the the performance of a single basin solar still in outdoor condition. Productivity in this method increase 50.2% compared to normal basin type solar still
Minaisian, *et al*. (1992) Good productivity and limited operation requirements, the proposed floating vertical still seems to be well suited for ensuring fresh water for drinking purposes in marsh areas of poor water quality.
A study conducted by Farid, *et al*. (1993) shows an increase in still productivity with the increase in ambient temperature and decrease in wind velocity. This suggests that the still must be placed in the lowest wind velocity.
Murugavel, *et al*. (2008) figured out some work progress to improve the productivity. The production can be increased by increasing the condensation area, increasing the incident radiation through painting black and by intermittent shading on part of the condensation surface.
Arunkumar, *et al*. (2012) performed an experimental study & stated that hemispherical solar still produces more distillate than many other stills because of its large contact surface.

2.3 Tubular Type

A study conducted by Bari, *et al*. (2016) explores use of composite fiber in 'Tube in Tube' technique and observes that it gives around 70% increase in production.

In a study conducted by Anwar, *et.al*, (2016) the authors showed that use of composite fiber in 'Plate in Tube' technique increases the production to 2.3-3.61 l/m^2/day.

Hossain, *et al*. (2016) states that painting the outside of the tray with heat resisting paint increases production by 4%.

Chen, *et al*. (2013) performed an experimental analysis of the characteristics of heat and mass transfer of a three effect tubular solar still and showed that the yield rate is higher under saturation vapor pressure at a high temperature. The performance ratio can reach 1.3 when the heating power is 300W.

A paper published by Ahsan, *et al*. (2010) makes a comparison between two models of tubular solar stills (TSS). The first model uses vinyl chloride sheet and the second model uses ordinary polythene film. . In the end, it is concluded that the second model is simpler, lighter, cheaper and more durable than the first one because polythene film is much more durable and economic compared to vinyl chloride. However, the hourly evaporation and production are slightly lower in polythene cover method.

2.4 Humidification-Dehumidification Type

A study conducted by Khalil, *et al*. (2015) presents the air bubble column achieves higher performance than that for the conventional humidifier. The characteristics of the generated bubbles are modified by using a different sieve plate with different hole size.

A system carried out by Karke, *et al*. (2013) presented that a multistage flash and multiple effect distillation is mainly the whole process in fresh water production from salty water by enhancing the evaporation and condensation. It achieves 58% collector efficiency.

A study carried out by El-Agouz, *et al*. (2014) presents an experimental result for solar desalination using sprays evaporation technique. The whole system is designed to improve the evaporation rate by spraying water at low temperature.

A study conducted by Fath, *et al*. (2001) investigates the performance of a simple solar desalination system using humidification-dehumidification process. From the results the heater efficiency is in the range of 45%. Solar air heater significantly increases system efficiency. Also, increase in the solar intensity and ambient temperature along with the decrease in wind speed increases system productivity. Increase in air flow rate up to 0.6 kg/s increases the amount of seawater desalination.

2.5 Enhancement to Existing Systems

A paper conducted by Jitsuno, *et al*. (2012) presented a system for desalination of sea and brackish water using vacuum distillation system and solar heat. Using electric heater, 80% of heat was increased than that of sun ray. The amount of fresh water was about 15 liter/day. In this process, thermal efficiency was 70% which was equivalent to 10kg/m^2 of water per day.

A paper conducted by Auti, *et al*. (2013) presented a domestic water desalination system with condenser without using electricity in rural areas. . In collecting process, there occurred some heat loss. In this desalination process, for 8 liters of salt water, 10 hours was needed to evaporate the water to get pure drinking water.

A paper was presented by Sadeek, *et al*. (2014) about the experimental process of the development of hybrid water treatment system using solar still cum sand filter with ceramic media. In winter, average daily production rate was 2.1 L/m^2. In summer, daily production rate is 3.15 L/m^2.

A study conducted by El-Agouz, *et al*. (2014) discusses about the desalination using spray evaporation in a one-stage technique. The daily maximum efficiency of this plant was 87%. The cost estimation for each liter of distilled water was $0.029.
Tanaka, *et al*. (2002) proposed a new type of solar still and its performance is greatly enhanced by narrowing diffusion gaps in between the partitions. The use of 10mm diffusion gap decreases the productivity by 10% and use of 5mm gap decreases the productivity by 40%. The productivity of the 5mm gap can be increased by sandwiching nine small spacers in every diffusion gap. The still with 5mm gap with 11 spacers has a production of 14.8-18.7 kg/day.

3. METHODOLOGY

This method is based on the general principle of water turning into vapor as a result of temperature increase after absorbing solar energy. This method would consist of some primary elements such as; an outer transparent tube, a tray to hold saline water, an inner tube to increase the surface area and some composite fibers to increase the evaporation surface area. Solar radiation would pass through the outer tube and the water in the tray would absorb the solar radiation and evaporate. The use of composite fiber on the inner tube would work as a wick and increase the evaporation surface area. The evaporated water would condense at the inner side of the outer tube and roll down along the tube to the outlet. This output would be free from Salt and other impurities and could be used as drinking water.

3.1 Construction Materials

All materials used to make all the setup were locally available, cheapand collected from different sources. We used **stainless steel tray** having a dimension of 0.66m length, 0.178m

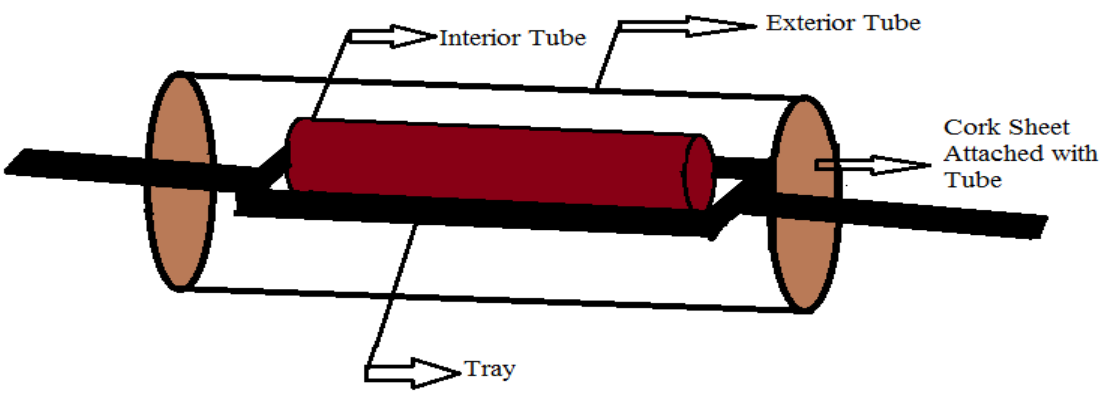

Figure 1: Schematic Diagram of the Setup

(0.254m in diameter & 0.076m thickness), transparent plastic sheet (TPS), composite fibers (jute, micro fiber cloths & jeans), thermometer (digital & analogue), inlet & outlet pipe, custom made elevated steel frame and filter paperto purify the distillate output.

Figure 2: Rolled TPS Sealed With CorkSheet Disc at Both End.

3.2 Model Setup

Transparent plastic sheet were cut out to obtain segments of dimension 0.914mX0.609m. Then two of those segments were taken and glued with super glue to one another along their width to form a sheet of dimension 0.914mX0.914m. Then the sheet was rolled into the form of a tube having a diameter of 0.254m and a length of 0.914m. Two circular disks were made from cork sheets and the end sections of the tube were covered.

(a) (b)

Figure 3: PVC Pipes Wrapped Up with Composite Fiber

To ensure that the distillate output will not leak out of the tube, the end near the outlet zone was attached with the cork sheet with melted stick gum.PVC pipe was wrapped up with composite fiber. First the PVC pipe was wrapped up with microfiber cloth and then the upper part of the pipe was covered with jeans or jute fiber to complete the implementation of composite fiber. The jeans or jute fiber was stitched with microfiber cloth in such a way that the saline water in tray will not touch the jeans or jute fiber. The water would flow through the microfiber cloth to the jeans or jute fiber and then evaporate. Then the pipe segment was placed in the tray. Afterwards the tray along with the PVC pipe was placed inside the transparent tube through the open end and the end was sealed with cork sheet disc as mentioned before. It was made sure that the handles of the tray remained outside of the tube and necessary adjustments were made to the discs to help the handles probe out of them and act as a support.

Figure 4: Placement of Wrapped PVC Pipe inside the Tray

3.3 Model Placement

We made six tubes in total at a time for this test. Two of them were made for Tube in Tube (Jeans),another two of them were made for Tube in Tube (Jute)and the last two of them were made simply where no fiber was used. After completing the setup, all the six models were placed on the roof of a building from where the adequate solar radiation is to be achieved. All models were from the same elevation from the floor and also were the same location where the temperature and humidity was same.

Figure 5: Placement of final model at roof top.

3.4 Data Collection Process

Different zones provide different temperature readings. The five temperature measurements that have been made were ambient temperature (T_A), temperature of air inside the tube (Ta), temperature of the tray (Tt), temperature of the composite fiber (Tc) and temperature of the water in the tray (Tw). On the surface of each tube, a number of holes were made to allow access through various regions inside the tube to take temperature readings. Digital thermometer was inserted inside each hole of the tube and kept for a full minute. In the end, temperature readings were taken. Readings were taken every two hour intervals for ten hours. The holes were temporarily sealed up by proper insulating materials after the completion of temperature assessment.

Figure 6: Collection of Distilled Water from System

Water evaporates as a result of absorbing heat from the incident solar radiation. The vapor created undergoes condensation at the inner surface of the exterior tube and roll downs to the bottom. The tube is placed in such a way that the exterior tube creates an angle of thirty degree with the horizontal while the tray inside the tube remains parallel to it. As a consequence the distillate output gets collected at one end of the tube where the outlet is located. Water is collected from the end through an outlet pipe connected to the sealed tube so that the collected water does not undergo further evaporation. Water collection was carried every 24 hours and the volume was measured using a measuring cylinder to acquire an understanding about distillate output rate and the quality of the water collected. Water samples of two different salt concentrations were prepared. One was sea water which had a salt concentration of 35000 mg/l. Another sample was brackish water which had a concentration of 2000 mg/l.

3.5 Salinity Measurement

This process involves determination of salt content from sea water by titration a sample of salt water using silver nitrate solution of known concentration. The purpose of this test is to chemically determine halide content and titration is continued until all halides (Chloride and a small amount of Bromide) have been precipitated as silver halides. The full conversion is ensured by the help of a suitable indicator or electrode system.

4. RESULTS & DISCUSSION

4.1 Data Collection

The data collected from the experimental setup has been analyzed in three segments. The distillate output rate, hourly temperature variation and salinity measurement data were analyzed to evaluate the parameters and to get an idea of the efficiency and effectiveness of Tube in Tube method.

4.1.1 Distillate Output Rate Calculation

Distillate output rate was calculated in ml/m^2 of the area of the tube, area of the tray and the area of the evaporation surface area.

The width of the tube = 0.254 m and the length of the tube = 0.9144 m.

So, the area of the tube = 0.254 m X 0.9144 m = 0.2322576 m^2.

The width of the tray = 0.178 m and the length of the tray = 0.660 m.

So, the area of the tray = 0.178 m X 0.660 m = 0.11741912 m^2.

The perimeter of the composite fiber = 0.2286 m and length of the composite fiber =0.508 m.

So, the evaporation surface area = 0.2286 m X 0.508 m = 0.1121664 m^2.

Three types of Variations were used in this experiment. They are- Tray in Tube, Tube in Tube (Jeans) and Tube in Tube (Jute). Two setups were prepared for each variation. All the tubes have been denoted in the following manner-

Tube-1 of tray in tube system – T1
Tube-2 of tray in tube system – T2
Tube-1 of tube in tube (Jeans) system – T3
Tube-2 of tube in tube (Jeans) system – T4
Tube-1 of tube in tube (Jute) system – T5
Tube-2 of tube in tube (Jute) system – T6

4.1.2 Temperature Variation Analysis

The tubular systems are designed to carry out observations related to temperature variation within the subject. For each system five temperature measurement zones were defined:
Ambient temperature – (Tair)
Temperature of air inside tube – (Ta)
Temperature of tray – (Tt)
Temperature of composite fiber – (Tc) and
Temperature of the water in the tray – (Tw)
Temperature readings are recorded as average temperature for the five months period at a specific time. This is done to keep the investigation as simple as possible.

4.1.3 Salinity Measurement of Treated Water

For the test to be carried out brackish water (2000 mg/l salt concentration) &sea water (3500 mg/l salt concentration) were prepared. It was observed that the Tray in Tube displayed around 36mg/l and 37mg/l salt concentration respectively. The Tube in Tube (Jeans) showed 32mg/l and 38 mg/l respectively and Tube in Tube (Jute) displayed around 32mg/l and 42 mg/l salt concentration respectively.

4.2 Evaluation of Data

The data collected from the three set ups were meticulously observed and calculated in this segment

4.2.1 Evaluation of Distillate Output Rate

The unit for water production rate is taken as ml/m^2/day and yield of these systems are observed for five months in total. Here as a sample the evaluation of March-2017 is displayed: Figure 7gives us the Production vs Date curve for the month of March. From the graph we can see that in March, as seen before, the Tube in Tube (Jeans) gives the maximum output of the

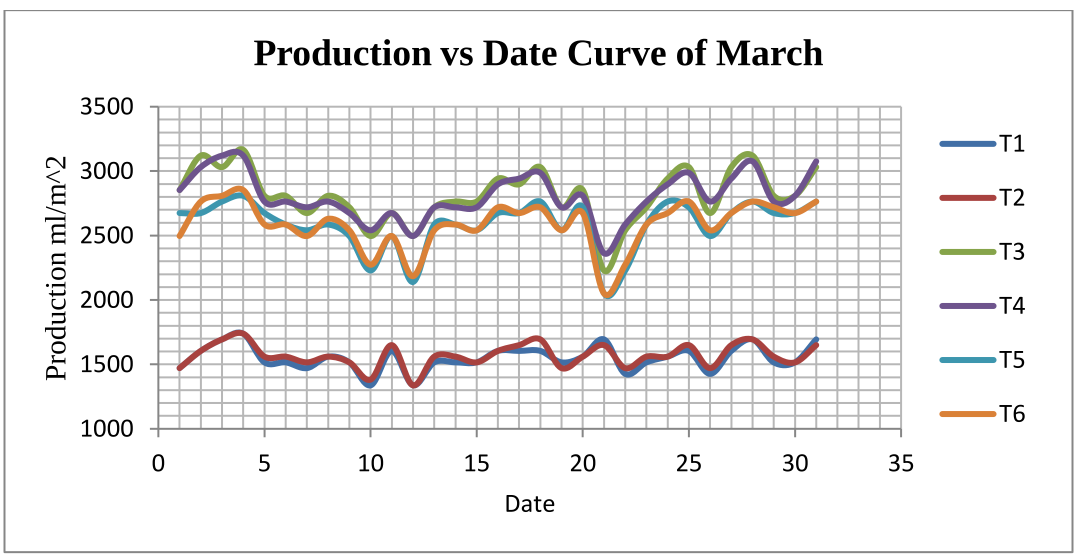

Figure 7: Production vs Date Curve, March 2017

three sets of tubes. There are some rapid drops in production in March as a result of rain fall which hindered the temperature to increase. The graph shows that the Tray in Tube, Tube in Tube (Jeans) and Tube in Tube (Jute) has a production rate of (1300 ml/m2/day–1800 ml/m2/day), (2400 ml/m2/day–3200 ml/m2/day) and (2000 ml/m2/day–2900 ml/m2/day) respectively.

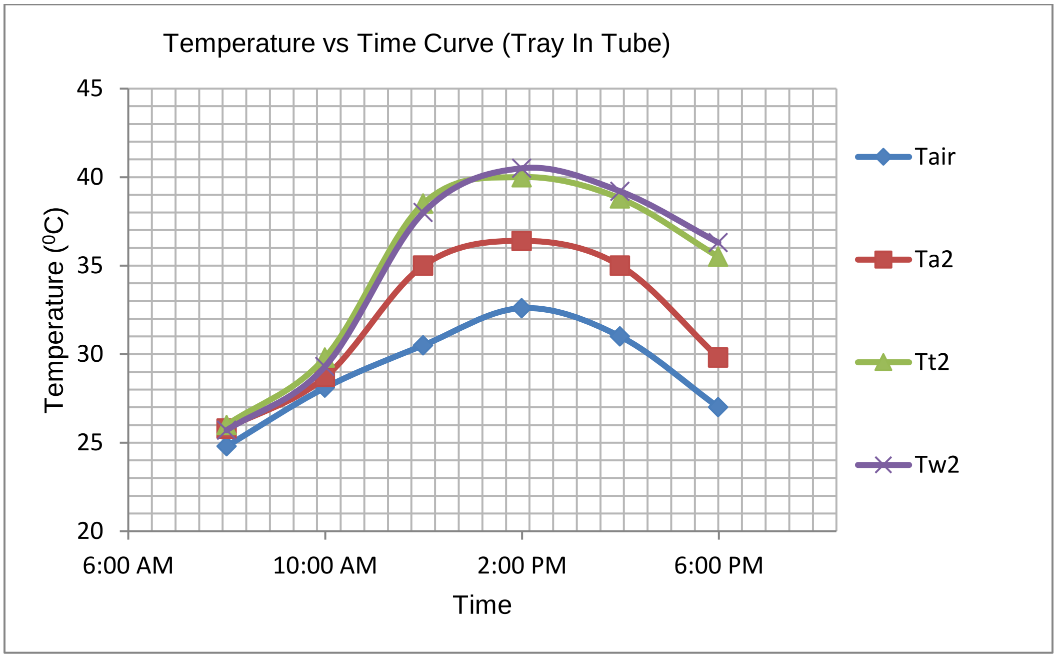

Figure 8: Temperature vs Time Curve (Tray in Tube)

Figure 9 gives us the Temperature vs Time Curve of Tube in Tube (Jeans) system.

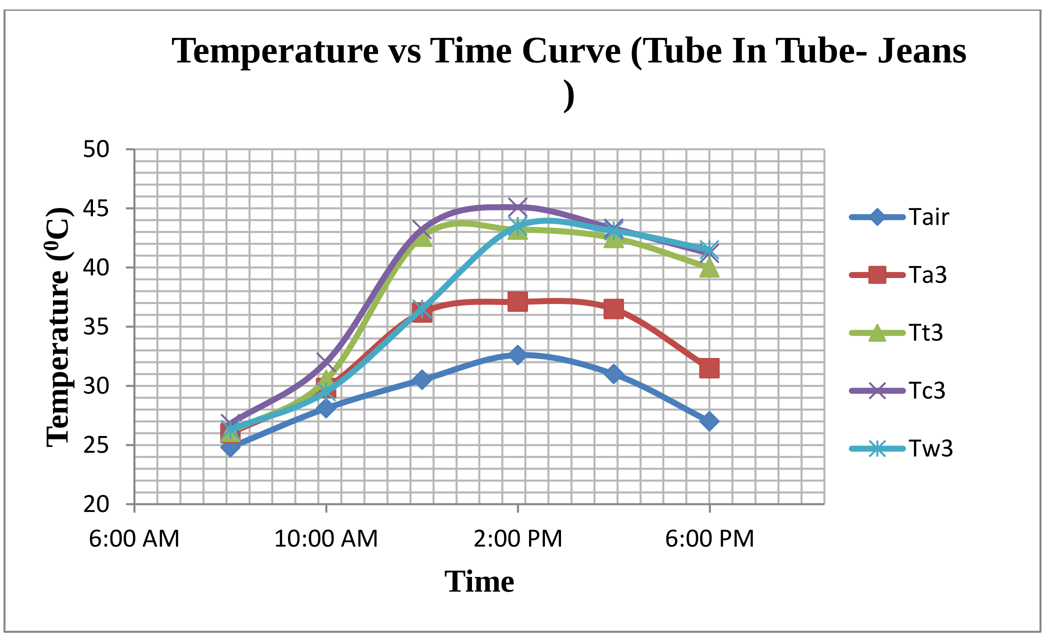

Figure 9: Temperature vs Time Curve (Tube in Tube- Jeans)

Figure 8 gives us the Temperature vs Time Curve of Tray in Tube system. It is seen that in both the graphs the temperature tends to rise from morning till noon and after that the temperature in different zones start to drop as the ambient temperature starts to fall. Figure 10 gives us the Temperature vs Time Curve of Tube in Tube (Jute) system.

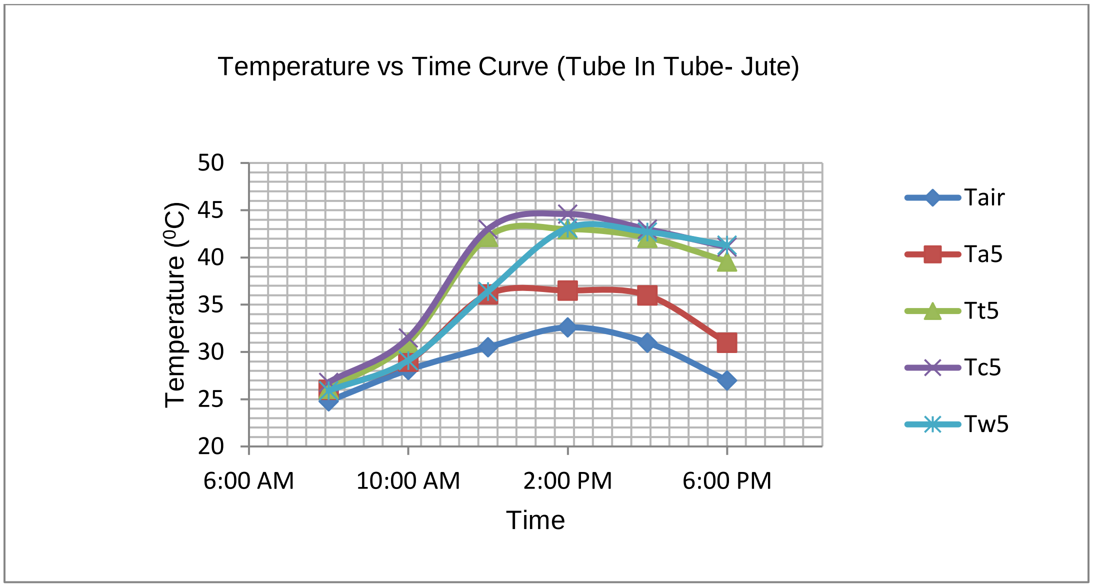

Figure 10: Temperature vs Time Curve (Tube in Tube- Jute)

The evaporation surface area was increased by wrapping a PVC pipe with composite fiber and placing it inside the tray. Two types of composite fiber was used- a) Jeans with microfiber cloth and b) Jute with microfiber cloth. It was found that the Tube in Tube (Jeans) gives a maximum of 72% increase and Tube in Tube (Jute) gives a maximum of 53.5% increase in distillate output from simple Tray in Tube system.

4.3 Cost Estimation

All the materials used in this experiment were locally available and easily affordable.
Total apparatus was handmade which made it very cheap. If it is fabricated commercially the cost of construction of the apparatus might be more reasonable than the cost mentioned above.

Materials	Cost (BDT)
Stainless Steel Tray	300
PVC Pipe	45
Cork Sheet	25
Transparent Plastic sheet	35
Composite Fibers	15
Super Glue	20
Stick Gum	10
Inlet pipe	15
Outlet pipe	15
Filter Paper	2
Total Cost	**482**

4.4 Discussion

This work could be implemented at a large scale to test its feasibility and broaden the scope for research. Systems for the research are assembled manually without taking quality under consideration. So, errors may occur in deriving output from the experiment.The mild curvature at the top of the tube slightly hampered the rolling down of water along the inner surface of the tube. So, a square tube placed at 45^0 angle with the horizontal may assist in overcoming the problem.

5. CONCLUSIONS

Tube in Tube (Jeans) outperforms Tray in Tube and Tube in Tube (Jute) systems in distillate output production. Although Tube in Tube (Jute) comes as a close competitor when it comes to distillate output collection. Tube in Tube (Jeans) gives 72% increase and Tube in Tube (Jute) gives 53.5% increase compared to Tray in Tube system. Tube in Tube (Jeans) seems to give a higher temperature reading compared to Tube in Tube (Jute) because it is superior in heat absorbing and storing than Tube in Tube (Jute) and Tray in Tube system. Jeans facilitates in rapid evaporation of water than compared to jute fiber. It was found that the Tube in Tube (Jeans) and Tube in Tube (Jute) exhibit 11ºC and 8ºC respectively. The salt concentrations measured of both feed and treated water were well below the acceptable 500 mg/l of World Health Organization (WHO). Although theoretically there should be no salinity at all. This indicates there might have been some mistakes along the course of the study.

ACKNOWLEDGEMENTS

We are very grateful to the Almighty Allah for giving us the patience and power to initiate and successfully complete this research. We would also like to express our sincere gratitude towards Prof. Dr. Quazi Hanidul Bari for his kind supervision and invaluable guidance which enabled us to complete the research

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DEVELOPMENT OF A MULTIGRADE FILTER FOR SURFACE WATER TREATMENT IN DRINKING PURPOSE

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ABSTRACT

Global water scarcity is becoming an increasing challenge to the global community, particularly in developing countries such as Mexico,Bangladesh,Northern and Southern Africa, India and Northern China; Due to a lack of available resources, knowledge and skills many of these developing countries are unable to upgrade their water supply to sustain the growing population. Most of people in this country use ground water which is more or less safe with respect to surface water. This study aims at developing a multigrade filter unit for surface water treatment which contains sand, gravel and brick chips. From the research it has been found that bacteria removal efficiency was 100% in developed filter unit. Other water quality parameters such as Color and TSS were removed approximately about 100% and 67% for sample 1 and for sample 2 it was found that 77% and 50%. In this study head loss of the developed filter is also determined with respect to depth of filter media. From this research it has been found that head loss of the filter increases with the increase of depth of filter media. At a sand depth of 12 cm head loss was estimated as 7.56 cm and at a depth of 20 cm head loss was estimated as 17.63 cm.

Keywords: Multigrade Filter, Surface water treatment, Head loss

1. INTRODUCTION

Water is the essence of life and access to safe drinking water is a fundamental human need and, therefore a basic human right essential to all. Supply of safe water of appropriate quality is important to the well-being of mankind and development of any country because it supports public health and, therefore, ensures economic growth. The provision of water, sanitation and good hygiene services is vital for the protection and development of human resources (Cocks, N 2009). The supply facilities of drinking water are not enough all over the country.In developing countries, it is often impossible to provide adequate water treatment due to the lack of up-to-date technology and sufficient financial support (Brikke & Bredero, 2003). Underground water flow through soil particles, it is more or less pure. Surface water is sometimes affects by different types of microorganism, which is harmful for the people. Contaminated drinking water is cause of major outbreaks of diarrheal diseases not only in developing but also in developed countries (Barker, J 1998). Approximately over one billion people world-wide lacks access to adequate amounts of safe water and rely on unsafe drinking water sources from lakes, rivers and open well. Nearly all of these people live in developing countries, especially in rapidly expanding urban fringes, poor rural areas, and indigenous communities (Galvis, G. 1999). Much of the global population now consumes untreated, non piped drinking water, usually consisting of small volumes <40 lpcd (liter per capita per day) collected and stored in the home by users. Typically, people collect water from any available source and store it in a vessel in the home for domestic and potable use, often without treatment and protection from further contamination. In many cases, such collected household water is heavily contaminated with faecal microbes and possess risks of exposure to water borne pathogens and thus to infectious diseases (Sobsey, 2003).The greatest risk associated with the ingestion of water is the microbial risk due to water contamination by human and/or animal feces. The effects of drinking contaminated water result in thousands of deaths every day, mostly in children under five years of age in developing countries (WHO, 2004a). Diseases caused by consumption of contaminated water, and poor hygiene practices are the leading causes of death among children world wide, after respiratory diseases (WHO, 2003).Thus lack of safe drinking water supply, basic sanitation and hygienic practices are associated with high morbidity and mortality from excreta related diseases. Because of the magnitude of the health problems associated with water of inadequate quality and quantity, substantial efforts have focused on how to evaluate and maximize the health benefits derived from improved water supplies. In many developing countries, the high incidence of water borne diseases and wide-spread use of untreated and often highly polluted water sources necessitate the accurate assessment of faecal contamination of water.

In pursuit of solution water purification is necessary. There are different types of filtration system. Such as Slow and Rapid sand filtration, direct filtration and Membrane filtration, Multigrade filtration etc . Slow sand filtration systems have become one of the most successful technologies for removing disease-causing organisms. The average removal effectiveness of *E.coli* (indicative pathogen of faecal coliforms) and Total coliform is 99% comprising with previews thesis result, where previews result shows the 100% removal of E.coli and Total coliform (Aminul, 2009).

This study aims at developing a Multigrade Filter (MGF) for surface water treatment in drinking purpose which contains sand, gravel and brick chips. The filtration performance was determined with respect to removal efficiencies of total coliform, faecal coliform, color, TSS, BOD_5 and estimation of filter head loss. The final objective was to find out the problems associated with developed filter and to propose for mitigation measures for improvement.

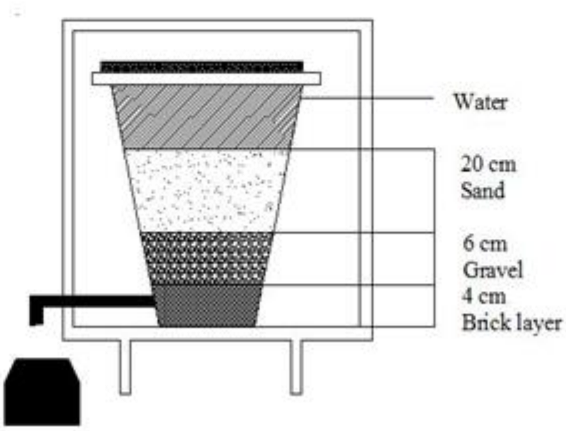
2. MATERIALS AND METHODS

Water samples were collected from two ponds (pond behind Rokeya hall and Khan jahan ali hall) of KUET campus. Raw water quality parameters such as TC, FC, color, TSS and BOD_5 were analysed at KUET environmental laboratory. Multigrade Filter unit was constructed in laboratory. On the developed filter locally available materials such as Coarse Sand, Brick Chips and Gravel were used. Detailed laboratory tests were done to determine the effectiveness of the treatment unit.The performances of the treatment unit were analysed with respect to the removal efficiency of color, TC, FC, BOD_5 and TSS. Head loss of the filter unit was also determined with respect to sand depth. Problems associated with developed filter unit were also identified. Head loss of developed filter unit was measured using the following equations: $H_L = 1.067 C_d v^2 D f / g d \psi e^4$

2.1 Development Of Multigrade Filter (MGF)

2.1.1 Design of MGF

For the removal of micro-organisms and other contaminants from surface water a MGF was developed under submerged condition using coarse sand, stone chips and brick chips. The developed MGF consists of a bucket (Figure 1 & 2). The layers in bucket are from the top 20 cm coarse sand,then 6 cm gravel and then 4 cm brick chips. The unit is down flow process as raw water passing through the sand. As the sand is always a submerged condition it creates a stable bio- flim slime layer of gelatinous coating formed by the micro-organisms on the sand bed.



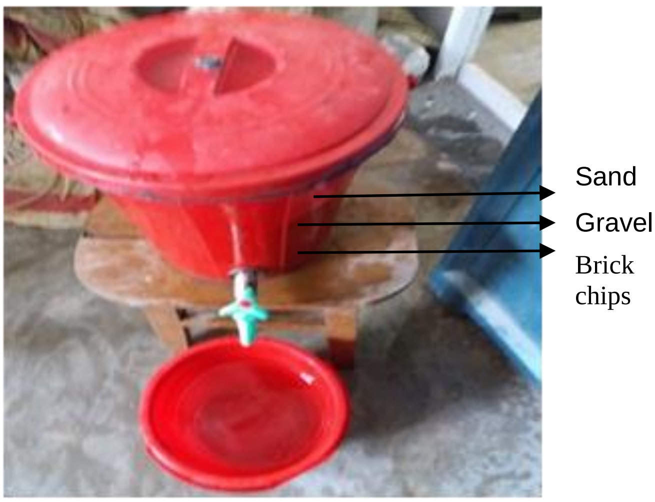


Figure 1: Line diagram of filter unit

Figure 2: Experimental setup of developed filter

2.1.2 Materials Used For MGF

Coarse Sand (CS)

CS is an inactive material used as coarse particulate filter. In the United States, sand is commonly divided into five sub-categories based on size: very fine sand (1⁄16 – 1⁄8 mm diameter), fine sand (1⁄8 mm – 1⁄4 mm), medium sand (1⁄4 mm – 1⁄2 mm), coarse sand (1⁄2 mm – 1 mm), and very coarse sand (1 mm – 2 mm).Locally available CS is collected.Then sieve analysis was done.Then they were thoroughly washed several times and then boiled for disinfection before use.

Gravel

Gravel are composed of sub-angular, hard durable, and dense grains of predominately siliceous material. Gravel are used as flow stabilizing media. Gravel were obtained from local manufacturers. Gravel were also sieved by ASTM standard sieve as BC. Gravel were throughly washed, bolied, clean dried, and screened to meet exacting specifications with strict adherence to quality control.

Brick Chips (BC)

BC are inactive material. BC are from local brick manufacturer which is the crushed aggregated form of brick. They were sieved through ASTM standard sieves. BC were washed several times and disinfected by boiling.

Figure 3: Sand

Figure 4: Gravel

Figure 5: Brick chips

Other materials Plastic bucket

Only food-grade high density polypropylene (HDPP) buckets are used Local plastic moulding industries. Buckets were retrofitted with top cover and outlets for flow controller taps.

Nylon net

Nylon is a generic designation for a family of synthetic polymers, more specifically aliphatic or semi-aromatic polyamides. These chains are naturally very resistant to wear and tear, temperature and chemicals. They can be melt-processed into fibers, films or shapes. Nylon decays very slowly and can take many years to biodegrade. It normally takes between 30 and 40 years to biodegrade. Nylon net is used for separating top layer of the course sand from corresponding 2nd layer.

Figure 6**:** Nylon net

Flow controllers (Tap)

Control flow to maintain optimum residence time. This is fixed in the factory. Moulded plastic or metal taps are avilable in local hardware stores.

2.1.3 Grain Size Analysis Of Sand, Gravel & Brick Chips

Effective size of sand, gravel and brick chips were estimated by sieve analysis. D_{10} of sand is 0.23 mm, $D_{60=}$ 0.87 mm and uniformity coefficient d_{60}/d_{10}=3.91. D_{10} of gravel is 9.9 mm D_{60}= 20.5 mm and uniformity coefficient D_{60}/D_{10} =2.07 .D_{10} of brick chips is 8.5 mm , D_{60}= 20 mm and uniformity coefficient D_{60}/D_{10} =2.35

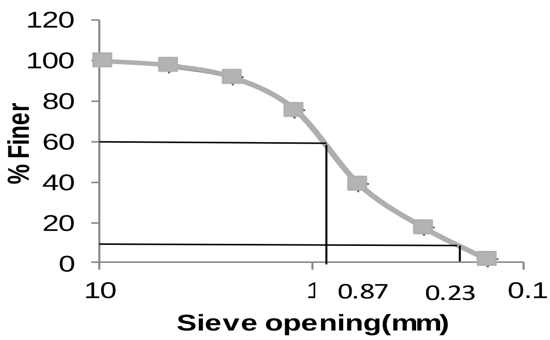


Figure 7: Gradation curve of sand

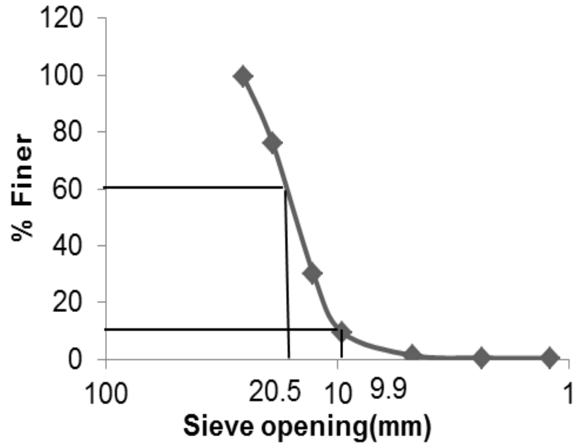


Figure 8: Gradion curve of gravel

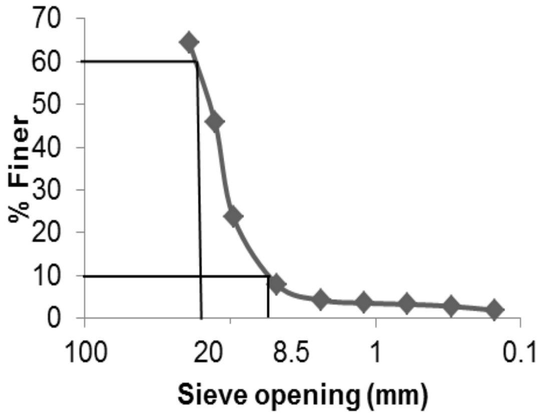


Figure 9: Gradation curve of brick chips

2.2 Filter Head Loss

Head loss rise (HLR) in a filter is a function of the amount of material (particles) accumulated in the interstices and pore space of the filter. The larger the quantity of particulates removed from the separation process, the higher the head loss rise (Kebreab, A. Ghebremichael, 2004).

The loss of pressure (head loss) through a clean stratified-sand filter with uniform porosity was described by Rose:

$H_L = 1.067 C_d v^2 D f / g d \psi e^4$……………. (1)

Where, H_L = head loss in bed of depth D with face velocity v.

e = bed porosity

d = characteristic diameter of bed particles

ψ = particle shape factor

C_d = Newton's drag coefficient = 24/R

D = bed depth

f = mass fraction of sand particles of diameter d

3. RESULTS AND DISCUSSION

Detailed laboratory test and analysis were carried out through developed filter unit to investigate the change in some drinking water quality parameters. The performances of the treatment unit were analysed with respect to the removal efficiency of color, TC, FC, BOD_5 and TSS.

Table 1: Results summary of raw and filter water

Water quality parameters	BD Standard (ECR'97)	Raw water		Filter water		%Removal	
		Sample1	Sample2	Sample1	Sample2	Sample1	Sample2
Total Coliform(N/ 100mL)	0	12	10	0	0	100	100
Faecal Coliform(N/ 100mL)	0	3	0	0	0	100	_
Color(Pt.Co unit)	15	25	17	0	4	100	77
Total Suspended Solid(mg/L)	10	30	40	10	20	67	50
BOD_5(mg/L)	0.2	3.47	1	0.35	1	90	0

3.1 Total Coliform & Faecal Coliform

Coliform bacteria are described and grouped, based on their common origin or characteristics, as either Total or Fecal Coliform. The Total group includes Fecal Coliform bacteria such as Escherichia coli (E .coli), as well as other types of Coliform bacteria that are naturally found in the soil. Figure 10 shows that total coliform in raw samples were found in 1 and 2 were 12 and 10 N/100mL, respectively which were totally removed from water after fitering through MGF. The results found after filtering satisfied the Bangladesh Standard. Figure 11 shows that in raw water samples 1 and 2 the concentration of feacal coliform were 3 and 0 N/100mL but after filtering feacal coliform was entirely removed

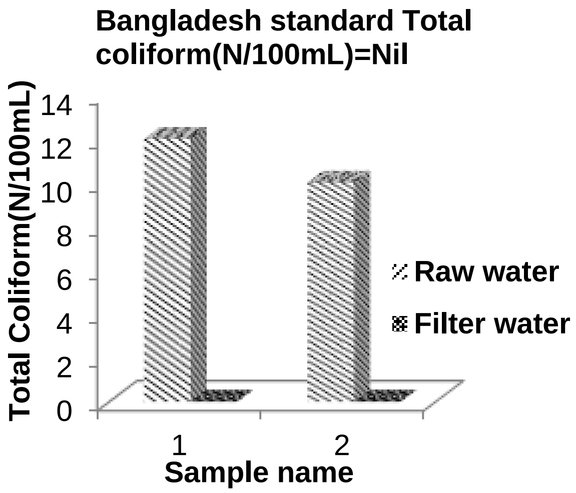


Figure 10: Variation of Total Coliform concentration in raw and treated water

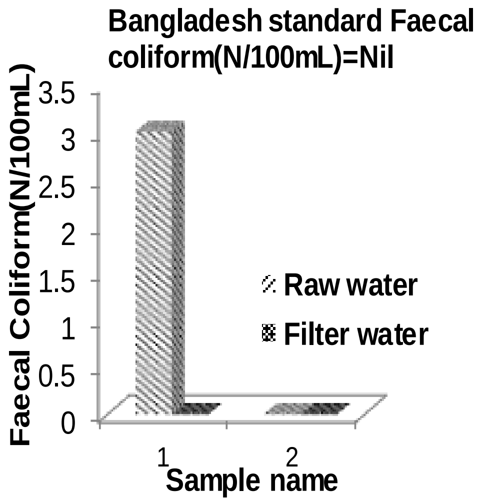


Figure 11: Variation of Faecal Coliform concentration in raw and treated water

3.2 Color

Colour is measured in platinum cobalt units and is an important physical parameter of water. Colour is due to the presence of organic matter; namely humic and fulvic acids as well as iron manganese or highly colored industrial waste (Ahmed & Rahman, 2000) .From figure 12 it is observed that after filtered color of collected sample reduced and below the Bangladesh Standard 15 Pt.Co unit. In raw samples 1 and 2 color were 25 and 17(Pt.Co), respectively and in the filtrated water it became 0 and 4(Pt.Co) respectively.

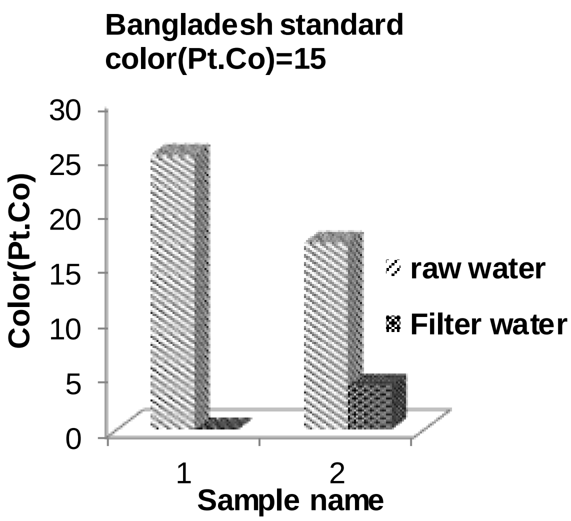


Figure 12: Variation of Color concentration in raw and treated water

3.3 BOD_5

Biochemical oxygen demand (BOD, also called biological oxygen demand) is the amount of dissolved oxygen needed (i.e. demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. From figure 13 it is observed that BOD_5 in raw water sample 1 and 2 were 3.47 and 1 mg/L, respectively and after filtering the concentration becomes 0.35 and 1 mg/L, respectively. In both cases the values exceeds Bangladesh standard limit.

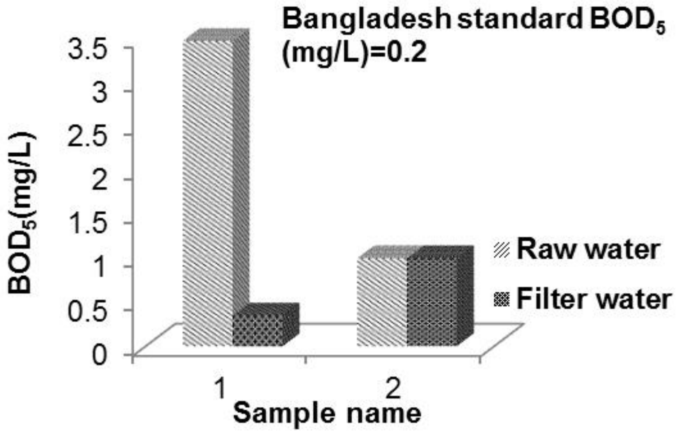


Figure 13: Variation of BOD_5 concentration in raw and treated water

3.4 Total Suspended Solid (TSS)

Total Suspended Solids (TSS) is the dry-weight of particles trapped by a filter. It is a water quality parameter used for example to assess the quality of wastewater after treatment in a wastewater treatment plant. From figure 14 it is observed that total suspended solid in raw water sample 1 and 2 were 30 and 40 mg/L, respectively and after filtering it decreases at a concentration of 10 and 20 mg/L, respectively.However in sample 2 TSS concentration decreases after filtering but it exceeds Bangladesh standard limit.

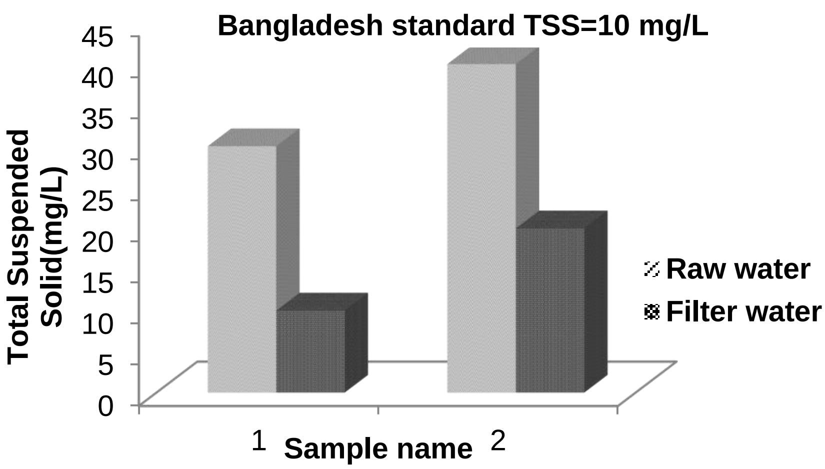


Figure 14: Variation of Total Suspended Solid concentration in raw and treated water

3.5 Estimation Of Filter Head Loss

Head loss rise (HLR) in a filter is a function of the amount of material (particles) accumulated in the interstices and pore space of the filter. The larger the quantity of particulates removed from the separation process, the higher the head loss rise. Head loss was determined with respect to sand depth using equation 1. At a sand depth of 12 cm,14cm, 16cm, 18 cm and 20 cm head loss were estimated as 7.56 cm, 8.27 cm, 10.16 cm, 14.24 cm and 17.63 cm, respectively. From figure 15 it is observed that head loss of developed filter increases with increase of sand depth.

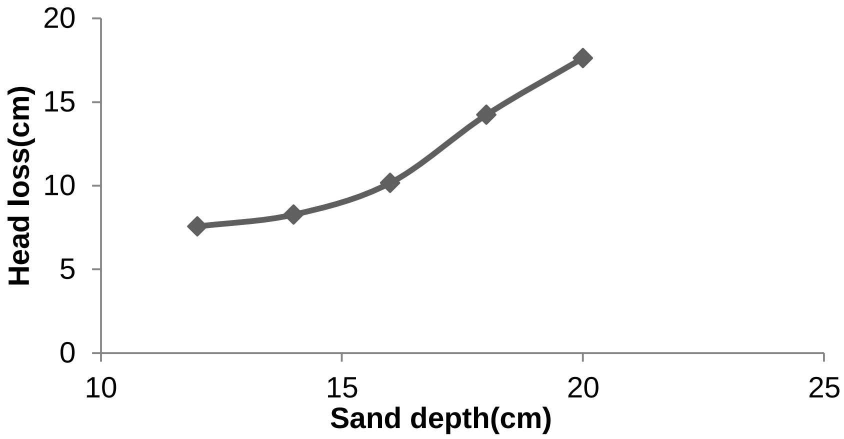


Figure 15: Variation of head loss with respect to sand depth

4. CONCLUSIONS

Color, total coliform, faecal coliform, TSS, BOD_5 concentration of raw water for sample 1 were found to be 25 Pt.Co, 12 N/100mL, 3 N/100 mL, 30 mg/L and 3.47 mg/L, respectively and for sample 2 these were found to be 17 Pt.Co, 10 N/100mL, 0 N/100mL, 40 mg/L and 1 mg/L, respectively. Multigrade Filter unit was constructed in laboratory. The filter unit consists of coarse sand, gravel and brick chips.Total coliform and Faecal coliform removal efficiency was 100% in developed filter unit. Other water quality parameters such as Color and TSS were removed approximately about 100% and 67% for sample 1 and for sample 2 it was found that 77% and 50%. At a sand depth of 12 cm,14cm, 16cm, 18 cm and 20 cm head loss were estimated as 7.56 cm, 8.27 cm, 10.16 cm, 14.24 cm and 17.63 cm, respectively. The main maintaining problem of this type of filter is, hence BOD_5 and TSS concentration reduced after filtering, but the values exceeds Bangladesh standard limit. Another problem is development of filter head loss for clogging of filter materials. For minimizing this problem, the layer of sand in bucket is kept within the lylon net. When the filter is clogged then one has to put the lylon net with Coarse Sand out and washed with water. By doing this simple tasks clogging can be reduced .

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ASSESSMENT OF ROOF TOP RAINWATER HARVESTING SYSTEM IN SALINE PRONE AREA; A CASE STUDY OF MUSLIMABAD HOUSING SOCIETY, CHITTAGONG

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ABSTRACT

The increasing safe water demand has triggered the initiatives to look for alternative sources of water supply. Among the various alternatives, rainwater harvesting or the collection of rainwater in a proper way can be a permanent solution to the problem of safe water crisis in different parts of Bangladesh. Although, Muslimabad area is within the city corporation area, but there is no pipe water supply so far, so groundwater is the only option for the dwellers. However, ground water condition in this area was not suitable to the dwellers due to not only high concentration of salinity but also arsenic contamination. People of this area have been using rainwater since last 20 years. In this study, the quality of ground water and the rainwater are assessed. The observation was made for a 12 months' time period. It was observed that apart from the acute salinity problem, ground water is also contaminated by Arsenic and it was also observed that rainwater can be used for both potable and daily other purposes. Finally, to assess the potentiality of rain water harvesting, an approximate cost-benefit analysis was carried out considering the total number of inhabitants living in Muslimabad Housing Society and prospective tank sizes and cost effectiveness were calculated.

Keywords: *Rainwater, Groundwater, Water Supply, Contamination, Salinity, Arsenic*

1. INTRODUCTION

The human civilization, entirely depend upon rivers, lakes and ground water to fulfil their water demands. Since 4500 B.C. rainwater harvesting (RWH) has been practicing in several parts of the world, and due to cost effectiveness and easy maintenance, this becomes the most common alternative water source in developing countries(Akter and Ahmed 2015). The rooftop RWH technology usually involves small-scale structures to collect runoff for either domestic usage or groundwater recharge. Roofs are the first candidates for RWH systems because their runoff is often regarded to be unpolluted or, at least, it presents relatively good quality standards compared to the rainwater from surface catchment areas(Göbel, Dierkes, and Coldewey 2007). Rooftop runoff quality is dependent on both the roof type and the environmental conditions (not only the local climate but also the atmosphere pollution) (farreny et al. 2011).

Bangladesh is a low-lying country with a total area of 147570 Sq. km's. It stretches latitudinally between 20°34' and 26°38' north and longitudinally between 88°01' and 92°41' east. It is mostly surrounded by Indian Territory except for a small strip in the southeast by Myanmar. Bay of Bengal lies on the south. Most of its area is relatively flat lying in the deltaic plain of the Ganges-Brahmaputra-Meghna river system. Chittagong is the second largest city and commercial capital of Bangladesh. This city is also witness major population growth over the last three decades, mainly due to migration from the villages and other part of the country. The population of the city was 0.5 million in 1971, which has grown to more than 3 million in 2017. The city area has also expanded considerably. The city area has also expanded. The total area of Chittagong and suburban areas (including proposed Hathazari and Sitakunda) is around 270 sq. km. Between 1974 (77 sq. km.) and 2017, the built-up area has increased by around 250%(James, Hu, and Kong 2001).

This growth presents tremendous challenge to the Chittagong Water Supply and Sewerage Authority (CWASA) in providing services to the city dwellers. Presently CWASA is supplying potable water in the city. There is no sewerage facility in the city. Due to limitation in resources, many development initiatives are being restricted. CWASA came into existence in November 1963, when the water demand of the city was nearly 30 MLD. After 40 years the demand has increased to about 536 MLD. Now the capacity of supply of CWASA is 323 MLD which is around 56% of demand (578 MLD)(James, Hu, and Kong 2001).

Muslimabad is small area located in Uttar Patenga 40no.word one of the coastal part of Chittagong, Bangladesh. The only source of water is ground water. But salinity and arsenic problems involve in ground water meanwhile there is no CWASA connection.

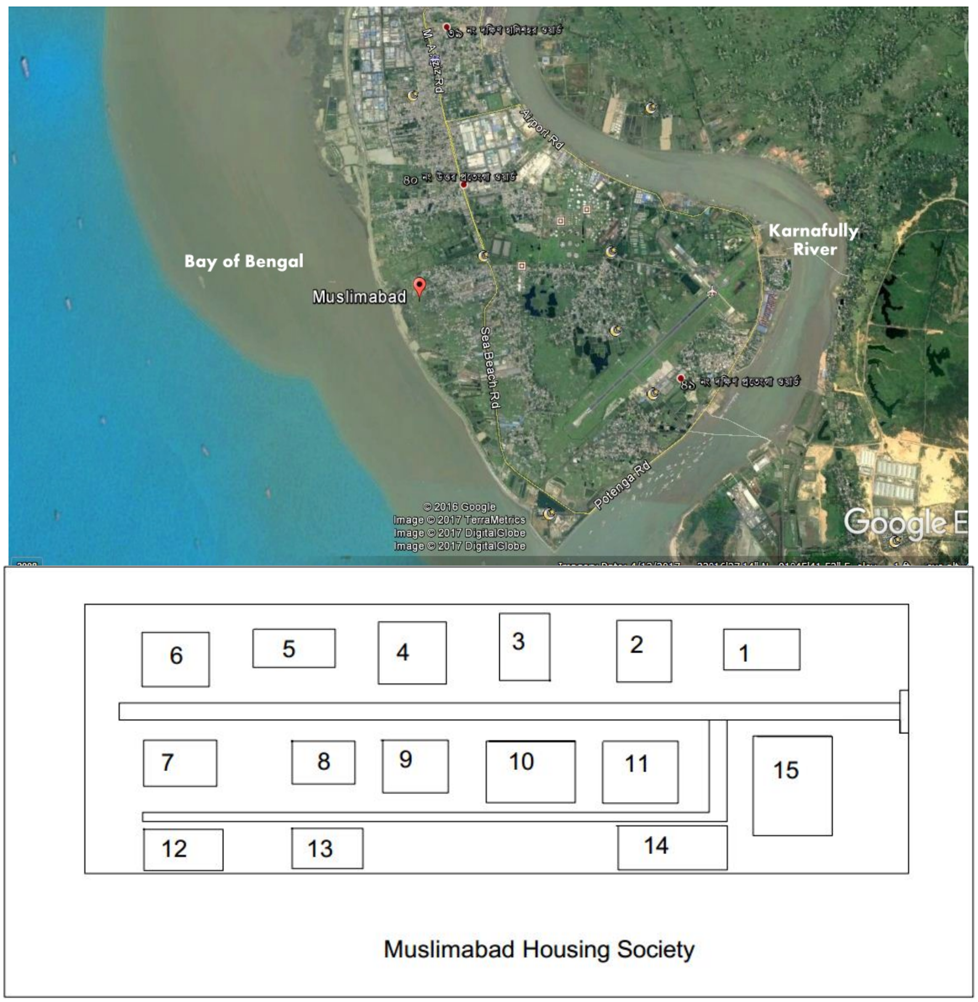

Figure 1: Study Area (Muslimabad)

To address this crisis of water sources, rainwater harvesting has been thought as one of the potential alternatives since Bangladesh has been blessed with huge amount of rainfall every year (Dakua et al. 2013). A significant portion of the demand during rainy season could be met from this rainwater which would also reduce the pressure from city water supply. But the main challenge identified to use rainwater is the storage system. Most of the people of

Muslimabad Housing Society are using Roof Top Harvested Rain Water only safe source of drinking water.

2. METHODOLOGY

The method of the experiment described step by step in a brief as follows:

Potentiality of RWH

Rainfall is an unpredictable variable to calculate the potential of rainwater harvesting of an area. In this study, average monthly rainfall of 30 years (1980-2010) from Bangladesh Meteorological Department (BMD) was used.

The rooftop of the buildings was considered as catchment. The rain that falls on this rooftop was considered for calculating the rainfall potential. Rain falling on ground was not considered as it often carries contamination. The capacity of underground storage tank was calculated during survey. The average rainfall was taken as monthly basis and monthly consumption of the buildings was compared to available monthly rainfall. The calculated probable supply of water from rainwater is based on the assumption that rainfall event will be evenly distributed throughout the month. But the analysis based on such assumption may not fully comply with actual scenario as the distribution of rainfall often varies and is not uniform.

Rainwater harvesting potential was measured by using the formula

Runoff (Potential for Harvesting) =A x R x C

Where,

A =Area in sq. m

R = Annual Rainfall in mm

C =Runoff Coefficient

For knowing the existing condition of Roof Top Rain Water Harvesting (RWH) System questionaries' was done.

Cost Effectiveness analysis was done using water demand and corresponding size of the storage tanks for different purposes such as drinking, cooking, dishwashing, bathing and cloth washing. The cost of different sizes of storage tanks was estimated.

Water Quality Analysis

Water samples were collected by random sampling method from all the building of Muslimabad Housing society. The water samples were collected in the month of April 2016 to April 2017 in every month. Sample water was collected in a 500milimeter plastic bottle and filled the total volume of the container and cap was locked sufficiently so that no air space can be remained inside to minimize the chemical changes. Proper labeling was made in each sample by mentioning the building number as per above mentioned figure.

3. RESULT ANALYSIS AND DISCUSSIONS

3.1 Survey Report of Existing RWH system:

A questionnaire survey was done to know the existing conditions. Out of fifteen building, in ten buildings RWH system is running. Due to severe scarcity of water and worse condition of ground water in 2002, one of the dwellers started to harvest rain water. At present, most of the families fulfilled there needs of water basically for drinking and cooking throughout the year by harvesting rain water. Due to the limitation of storage capacity, only the owners are fulfilling their demands except rentals.

Table 1: Existing and Proposed corresponding size of the storage tanks for different purposes cosidering present water demand

Building No.	Rooftop Area (m^2)	Existing tank size	No. of person used	Proposed tank size (ft)	No. of person used	Existence of RWH Water (months)	
						Existing	Proposed
1	200			8×7×5	8		12
2	130	8×5×4	6	11×8×6	15	12	12
3	100	6×5×4	8	11×8×5	13	12	12
4	210	10×6×4	8	13×11×6	25	8	12
5	100			10×7×6	12		12
6	260	8×5×4	10	15×12×6	30	6	12
7	250			7×6×5	6		12
8	130	6×5×4	6	14×10×5	20	8	12
9	130	8×5×4	8	15×12×6	30	6	12
10	220	8×5×4	8	15×13×7	40	6	12
11	220			18×14×7	50		12
12	160	8×5×4	5	15×12×7	30	8	12
13	100			10×7×5	10		12
14	120	7×5×4	8	14×10×5	20	6	12
15	200			15×13×8	45		12

3.2 Cost Effectiveness Analysis

Two types of cost effectiveness analysis were done for the experiment such as (i) for materials and costing of storage tank and also (ii) systems for existing and RCC storage tanks. These analyses can be shown in Table 2

Table 2: Cost Effectiveness Analysis for two systems

Rain Water Harvesting Technique	Existing Water and Sewerage Authority
Building No. 1 Cost: Total Construction Cost Tk. 45,000 (Concrete tank Size 8'x7'x5') Maintenance cost Tk. 500/year (including cleaning by chlorine and repairing if any leakage detected) Life time = 50 years Therefore total cost =(45000 + 500 x 49) = Tk. 69,500 Annual Cost = (69500/50) = Tk.1390 Cost/liter = (1390/23360) = Tk.0.06	Building No. 1 Cost: Connection cost = Tk.15,000/Connection for 3" diameter pipe Water use rate = Tk.0.15 to 0.25/liter Total cost = (0.20 x 23360 x 50) + 15000 =Tk. 248600 Annual Cost = (248600/50) = Tk.4972

3.3 Ground Water conditions

Arsenic: Arsenic is highly toxic in its inorganic form. Long-term exposure to arsenic from drinking-water and food can cause cancer and skin lesions. It has also been associated with developmental effects, cardiovascular disease, neurotoxicity and diabetes. After analyzing the entire ground water source in Muslimabad Housing Society, the maximum concentration of arsenic was found 100 µg/l in most of the wells. This is too much higher than both Bangladesh and WHO standards. Actually the highest capacity of the Arsenator which was used in this study to measure arsenic concentration is 100 µg/l. So the highest concentration may be higher than which was found. Figure 3 showing the variation of arsenic concentration in monsoon (May to October) and non-monsoon (November to April). In every cases the concentration is higher for non-monsoon period.

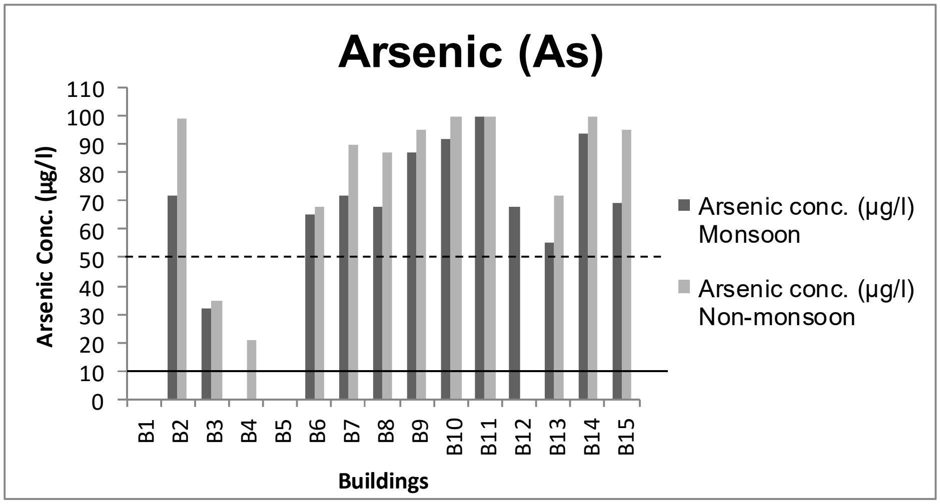

Figure 3: Variation of Arsenic concentration in ground water

Iron: The iron occurs naturally in the aquifer but levels in groundwater can be increased by dissolution of ferrous borehole and hand pump components. Iron-bearing groundwater is often noticeably orange in color, causing discoloration of laundry, and has an unpleasant taste, which is apparent in drinking and food preparation. The highest concentration of iron was found 2.4 mg/l. From figure 4 it is shown that for every source the concentration above the standard limit. The concentration is higher in non-monsoon period.

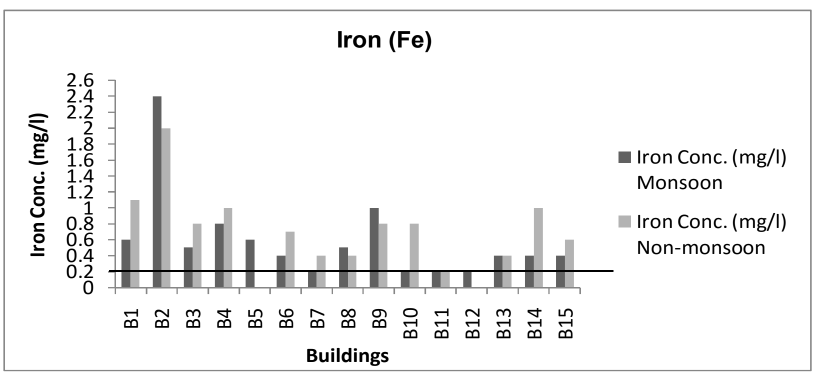

Figure 4: Variation of Iron concentration in ground water

Chloride: According to WHO standards the permissible limit of chloride concentration is 250 mg/l and Bangladesh standards around 600 mg/l. But the found average concentration of chloride in the site is 100 times higher than the standards. Figure 5 shows, the concentration dilute in the monsoon period.

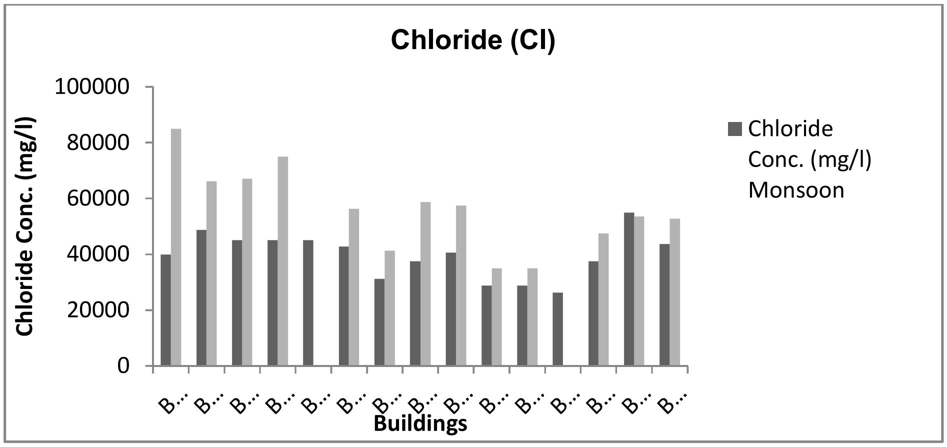

Figure 5: Variation of Chloride concentration in ground water

Electrical Conductivity: Conductivity is a measure of water's capability to pass electrical flow. This ability is directly related to the concentration of ions in the water. These conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides and carbonate compounds.

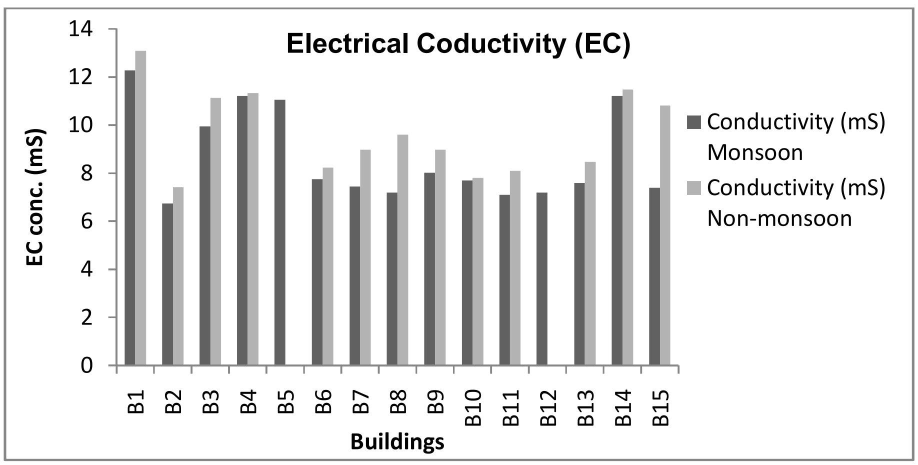

Figure 5: Variation of Electrical conductivity (EC) concentration in ground water

Total Dissolved Solids: The permissible value of TDS according to Bangladesh standards is 1000mg/l but the found concentration in almost every location 4-5 times higher than the standards. Figure 6 showing the variation of TDS in monsoon and non-monsoon period. Total dissolved solids comprise inorganic salts and small amounts of organic matter. There is no health effect data reported due to TDS in drinking water.

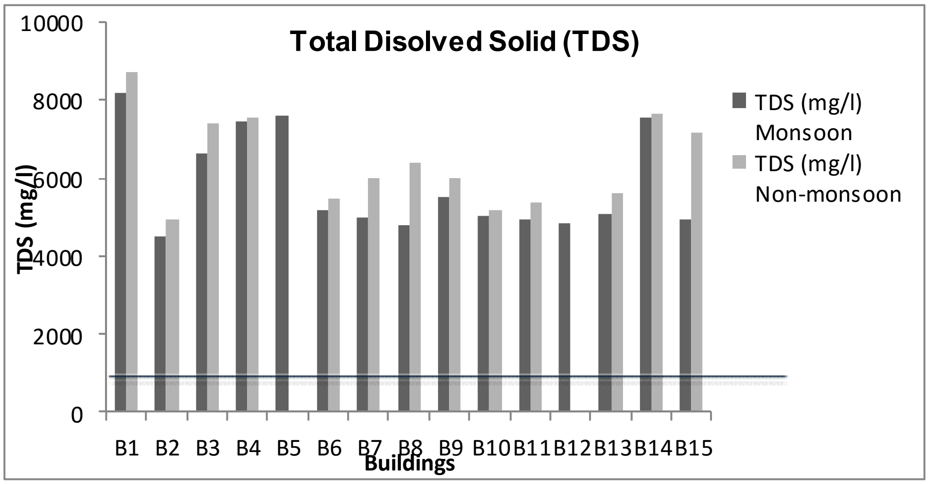

Figure 6: Variation of Electrical conductivity (EC) concentration in ground water

Alkalinity: Figure 07 depicted that within fifteen wells, the highest value of alkalinity was found 1500 mg/l during monsoon period. The average concentration of alkalinity both in monsoon period and non-monsoon period is higher than the Bangladesh drinking standard. Alkalinity of water measures capacity to neutralize acids. Most of the alkalinity in natural water causes by three major classes: bicarbonates, carbonates and hydroxides. High alkalinity in drinking water shows soda-like taste. It can dry out skin and sometimes cause scaling problems in water pipes (SDWF, 2015). The values found in this study were under the safe range which might not interfere in water treatment process.

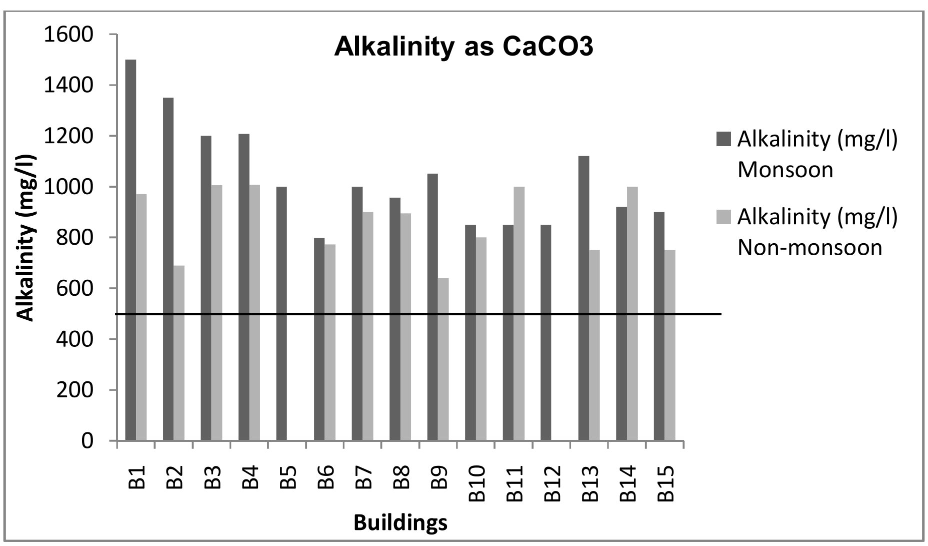

Figure 7: Variation of Alkalinity concentration in ground water

Turbidity: There is no stable value of turbidity found. The concentration fluctuates during monsoon and non-monsoon period.

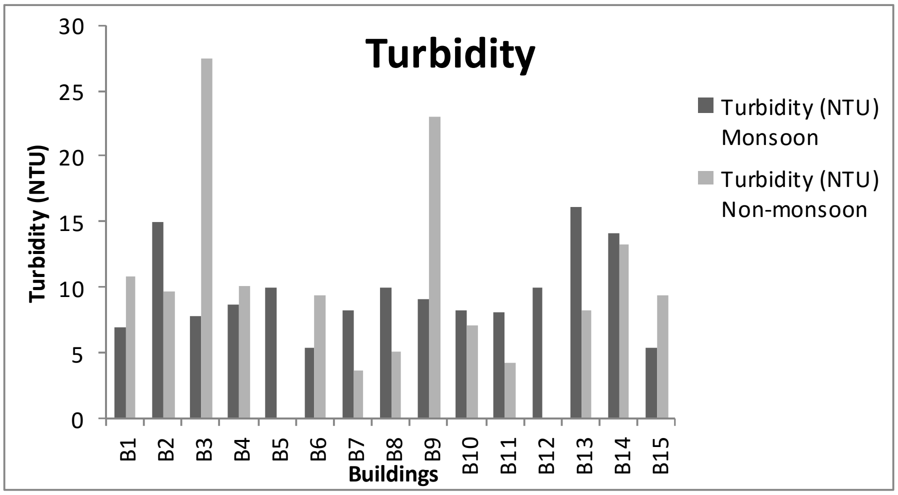

Figure 8: Variation of turbidity concentration in ground water

pH: Within fifteen wells, the highest value of pH was found 8.1 during n0-monsoon period. In biological treatment of water, pH is very important as the organisms involved in treatment processes operate within a certain pH range. Dissolution and mobility of metals in the natural water are also greatly influenced by pH.

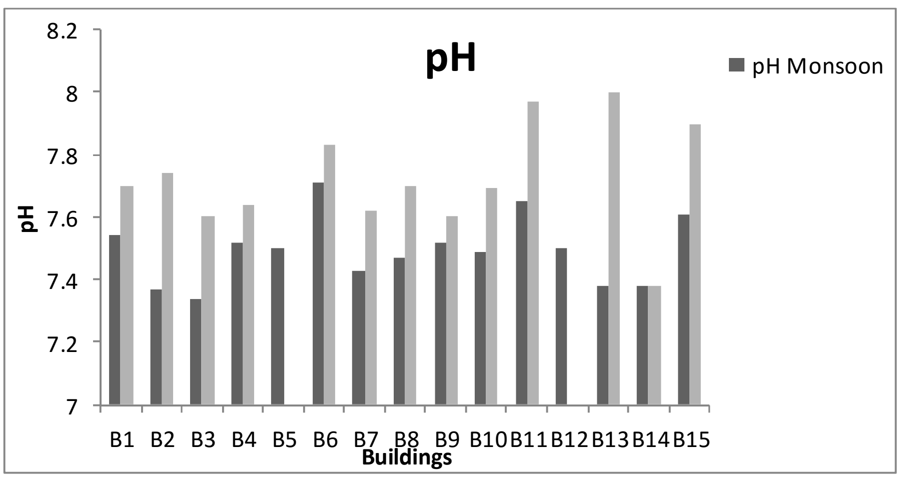

Figure 9: Variation of pH concentration in ground water

3.4 Rain Water conditions

From the table 3 it is clear except the chloride concentration in some dweller's stored rainwater, all the tested values were within the limit. Due to the more acceptable quality of rainwater the people of Muslimabad area contentedly using the Rooftop rainwater harvesting technology. Large storage tank is required for servising all the people of building and since initial cost is high the for the implementation of DRRH technology still not using throughout the community.

Table 3: rainwater quality of Muslimabad area

Building No./Parameter	Date	pH	Turbidity (NTU)	Conductivity (mS)	TDS (mg/l)	Alkalinity as CaCO3 (mg/l)	Chloride (mg/l)	TC and FC
B2	12/4/2017	7.8	2.03	0	0	60	825	Nil
B3	17/04/16	8.17	0.8	0.33	167	32	25	Nil
	19/05/16	7.67	0.76	0.23	147			Nil
	12/4/2017	7.9	1.94	0.88	587	59	925	Nil
B4	19/05/16	7.66	1.66	0.15	101			Nil
	12/4/2017	7.9	1.37	1.12	754	50	850	Nil
B6	26/04/16	8.8	1.16	0.541	361			Nil
B8	26/04/16	7.75	0.76	0.455	303			Nil
B9	4/10/2016	7.42		0.171	114	100	375	Nil
B10	19/05/16	7.75	0.79	0.12	78			Nil
	23/08/16	7.97	0.45	0.13	89	150	150	Nil
	4/10/2016	8.02		0.096	64	90	225	Nil
B12	26/04/16	8.54	0.69	0.224	149			Nil
B14	26/04/16	7.79	1.2	0.359	239			Nil

4. CONCLUSIONS

It was a big concern that only 2.5% of world's water is fresh and 30% of that freshwater is ground water. Though the scenario of world's water is crucial, we are the people of Bangladesh polluting water every day. From statistics the ground water table in Bangladesh is lowering every year due to unplanned over extraction.

Since Muslimabad is a saline prone area, not finding any other way they are using Harvested rainwater for their daily use without sanitary purpose. By analysing both ground water and rainwater it was found that with the other concerning parameters the concentration of Arsenic was high which is threatening. But the rainwater quality was found within the acceptable limit. Moreover, from our study we didn't find any TC and FC in stored rainwater.

Considering total household of every building, optimum storage tank size was estimated. From that estimation a cost effectiveness analysis was done between Rain Water Harvesting Technique and WASA price (though there is no WASA connection). From the analysis, though initial cost of RWH technology is higher, it is more cost effective.

Without water every development will be in a nutshell. Water resources are one of the most critical and a vulnerable component of the resources of a nation and availability of safe drinking water is an indicator of development. So, it is time to take proper step for sustainable technology of water like RWH technology.

Sample Calculation

Building No. 2 (2 story)

Table 4:

Months	Day	Avg. Rainfall (mm)	Demand (drinking, washing & cooking) @ 8 LPCD liters	Cumulative Demand (drinking, washing & cooking)	Demand Overall @80 LPCD	Cumulative Overall @80 LPCD	DRWH Volume (liters)	CUM DRWH (Liters)	R.O. Coefficient = 0.85				
									(8)-(4) liters	(9)-(5) liters	End of Month Storage needed@ 8 LPCD(litres)	DRWH Available for GW Recharge (litres)	% of Total Demand can met from DRWH
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Jun	30	533	1920	1920	19200	19200	81549	81549	79629	79629	0	81549	424.7344
Jul	31	598	1984	3904	19840	39040	91494	173043	89510	169139	0	91494	461.1593
Aug	31	519	1984	5888	19840	58880	79407	252450	77423	246562	0	79407	400.2369
Sep	30	321	1920	7808	19200	78080	49113	301563	47193	293755	7680	41433	255.7969
Oct	31	180	1984	9792	19840	97920	27540	329103	25556	319311	7680	27540	138.8105
Nov	30	55	1920	11712	19200	117120	8415	337518	6495	325806	7680	8415	43.82813
Dec	31	16	1984	13696	19840	136960	2448	339966	464	326270	5696	0	12.33871
Jan	31	6	1984	15680	19840	156800	918	340884	-1066	325204	3712	0	4.627016
Feb	28	28	1792	17472	17920	174720	4284	345168	2492	327696	1920	0	23.90625
Mar	31	63	1984	19456	19840	194560	9639	354807	7655	335351	0	0	48.58367
Apr	30	151	1920	21376	19200	213760	23103	377910	21183	356534	0	21183	120.3281
May	31	265	1984	23360	19840	233600	40545	418455	38561	395095	0	38561	204.3599

Table 5: Cost Effectiveness Analysis for two System

Building No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DRWH Annual Cost(Tk.)	1390	2190	1892	3254	1840	3962	1165	2740	3962	4878	6160	3962	1615	2740	5504
WASA Annual Cost(Tk.)	4972	9060	7892	14900	7308	17820	3804	11980	17820	23676	29500	17820	6140	11980	26580

ACKNOWLEDGEMENTS

The authors are thankfull to the laboratory technician of environmental lab and technitian of Center for Environmental Science and Engineering Research (CESER) for their efforts during the experiments. . It might have quite impossible to carry out of this work and final shape without their ardent cooperation.

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CHROMIUM REMOVAL FROM TANNERY WASTEWATER THROUGH ELECTROCOAGULATION

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ABSTRACT

The paper has focused on the chromium removal from tannery wastewater through electrocoagulation. The zinc (13.20 cm × 5.30 cm) and copper (13.20 cm × 5.30 cm) plates were used as electrodes for the electrocoagulation process. The effectiveness of the electrocoagulation for chromium removal efficiency was examined investigating various parameters: applied voltage, time, and current density. In thebatch experiment, 500 mL chromium-containing wastewater was used for electrocoagulation. Chromium content in the raw wastewater was 340.1 mg/L and after treatment at optimized conditions, chromium content was 6.9 mg/L. The chromium removal efficiency was obtained 98.0%. The reduction of biochemical oxygen demand(BOD) was 64.6%. Although total dissolved solids (TDS) was slightly increased. The increment of current density causes forming Zinc hydroxide causes damage to electrodes. The electrocoagulation is an effective technique to remove chromium from the wastewater especially tannery wastewater.

Keywords: *Tannery effluent, Chromium, Electrocoagulation, Electrodes, Current density.*

1. INTRODUCTION

Water pollution by heavy metals, especially chromium has sparked much concern to societies and regulatory authorities around the world. Due to wide usage of chromium by different industries such as metal plating, paints and pigments, leather tanning, textile dyeing, printing inks and wood preservation, huge amounts of wastewater containing chromium are discharged into the environment.

Tannery effluents are ranked as the highest pollutants among all industrial wastes. They are especially large contributors to chromium pollution(Belay, 2010).In tannery, basic chromium sulfate is used widely as tanning agent (Fahim, Barsoumb, Eid & Khalil, 2006).On average, 60-70% of total chromium salts react with the hide protein and the rest of 30-40% of the chromium remains in the solid and liquid phases(Ismailia, Mesdaghinia & Vazirinejad, 2005). Tannery wastewaterdecreases the quality of water bodies into which they are discharged. Disposition of tanning effluents e.g.,chromium into the environment creates inauspicious outcomes by modifying the normal physiochemical properties of soil and water (Sarker, Basak,& Islam,2013).Chromium contamination of soil, surface water, groundwater, and air under specific conditions is demonstrated e.g.,trivalent chromium is harmful to aquatic life and fish at excess level(>5.0 mg/L) (Overah, 2011). Chromium is not biodegradable that tends to accumulate in living organisms, causing serious diseases and disorders (Mohan, Kunwar, & Vinod, 2006).It has the toxic effecton humans at high doses. Trivalent chromium form is an essential trace element when present in micro level (Dahbi, Azzi, Saib, Guardia, Faure, &Durand, 2002). Chromium is discharged into the environment into two forms: trivalent and hexavalent. In contrast, the toxicity of tetravalent chromium is relatively low and in its trace amounts, it is not a problem for the environment (El-Taweel, Nassef, Elkheriany, & Sayed, 2015). On the other hand, hexavalent chromium form is 500 times more toxic than the trivalent chromium (Kowalski, 1994).

Various techniques have been employed for the treatment of heavy metals, including precipitation, adsorption, ion exchange and reverse osmosis. Among this precipitation is most commonly used in industries (Pachimatla, Pushkara, & Maheshwaria, 2014). To get more effective treatment electrocoagulation is considered to be used (Khalaf, Mubarak, & Nosier, 2016). In spite of having electrocoagulation not to be a new technology which had been known from 19th centuries, it hasn't been widely applied because of relatively large capital investment, expensive electricity requirement. However, electrochemical technologies have turned back since it is eco-friendly technology (Rajkumar &Palanivelu, 2004).

Electrocoagulation (EC) is one of the methods, which employs the direct current to remove pollutants (Akbal & Camcı, 2011).In recent decades, this method has been developed to be used for thetreatment of industrial wastewater comprising metals. In this method, an electric current passes through two electrode plates and induces metal oxidation in its cation. At the same time, water is reduced to hydrogen gas and hydroxide ion. In this way, EC process produces metal cation through theelectrochemical method and by using consumable anodes (Arroyo, Pérez-Herranz, Montanés, García-Antón, & Guinón, 2009).The Hydrolysis of cation within water forms a hydroxide with dominant species suited to pH solution. In General, mutual reactions between the species occur in a different manner within the solution and consequently lead to theremoval of the pollutants.

In this study, an investigation was made to remove chromium from the tannery wastewater through electrocoagulation. The performance of electrocoagulation process was determined to investigate different parameters: applied voltage, current, and time using zinc (Zn) and copper (Cu) electrodes.

2. MATERIALS ANDMETHODOLOGY

2.1 Sample Collection

Chrome tanning wastewater was collected from the tannery at Jessore, Bangladesh. The wastewater containing chromium sample was collected in a plastic container, pre-washed with diluted nitric acid, and immediately transported to the laboratory for experimentation.

2.2 Reagents

Reagents: nitric acid (Merck KGaA, Germany), sulphuric acid (Merck KGaA, Germany), perchloric acid (Merck, India), N-phenyl anthranilic acid (Merck, India), ferrous ammonium sulphate (Merck, India) and glass beads (Loba Chemie, India) were purchased from a local scientific store, Khulna, Bangladesh.

2.3 Characterization of chrome tanning wastewater

Physicochemical parameters of the untreated and treated spent chrome liquors: chromium content, total dissolved solids (TDS), total suspended solids (TSS), pH,electrical conductivity (EC), turbidity, biochemical oxygen demand (BOD) and chemical oxygen demand (COD)in the chrome tanning wastewater was measured. All measurement was maintained in triplicate.

2.3.1 Determination of Chromium

Chromium content in the untreated spent chrome liquor and after treatment in the filtrate was performed by the titrimetric method by following the official methods of analysis of Society of Leather Technologist and Chemists (SLTC, 1996) official method of analysis (SLC 208). A 50 mL ofsample was taken in 500 mL conical flask. Heating was started after mixing of 20 mL nitric acid and 20 mL of concentrated sulphuric acid & perchloric acid mixture. The funnel was placed in the mouth of the conical flask for refluxed and after complete digestion, with theacid mixture, the solution turned into red brick color. Extra 1 minute continued heating and quickly brought down from the heating and cooled in a water bath. 100 mL distilled water and few glass beads were mixed with the solutions and boiled 10 minutes for chlorine removal. 10 mL of 30% concentrated sulphuric acid was added after cooling and took for titration with ferrous ammonium sulfate. 5-6 drops of N-Phynylanthralinic acid used as anindicator and end point detected by green color.

2.3.2 Determination of pH

pH was measured by the digital pH meter (UPH-314, UNILAB, USA). Before measuring pH, the meter was calibrated in the two points with standard solutions of pH 4.01 and pH 7.00, respectively.

2.3.3 Determination of TSS, TDS, EC,and turbidity

TSS and TDS of the chromium-containingwastewater and treated liquor were determined following APHA-2540D method. A well-mixed sample was filtered through a weighed standard filter paper and the residue retained on the filter was dried to a constant weight at 103-105°C. The increase in weight of the filter represents the total suspended solids. To obtain an estimate of total suspended solids, the difference between total dissolved solids and total solids was calculated. Electrical conductivity (EC) was measured by using the conductivity meter (CT-676, BOECO, Germany) and the turbidity was measured with aportable turbidity meter (Hach 2100Q, 2100Q, Germany).

2.3.4 Determination of BOD

Biochemical oxygen demand (BOD) was measured by APHA standard method 5210B (APHA, 2012). Dilution water was prepared by placing thedesired volume of water in a bottle and phosphate buffer, magnesium sulfate, calcium chloride and ferric chloride solutions. pH was adjusted at 6.5 to 7.5 with sulphuric acid or sodium hydroxide solution. Sample volume 300 mL was filled in BOD bottle with enough dilution water thus insertion of stopper will remove air, leaving no bubbles. A blank sample (only diluted water) was also incubated as a rough check on thequality of diluted water and cleanliness of incubation bottle. Initial DO was measured with DO meter (DO-580, BOECO, Germany). BOD bottle was incubated at 20±1˚C for 5 days. After 5 day incubation, final DO was determined and calculated as BOD.

2.4 Batch-wise electrocoagulation test

The schematic diagram of the electrocoagulation process is shown in Fig. 1. A zinc plate (13.20 cm × 5.30 cm) and cupper plate (13.20 cm × 5.30 cm) were used as anode and cathode. In the batch experiment, 500 mL chromium-containing wastewater was used for electrocoagulation process where electrodes were immersedin the wastewater. Direct current (DC) was supplied and at different time interval 50 mL supernatant was taken for chromium measurement.

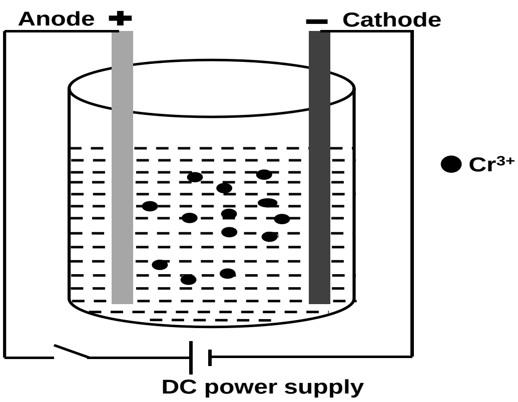

Figure 1: Schematic diagram for electrocoagulation process

Electrocoagulation process involves the generation of coagulants and form co-precipitation. Water is ionized byDC supply and produce hydroxyl radical andhydrogen gas. In the cell, the following reactions occur.

$$2H_2O + 2e^- \Leftrightarrow H_2 + 2OH^-$$

$$\text{Anode (oxidation)}: Zn \Leftrightarrow Zn^{2+} + 2e^-$$

$$Cr \Leftrightarrow Cr^{3+} + 3e^-$$

$$\text{Co-precipitation}: Cr^{3+} + 3OH^- \Leftrightarrow Cr(OH)_3$$

$$Zn^{2+} + 2OH^- \Leftrightarrow Zn(OH)_2 \text{ (at high current density)}$$

2.5 Process optimization

The electrocoagulation process was optimized to obtain maximum chromium removal efficiency. Tests were carried out to optimize the chromium removal parameters: applied voltage, time and the current density. The optimized conditions were established by investigating the chromium removal efficiency.

3. RESULTS AND DISCUSSION

3.1 Optimal Voltage

In the batchexperiment, chromium removal efficiency was observed at different voltages: 6V, 9V, 12V, 15V and 18V by electrocoagulation. It is clear from the Fig. 1 that with increasing the applied voltage chromium removal efficiency was increased. At applied voltage 6 V, 9 V, and 12 V chromium removal efficiency was 57.2%, 58.7%, and 64.8%, respectively. It seems that with increasing the applied voltage upto 12 V, chromium removal efficiency was increased very slightly. But, at applied voltage15 V, chromium removal efficiency was maximum (80.1%). Unfortunately, above applied voltage (>15 V), chromium removal efficiency was decreased (72.5%). Therefore, theapplied voltage was selected15V for chromium removal through electrocoagulation.

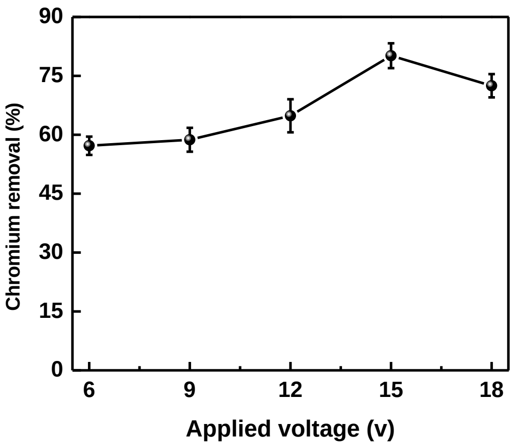

Figure 2: Effect of appliedvoltageon chromium removal efficiency

3.2 Optimal Current Density

In electrocoagulation, current density is one of the most important parameters. With applied several current density in the cell e. g.,0.07 mA/cm^2, 0.10 mA/cm^2, 0.17 mA/cm^2, 0.24 mA/cm^2, 0.36 mA/cm^2 and 0.46 mA/cm^2;chromium removal efficiency was found 51.1%, 60.3%, 71.4%, 92.4%, 95.4%, and 93.9%, respectively. It is obvious from Fig. 2that there was a good liner relationship between current density (0.07, 0.10, 0.17, 0.24 mA/cm^2;

correlation coefficient $R^2=0.983$) and chromium removal efficiency. The chromium removal efficiency for the current densities 0.24 mA/cm^2, 0.36 mA/cm^2 and 0.46 mA/cm^{2}was almost same (92.4%, 95.4%, and 93.9%).

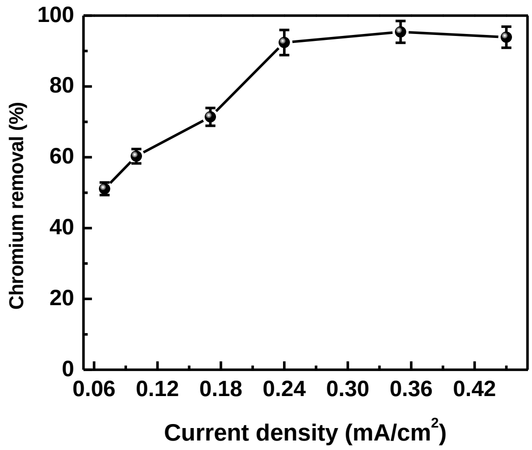

Figure 3: Effect of current density on chromium removal efficiency

At higher the current density e. g.,0.42 mA/cm^2 amount of co-precipitation forming of $Zn(OH)_2$ was so much**.** It is observed that with increasingthe current density, the turbidity of wastewater was also increased. Thus, 0.36 mA/cm^2 considered the favorable current density for electrocoagulation technique.

3.3 Optimal Time

Time is one of the essential parameters for the removal of chromium from the tannery wastewater. In Fig. 3represents the effect of time on chromium removal at different time interval as 6h, 12h, 18h, 24h, and 30h was observed at constant voltage and current density. Fig. 3 also indicates that chromium removal efficiency was gradually increased with increasing the process time. The removal efficiency for 6 h, 12 and 18 h was 27.77%, 63.37%,and 97.96%, respectively. After 18 h, chromium removal efficiency was decreased as the time was increased.

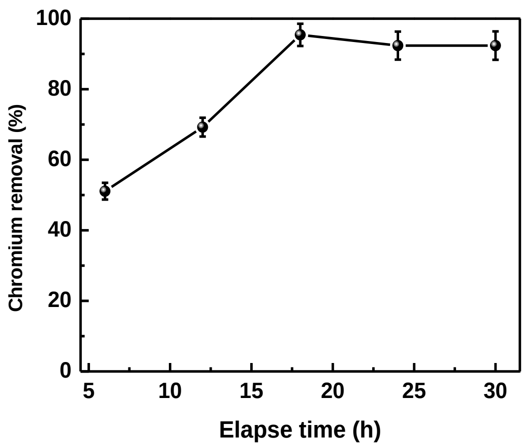

Figure 4: Effect of time on chromium removal efficiency

It may be the reason is that after 18 h, chromium removal efficiency was decreased because the coprecipitated $Cr(OH)_3$ dissolved and return to the aqueousphase. The chromiumremoval efficiency by this electrocoagulation was declined and simultaneouslythe

TDS was increased.Therefore, 18h was decided as theoptimum time for chromium removal inthis electrocoagulation process.

3.4 Removal Efficiency at Optimal Conditions

Considering all the parameters for electrocoagulation obtained data is presented in Table 1. The physicochemical parameters were obtained at optimized conditions: pH, TDS, BOD, chromium, turbidity,and EC were 7.0, 2756 g/L, 780 mg/L, 6.9 mg/L, 57 NTU and 8.7 mS, respectively.

Table 1: Data comparison between raw sample and treated sample

Parameters	Raw sample	Treated sample	ECR,1997
pH	4.8	7.0	6-9
TDS (g/L)	2248	2756	2100
BOD(mg/L)	2200	780	250
Cr (mg/L)	340.1	6.9	2.0
Turbidity (NTU)	233	57	-
Conductivity (mS)	7.5	8.7	-

The Table 1 shows that the TDS of the treated liquor was slightly increased and rest of the parameters were decreased as near to the discharged level. The reduction of BOD, chromium, and turbidity was 64.6%, 98.0%, and 75.5%, respectively.

4.CONCLUSION

In batch wise electrocoagulation process was effective to remove chromium from the tannery wastewater. Although total dissolved solids were slightly increased. The removal efficiency of chromium at optimized condition was 98.0%. The reduction of BODand turbidity was 64.5% and 75.5%.The investigation indicates that it was an effective technique to remove chromium from the tannery wastewater.

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Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), 9~11 February 2018, KUET, Khulna, Bangladesh (ISBN-978-984-34-3502-6)

BANANA RACHIS CHARCOAL TO REMOVE CHROMIUM FROM TANNERY WASTEWATER

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ABSTRACT

In this study, banana rachis waste, a carbonaceous material, was used to remove chromium from a real chrome tanning wastewater. The process was carried out using this banana rachis waste as an adsorbent. The waste solid banana rachis was cut, dried, and then burnt to produce charcoal. In the batch experiment, the ground charcoal was used for the treatment process: at optimized conditions, 3g charcoal was mixed with 75 mL chromium-containing wastewater, stirred for 15 min, settled, and then chromium content in the filtrate was measured by the titrimetric method. Chromium content in the raw wastewater and filtrate was been 3373.5 mg/L and 12.1 mg/L respectively. The chromium removal efficiency was 99.8% at pH 6.7. The reduction efficiencies for biological biochemical oxygen demand, chemical oxygen demand and chloride were 97%, 93%, and 60% respectively. The effectiveness of charcoal for the chromium removal efficiency was studied against different parameters, e.g., charcoal dose, contact time, and relative pH. This study revealed banana rachis waste as an efficient adsorbent for the remediation of chrome tanning wastewater.

Keywords: *Tannery wastewater, Chromium, Banana Rachis, Environment*

1. INTRODUCTION

Heavy metals contamination is now one of the most familiar and growing issues affecting biodiversity throughout the world (Khamis, Jumean & Abdo, 2009). Due to rapid industrialization, direct and indirect discharges of heavy metals to the environment through wastewater have tremendously been increased (Khamis, Jumean & Abdo, 2009). Among other heavy metals chromium, lead, arsenic, nickel, zinc are the most common and harmful heavy metals.

Tanning is the process of converting putrescible raw hide/skin into leather. During this process, the desired qualities are achieved by a series of chemical and mechanical operations. Currently more than 90% of the global leather production of 18 billion sq. ft ~~is~~ are tanned through chrome tanning process (Sundar, Rao & Muralidharan, 2002). Averagely, 60-70% of total chromium salts react with the hide protein and the rest of 30-40% of the chromium remains in the solid and liquid phases (especially as spent tanning liquor) (Ismailia, Mesdaghania & Vasirinejad, 2005). These remaining chromium pollutants, originating from the tannery wastewater possess a great hazard to human, animals, and plants through their incorporation in the food chain and the bioaccumulation effect (Khamis, Jumean & Abdo, 2009).

Chromium has several oxidation states among them trivalent and hexavalent chromium forms are common (Occupational Safety and Health Administration, 2003). High concentrations chromium is toxic, mutagenic, carcinogenic and teratogenic (Altaf, Masood & Malik, 2008). International Agency for Research on Cancer (IARC) has classified chromium (VI) in Group 1 (carcinogenic to humans) and metallic chromium and chromium (III) in Group 3 (not classifiable as to their carcinogenicity to humans (International Agency for Research on Cancer, 1994).

Concerns regarding the presence of chromium in the environment focus on the potential adverse health effects of Cr contaminated soils, groundwater, and surface water. According to Environmental Conservation Rules, 1997 the standard values of chromium (VI) discharge limit from industrial waste to inland surface water, public sewerage, irrigated land are 0.1, 1.0, 1.0 mg/L respectively (Environmental Conservation Rules, 1997).

Thus, chromium removal from the tannery wastewater is an important issue. Till today, numerous methods have been developed to remove chromium from the tannery wastewater. Chemical precipitation and electrochemical precipitation are widely used for the removal of heavy metals. But these techniques have a significant problem in terms of disposal of the precipitated wastes (Ozdemir, Karatas, Dursun, Argun & Dogan, 2005; Meunier, Drogui, Montane, Hausler, Mercier & Blais, 2006). The sedimentation (Song, Williams & Edyvean, 2000), electrochemical processes (Oda & Nakagawa, 2003), biological operations (Kapoora, Viraraghavana & Cullimoreb, 1999), cementation (Filibeli, Buyukkamaci & Senol, 2000), coagulation/flocculation (Song, Williams & Edyvean, 2004), filtration and membrane processes (Hafez, El-Manharawy & Khedr, 2002), chemical precipitation and solvent extraction (Macchi, Pagano, Pettine, Santrori & Tiravanti, 1991) are also used. Some of the low cost, non-conventional adsorbents include anaerobic sludge (Ulmanu, Marañón, Fernández, Castrillón, Anger & Dumitriu, 2003), apple residue (Lee, Jung, Chung, Lee & Yang, 1998), sawdust (Shukla, 2005), rice Polish (Singh, Rastogi & Hasan, 2005), clay (Farrah, & Pickering, 1977), zeolite (El-Kamash, Zaki & El Geleel, 2005), fly ash (Al-Qodah, 2006), chitosan (Jha, Iyengar & Rao, 1988), waste tea (Orhan & Büyükgüngör, 1993; Ahluwalia & Goyal, 2005), seaweeds (Da Costa & De França, 1996), polyaniline coated on sawdust (Mansour, Ossman & Farag, 2011), and *Carica papaya* plant (Sheikh, Apon & Hashem, 2017) which have been used for the purpose, but all these attempts have become inefficient because of the less available nature of adsorbent.

In this study, adsorbents prepared from waste banana rachis were used to remove chromium content from tannery wastewater. The estimated amount of banana rachis waste in Costa Rica (one of the biggest banana producers in the world) is 797,000 metric ton per year (Sibaja, Alvarado, Pereira & Moya, 1997). The banana rachis is usually unutilized and when disposed to water, it biologically degrades raising the oxygen demand of water body.

The main advantage of adsorption is that it gives the significant amount of energy saving from a more efficient wastewater treatment system operating for fewer hours; it is economically attractive because waste biomass is inexpensive and widely available.

In the present study, an attempt was made to remove chromium from tannery wastewater using low-cost charcoal prepared from banana rachis. The aims of the study are: **i**) remediation of chromium contaminated tannery effluent, **ii**) solid waste management of the unutilized banana rachis and **iii**) introduction of a convenient method to achieve a greater chrome removal efficiency than the previous studies using handy raw materials. The effectiveness of chromium removal was determined to investigate different parameters e.g. charcoal dose, contact time, and pH effect.

2. MATERIALS AND METHODS

2.1 Collection of Banana Rachis

Banana rachis waste was collected from a nearby banana market at Khulna, Bangladesh and was burnt to prepare charcoal for wastewater treatment.

2.2 Charcoal Preparation

After collection of banana rachis waste, it was washed and then cut into small pieces and was sun-dried. Then the dried pieces of banana rachis were burnt in aerobic condition, cooled and ground to make a powder using a mortar. The ground charcoal was sieved and preserved for the experiment.

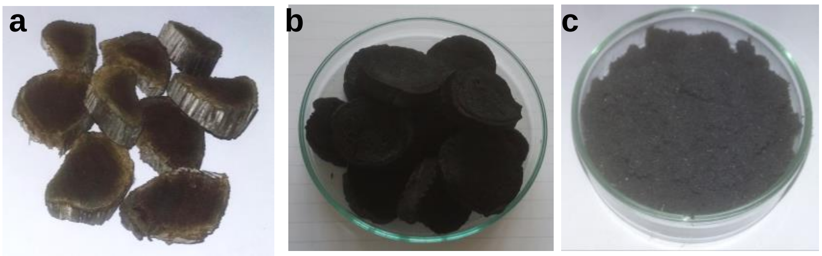

Figure 1: Dried waste banana rachis a) Burnt waste banana rachis and c) ground banana rachis charcoal

2.3 Wastewater Collection

Chromium-containing wastewater was collected from a local tannery at Khulna, Bangladesh. The wastewater containing chromium was collected in a plastic container pre-washed with diluted nitric acid and rinsed with distilled water. It was immediately transported to the laboratory for experiments.

2.4 Reagents

Nitric acid (Merck KGaA, Germany), sulphuric acid (Merck KGaA, Germany), perchloric acid (Merck, India), N-phenyl anthranilic acid (Merck, India), ferrous ammonium sulphate (Merck, India) and glass beads (Loba Chemie, India) were purchased from a local scientific store, Khulna, Bangladesh.

2.5 Characterization of Tanning Wastewater

Physicochemical properties of wastewater were measured in terms of chromium, pH, total dissolved solids (TDS), electrical conductivity (EC), salinity, dissolved oxygen (DO), biochemical oxygen demand for 5 days (BOD_5), and chemical oxygen demand (COD).

2.5.1 Determination of pH

The pH of the spent chrome liquor was measured by using the pH (UPH-314, UNILAB, USA) meter. Before measuring the pH meter was calibrated with the standard buffer solution.

2.5.2 Determination of TS, TSS, TDS, and EC

TS, TSS, and TDS of the spent chrome liquor and treated liquor were determined by APHA-2540 D method. A well-mixed sample was filtered through a weighed standard filter paper and the residue retained on the filter was dried to a constant weight at 103-105°C. The increase in weight of the filter represents the total suspended solids. To obtain an estimate of total suspended solids, the difference between total dissolved solids and total solids was calculated. Electrical conductivity (EC) was measured by using the conductivity meter (CT-676, BOECO, Germany).

2.5.3 Biochemical Oxygen Demand

Biochemical oxygen demand of the spent chrome liquor and treated liquor were determined by APHA-5210 B method. The sample was filled in an airtight bottle and was incubated at a specific temperature for 5 days. The dissolved oxygen (DO) content was determined before and after five days of incubation at 20°C and the BOD were calculated from the difference between initial and final DO.

2.5.4 Chemical Oxygen Demand

Chemical oxygen demand of the spent chrome liquor and the treated liquor were determined by APHA-5220 C method. The organic matter present in sample gets oxidized completely by potassium dichromate ($K_2Cr_2O_7$) in the presence of sulphuric acid (H_2SO_4), silver sulfate (Ag_2SO_4) and mercury sulfate ($HgSO_4$) to produce CO_2 and H_2O. The sample was refluxed with a known amount of potassium dichromate ($K_2Cr_2O_7$) in the sulfuric acid medium and the excess potassium dichromate ($K_2Cr_2O_7$) was determined by titration against ferrous ammonium sulfate, using ferroin as an indicator. The dichromate consumed by the sample is equivalent to the amount of O_2 required to oxidize the organic matter.

2.5.5 Chloride Content

50 mL of the sample in a beaker with 5 drops (about 1mL) of potassium chromate indicator was titrated by standard (0.0141 N) silver nitrate solution from a burette, with constant stirring until the first permanent reddish color appeared. Chloride content was determined from the required amount of silver nitrate comparing with distilled water for blank following APHA-4500B method. If more than 7-8 mL of silver nitrate solution is required, the entire procedure should be repeated using a smaller sample diluted to 50 mL of distilled water.

2.5.6 Determination of Chromium

Chromium content in the untreated spent liquor and after treatment in the filtrate was measured by the titrimetric method by following the official methods of analysis of Society of Leather Technologist and Chemists (1996) official method of analysis SLC 208 (SLT6/4). A 50 mL sample was taken in 500 mL conical flask. 20 mL concentrated nitric acid was added followed by 20 mL perchloric acid/sulphuric acid mixture; the flask was gently heated and boiled until the mixture had become a pure orange-red color and continue boiling for one minute. The flask was removed from the heating source and as soon as ebullition has ceased; rapidly the flask was cooled by swirling in cold water bath. Carefully, 100 mL distilled water was added with a few glass beads and boiled for 10 minutes to remove free chlorine. Then, 10 mL 30% (v/v) sulphuric acid was added and cooled to room temperature. The mixture was titrated with freshly prepared 0.1N ferrous ammonium sulfate solution with six drops of N-phenyl anthranilic acid as an indicator. The end color was indicated by a color change from the violet to green.

2.6 Treatment of Chromium Containing Wastewater

Batch-wise chromium removal examination was performed with the prepared charcoal. Firstly, physicochemical parameters of the untreated chromium-containing wastewater were analyzed and filtered through 0.45 µm pore size filter. Secondly, 75 mL filtrate wastewater was mixed the prepared charcoal. The charcoal mixed wastewater was stirred over a fixed period of time and the mixture was then allowed for settling for a fixed time. After settling, the mixture was filtered through 0.45 µm pore size filter again chromium content measurement was performed the same procedure as described in section 2.5.6.

3. RESULT AND DISCUSSION

3.1 Process Optimization

The removal efficiency of the experiment was optimized by carrying out different chromium removal parameters: charcoal dose, contact time, stirring time. The optimized conditions were established by investigating the removal efficiency of chromium of the wastewater based on the above parameters.

3.2 Effect of Adsorbent Dosage

The charcoal dose is the most important parameters that have a significant effect on the chromium removal. Chromium removal efficiency on charcoal dose and relative pH changes are shown in Fig. 2. The initial concentration of chromium (3373.5 mg/L) in the real chrome tanning wastewater, the number of adsorbent doses (1 g to 5 g for every 75 mL wastewater) and contact time (10 min) were kept constant.

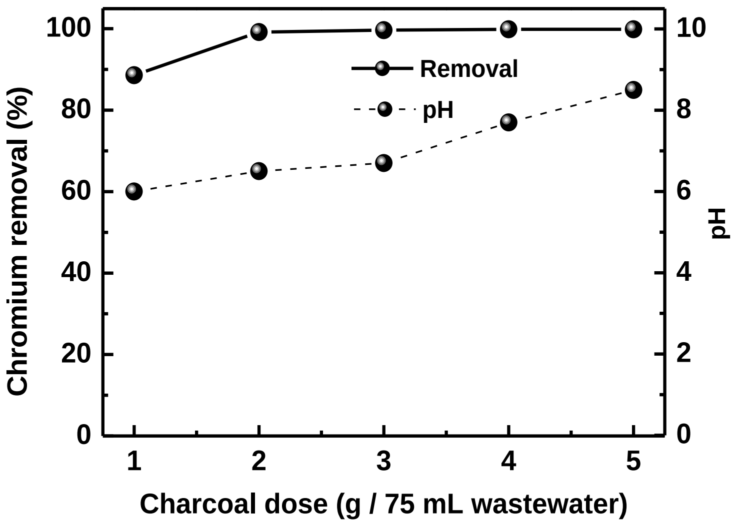

Figure 2: Batch wise chromium removal efficiency on different charcoal doses: 1 g, 2 g, 3 g, 4 g, and 5 g. In each batch 75 mL wastewater with fixed 10 min contact time was used.

It is clear from the Fig. 2 that the increase of charcoal dose results in the increase of pH. pH is an important parameter in adsorption because it is responsible for the protonation of metal (chromium) binding site. At lower pH (2 and 3), the low chromium removal may be attributed to: (i) the elevated concentration of protons that will compete with chromium cations on the surface sorbent active sites and hence reduce their adsorption; (ii) the dissolution of CaCO3, the principal constituent of the two adsorbents which lowers the adsorption. At higher pH (4 and 5), the important removal of chromium in the range can be attributed to: (i) the competitive effect (H^+ vs. Cr^{3+}) which becomes weaker, increasing the adsorption of Cr(III) (Chojnacka, 2005); (ii) the adsorption of hydrolysis products and precipitation of the metal as colloidal insoluble hydroxides, $Cr(OH)_3$.

Thus chromium removal efficiency was increased with the increase of adsorbent dose. At adsorbent dose, 3 g per 75 mL wastewater, chromium removal efficiency was 99.6%. After that, there were no significant changes in chromium removal. Therefore, it was projected that the maximum chromium removal occurred with 3 g adsorbent dose for every 75 mL wastewater at pH 6.7.

3.3 Effect of Contact Time

Fig. 3 shows that chromium removal efficiency was increased with the increase of contact time. When the contact time of the chromium ions and binding sites was extended, the adsorption became more effective. The optimized removal efficiency was 99.8% at 15 min. For the first two batches, the adsorption rate increases more rapidly. After that, the reaction becomes lower when the remaining active sites are less available and the equilibrium phase was reached.

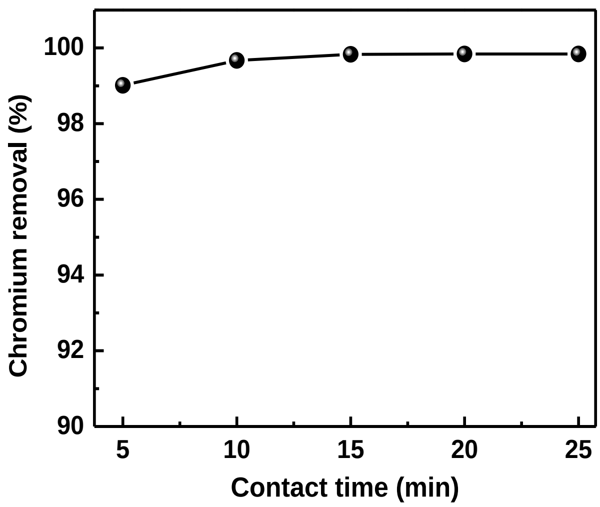

Figure 3: Batch wise chromium removal efficiency on different contact time: 1, 5, 10, 15, 20, and 25 min, each batch 75 mL wastewater with fixed 3 g charcoal was used.

Figure 3 shows that chromium removal percentage was increased with the increase of contact time. When the contact time of the chromium ions and binding sites was extended, the adsorption becomes more effective. So the removal efficiency increases with the increase of time. The optimized removal efficiency was 99.8% at 15 min. For the first two batches, the adsorption rate increases more rapidly. After that, the reaction becomes lower when the remaining active sites are less available and the equilibrium phase was reached.

3.4 Treatment Process Efficiency

Characteristics of wastewater are shown in Table 1. It seems that wastewater had heavy pollution loads because it contained higher quantities of pollutants e. g., high chromium content, total dissolved solids (TDS), high acidity (pH 3.9). Wastewater containing chromium is a threat to the environment, so it is very important to treat the chromium-containing wastewater before discharging it to the environment.

Table 1: Data comparison with Bangladesh standard (ECR 1997)

Parameters	Raw sample	Treated sample	(ECR 1997)
Cr (mg/L)	3373.5	12.1	2.0
pH	4.5	6.7	6–9
BOD (mg/L)	3197	107	250
COD (mg/L)	4297	293	400
TDS (g/L)	29.83	36.3	2.1
EC (mS)	66.9	81.2	1.20
Chloride (mg/L)	17021	6872	600

The results of the treatment process with optimum conditions are represented in Table 1. It shows that after treatment pH, BOD, COD was within the discharged level although other parameters e.g., TDS, EC, chloride (Cl^-) were high from the discharge limit; but after treatment, they were reduced a noticeable level. During treatment banana rachis charcoal acts as adsorbent and the inorganic and organic pollutants are adsorbed on the charcoal surface. Thus, after filtration, the pollutants are removed with the adsorbent from the wastewater and reduce Cr, BOD, and COD.

Table 2: Data comparison with the previous works

Adsorbent	Chrome removal efficiency (%)	
	Previous studies	This study
Almond Shell (Pehlivan & Altun, 2008)	55.00	99.8
Waste newspaper (Dehghani, Sanaei, Ali & Bhatnagar, 2016)	64.00	
Walnut Shell (Pehlivan & Altun, 2008)	85.32	
Hazelnut Shell (Pehlivan & Altun, 2008)	88.46	

In Table 2 shows that chromium removal efficiency of this study was compared with the previous works. In this present study, the percentage of chromium removal efficiency was 99.8% whereas in the previous work chromium removal efficiency was maximum 88.46%. This study shows a noticeable increment of chromium removal efficiency.

4. CONCLUSIONS

In the batch-wise technique, chromium-containing wastewater was treated to remove chromium using banana rachis charcoal. The removal efficiency of chromium at optimized condition was 99.8%. The reduction of BOD, COD, and chloride were 97%, 93%, and 60%, respectively. The investigation indicates that it was an effective technique to reduce toxic substances, which will minimize pollution load from the spent chrome liquor as well as an efficient approach towards solid waste management. The study could be helpful to design the treatment of spent chrome liquor in the reservoir prior to discharge.

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CHEMICAL FERTILIZERS EFFECT ON ARSENIC LEACHING FROM THE CONTAMINATED SEDIMENT UNDER AEROBIC CONDITIONS

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ABSTRACT

In this work, batch-wise leaching behavior of arsenic from the contaminated sediment by the effect chemical fertilizers especially triple super phosphate (TSP) and diammonium phosphate (DAP) is stated. The split barrel sampler equipment was used to collect sediments from three depth relatively undisturbed sediments. Arsenic content in the designated sediments was 3.63 mg/kg, 8.96 mg/kg, 0.71 mg/kg, respectively. In batch leaching experiment, 2 g sediment sample was added into a reactor containing 25 mL distilled water with different doses of chemical fertilizers: 0.0 (without fertilizers), 0.2, 0.4, 0.6, 0.8 and 1.0 g. Leachates were analyzed by the atomic absorption spectroscopy. Results indicate that arsenic concentration in the leachates was gradually increased with increasing the TSP and DAP doses in the suspension. TSP was extracted more arsenic than DAP from the sediment adsorption sites. It could be said that phosphate fertilizers enhance leach arsenic from the contaminated sediments.

Keywords: *Arsenic, Contamination, Leaching, Sediment, Fertilizers*

1. INTRODUCTION

Arsenic is distributed throughout the rocks, soil, and natural water. Elevated levels of arsenic occur in the environment from the various manmade activities and natural geochemical processes (Kinniburgh & Kosmus 2002; Roussel, Neel, & Bril, 2000). Arsenic occurrence, toxicity, and mobility in groundwater have gained significantly increasing attention (Anawar, Akai, Komaki, Terao, Yoshioka, Ishizuka, Safiullah, & Kato, 2003). Industrialization increases the disposing of mine tailings and metallurgical slags (Jacob & Otte, 2004; Stoltz & Greger, 2006; Ettler, Komarkova, Jehlicka, Coufal, Hradil, Machovic, & Delorme, 2004). Hereafter, the soil is contaminated with toxic heavy metals from where possible mobilization/leaching of metals into groundwater or enter the human food chain. Arsenic is one of the major environmental concerns and excessive exposure to arsenic causes carcinogenic effects in mankind (Baig, Sheng, Hu, Xu, & Xu, 2015).

The toxicity of arsenic is well known (Choong, Chuah, Robiah, Koay, & Azni, 2007). Due to its toxicity, the World Health Organization has categorized arsenic as group 1 carcinogenic element (NRC, 1999). Of course, the toxicity of arsenic depends on its oxidation state, arsenite is more toxic than arsenate (Fazal, Kawachi, & Ichion, 2001). Long-term exposure to arsenic causes arsenicosis, keratosis and cancers of the skin, kidney, and lungs (Tabelin, Igarashi, & Takahashi, 2012). Worldwide in 20 countries groundwater is contaminated with arsenic; the most severely affected countries are Bangladesh, West Bengal (India), Taiwan, Vietnam, Cambodia, Argentina (Naidu, Smith, Owens, Bhattacharya, & Nadebaum, 2006).
The mobility of arsenic from the sediment or soil into groundwater is a great concern. Over-exploitation of groundwater for irrigation, atmospheric oxygen enters into the aquifer where it reacts with the arsenopyrite (Eq. 1), which influences the release of arsenic into the groundwater (Neil, Yang, & Jun, 2012). Application of phosphate fertilizer causes to mobilize

arsenic due to anion exchange onto the reactive mineral surfaces (Acharyya, Lahiri, Raymahashay, & Bhowmik, 2000). Phosphate having the smaller in size, higher charge density, therefore, increasing phosphate concentration in the suspension the leached amount of arsenic also increased (Zhang & Magdi, 2008).

$$4FeAsS + 6H_2O + 11O_2 \leftrightarrow 4Fe^{2+} + 4H_3AsO_3 + 4SO_4{}^{2-} \quad \text{...} (i)$$

Many types of research have investigated the mechanism of geochemical occurrence of arsenic into groundwater but still, the mechanism of arsenic leaching is not clear (Anawar, Akai, Komaki, Terao, Yoshioka, Ishizuka, Safiullah, & Kato, 2003). In the last decades, many researchers have investigated the potential leaching of arsenic from the contaminated sediment/solid with various leaching agents e.g., bicarbonate ion (Anawar, Akai, & Sakugawa, 2004), phosphate ion (Hashem, Toda, & Ohira, 2015), citric solution (Ettler, Komarkova, Jehlicka, Coufal, Hradil, Machovic, & Delorme, 2004), chelating agent (Garrabrants & Kosson, 2000), etc. Miro, Hansen, Chomchoei, & Frenzel (2005) have proposed the protocol of leaching traces metals from the environmental samples. Of course, their attempts were good but unfortunately, most of them used the chemical for leaching tests as analytical grade reagents. It is necessary to examine how arsenic is behaved by the effect of chemical fertilizers. Because it is claimed that application of triple super phosphate (TSP) accelerates to leach arsenic from the sediment/soil to the groundwater.

Here an investigation was done the leaching behavior of arsenic from the contaminated sediment at different depth by the effect of chemical fertilizers especially triple super phosphate (TSP) and diammonium phosphate (DAP) under aerobic conditions. The leachates were analyzed for arsenic by the atomic absorption spectroscopy (AAS).

2. METHODOLOGY

2.1 Sampling

The sediments were collected from the arsenic contaminated area in Kustia district, Bangladesh. Sediments were collected from the different depth from the surface of 165-170 ft., 175-180 ft., and 210-215 ft. The split barrel sampler equipment was used for drilling to collect relatively undisturbed sediments. The sediment was collected into polyethylene and brought back to the laboratory. The granulometric composition of sediment was medium in coarse size and color was yellowish brown. The granulometric content includes gravel and sand.

2.2 Leaching Chemicals and Reagents

Chemical fertilizers: triple super phosphate (Bengal Corporation Ltd., Bangladesh) and diammonium phosphate (Bengal Corporation Ltd., Bangladesh) were collected from the local fertilizer dealer shop, Khulna, Bangladesh. All stock solutions were prepared from the analytical reagents (AR). Freshly prepared double deionized distilled water was used in all experiments. Arsenic (As) standard solutions were procured from Fluka-Analytical, Switzerland. Arsenic trihydride (AsH_3) generation was performed with 5M HCl (Sigma-Aldrich, USA) and 0.6% sodium borohydride solution (Sigma-Aldrich, USA).

2.3 Acid digestion

Total arsenic content in the sediment was determined by the acid digestion followed the standard method (Kagaku 1997). About two (2) gram sediment was digested with 15 mL of nitric acid and 15 mL of doubly diluted sulphuric acid. A 10 mL of nitric acid was added occasionally, and finally, 5 mL of nitric acid and 3 mL of perchloric acid were added and heated until the liquid volume became 5 mL. After cooling at room temperature, 50 mL deionized water (DIW) was added and again heated for 60 min. The resulting suspensions were filtered through the filter paper (Whatman 1) and made up to 100 mL with deionized water.

2.4 Batch leaching test

The collected sediments were air dried at room temperature and finally at 105°C in an oven for 3 h to remove the adsorbed water. Every 2 g sediment sample was added to reactor each containing 25 mL distilled water with six different amounts of fertilizers 0 (no fertilizer), 0.2, 0.4, 0.6, 0.8 and 1.0 g. Air was purged at the flow rate of 20 mL/min since 1 h before the addition of sediment through the solution to make it aerobic and after sediment addition air purging was continued for 1 h. Then, the suspension was filtered through filter paper and leachates were analyzed by AAS. The pH of the solutions was monitored with the pH meter (UPH-314, UNILAB, USA). The schematic diagram of leaching reactor is depicted in Fig. 1.

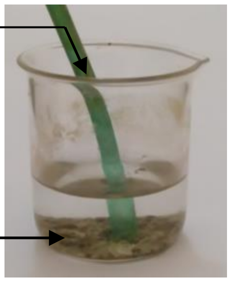

Figure 1: Schematic diagram of reactor for batch leaching test

2.5 Long time leaching test

To investigate the leaching behavior of arsenic from the sediment S2, S3 for a long time by the effect of DAP and TSP; each 4 g sediment was put into the reactor containing 100 mL distilled water. Air was purged at the flow rate of 20 mL/min since 1 h before addition of sediment through the distilled water to make it aerobic and continued until to complete the experiment. Every 6, 12, 24, 36, 48, 72, 96, 120, 144, and 168 h; 3 mL leachates were taken by filtering through the 0.45 μm filter paper. The leachates were measured for arsenic quantification by the AAS.

2.6 Determination of arsenic by AAS

Arsenic quantification of the acid digested aliquots and leachates were determined by the atomic absorption spectroscopy (SpectrAA-220, VARIAN, Australia). The arsenic measurement was performed by the hydride vapor generation (HVG) method. Arsenic trihydride (AsH_3) generation was achieved with 5M HCl (Sigma-Aldrich, USA) and 0.6% sodium borohydride solution (Sigma-Aldrich, USA). Argon was used as carrier gas (0.1 L/min) and measurement was performed at the wavelength of 193.7 nm. The limit of detection was obtained from the three times of the standard deviation of blank responses and the limits of quantification were obtained from the ten times the standard deviation of the blank responses. The detection limit was 0.5 μg/L.

3. RESULTS AND DISCUSSION

3.1. Physical properties and arsenic content in sediments

The granulometric composition of sediment is shown in Fig. 1. The color of the sediment was yellowish brown to gray. The granulometric content contains gravel and sand. Table 1 shows the arsenic content in sediments. Arsenic content in the sediment S1, S2, and S3 were 3.63 mg/kg, 8.96 mg/kg, and 0.71 mg/kg, respectively.

Figure 2: Physical appearance of sediment samples from different depth

It seems from the Table 1 that sediments are highly contaminated with arsenic. The arsenic could leach from the contaminated sediment into groundwater that could be a risk for human health. Remediation of the sediment or soil is one of the possible ways of stopping arsenic leaching.

Table 1: Arsenic content in the sediments

No.	Sample	Depth (feet)	Arsenic (mg/kg)
01	S1	165-170	3.63
03	S2	175-180	8.96
06	S3	210-215	0.71

3.2 Batch leaching test with TSP and DAP

Leaching of arsenic from the sediments by the effect of TSP and DAP under aerobic conditions is shown in Fig. 2. It is clear that the amount of leached arsenic from the sediment was gradually increased with increasing the number of chemical fertilizers of TSP and DAP in the suspensions. The leached amount of arsenic from the sediment was significantly related to the chemical fertilizers of TSP and DAP.

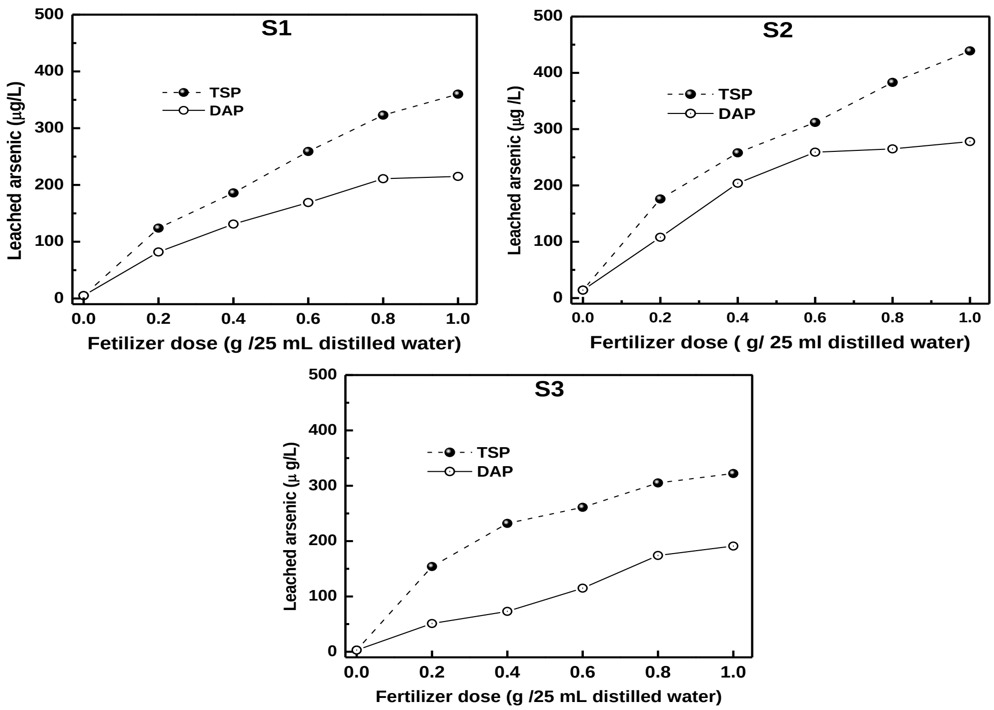

Figure 3: Batch leaching test with TSP and DAP under aerobic conditions. Every 2 g sediment samples each containing 25 mL distilled water in different fertilizers doses 0 (no fertilizer), 0.2, 0.4, 0.6, 0.8 and 1.0 g.

The leached amount of arsenic from the sediments was obviously related to the chemical fertilizers of TSP and DAP. Leaching amount of arsenic was gradually increased for each sediment samples S1, S2, and S3 with increasing the TSP in the suspension. It is also noticeable that the higher arsenic content in sediments; the higher amount of arsenic was leached from the sediments in the aqueous phases. For example, arsenic was contained in S1 and S2 sediment 3.63 mg/kg and 8.96 mg/kg, respectively. By the effect of TSP at 1.0 g/25 mL distilled water under aerobic condition, leached arsenic was 360 µg/L and 439 µg/L, respectively. In case of S3, arsenic contains in sediment was 0.71 mg/kg but the leached amount of arsenic was 322 µg/L, which was comparatively higher than the leached amount of arsenic from the sediment samples S1 and S2. It may be the reason, S3 was contained more leachable arsenic than S1 and S2.

Arsenic leaching from the sediment samples S1, S2, and S3 with increasing the DAP in the aqueous phase. It is clear from the Fig. 2 that leaching amount of arsenic was increased with increasing DAP concentration in the aqueous phase. Like TSP effect on arsenic leaching, arsenic as leached from the S1, S2 and S3 by the effect of DAP at 1.0 g/25 mL distilled water under aerobic condition 215 µg/L, 278 µg/L and 191 µg/L, respectively. It is also noticeable that although arsenic content in S1 and S2 was 5.1 and 12.6 times higher than in S3 leached amount of arsenic was comparatively more from the S3 by the effect of DAP under aerobic condition. It may be the reason that S3 had more leachable arsenic.

3.3 Long time leaching with TSP and DAP

Long-term leaching of arsenic from the sediment S2 and S3 by the effect of DAP and TSP under aerobic conditions is depicted in Fig. 3. It seems that up to 72 h, leached amount of arsenic in the aqueous phase was almost same by the effect of DAP and TSP. Afterwards, the leached amount of arsenic was varied from each other of sediment S2 and S3. At 96 h and 120 h, leached arsenic was 686 µg/L and 926 µg/L for S2 and 563 µg/L and 649 µg/L for S3 by the effect of DAP and TSP.

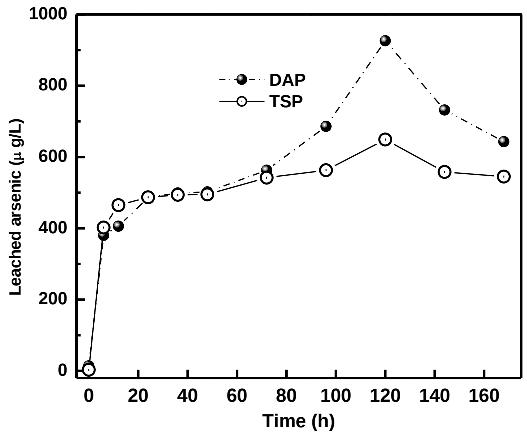

Figure 4: Long-term leaching of arsenic for sediment S1 and S2 by the effect of TSP and DAP under aerobic conditions.

After 120 h, leached amount of arsenic was gradually decreased. It may the reason that arsenic was readsorbed on the sediment surface. In sediment S2, arsenic was contained 12.6 times higher than S3 but the leached amount of arsenic in aqueous was relatively high. Possibilities are **i**) S3 was contained more leachable arsenic and **ii**) TSP was extracted more arsenic from the adsorption sites of sediment S3.

Both the TSP and DAP produce phosphate ion in the suspension therefore with increasing the TSP and DAP more arsenic was desorbed from the adsorption site from sediment. As phosphate (PO_4^{3-}) has higher charge density than arsenate (AsO_4^{3-}) consequently leached amount of arsenic was increased with increasing the TSP and DAP in the suspension (Violante & Pigna, 2002).

4. CONCLUSIONS

These study results reveal that chemical fertilizers can effectively leach arsenic from the selected sediment under aerobic condition. With increasing the chemical fertilizers doses in the suspension leached amount of arsenic was also increased. Triple super phosphate was effective extract arsenic from sediment adsorption sites than diammonium phosphate. It could be said that chemical fertilizers leach arsenic from the contaminated sediments or soil

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Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), 9~11 February 2018, KUET, Khulna, Bangladesh(ISBN-978-984-34-3502-6)

THE AMOUNT OF WASTE GENERATED FROM ROAD SIDE SHOP WITH IT CONSEQUENCES: CASE STUDY ON KUET POCKET GATE FULBARIGATEKHULNA, BANGLADESH

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ABSTRACT

The aim of the study is to recognize the amount of wastes generating from road side food shops and its consequences in KUET pocket gate, Fulbarigate, Khulna, Bangladesh. Every day food shops like tea stall, small restaurants, and hotels are generating a large amount of waste products in this area. But there is no proper waste management and dumping system here. A questionnaire survey was conducted to determine the amount of waste generates per shop per day, which types of waste is generating and also about their waste management and dumping system. Sorting the waste, their amount is determined and type is identified. From tea stall 229.95 kg/year waste generated . 142.35 kg/year watse are generated from Grocery shops and 186.15 kg/ year waste are generated from restaurants which are found from this research. The analysis shows that the waste has a bad impact on the adjacent environment where the satisfaction index shows the less value as it creates air, water pollution and that's why it has negative impact on KUET students as well as the local people. Road side waste dumping causes road blockage, in rainy season it also blocks the water drainage system and causes water logging in the area.

Key words: *Food shops, Waste production, Environment, Water logging.*

1. RESEARCH BACKGROUND

1.1 Introduction

The objective of the research is to assess the impact of waste, generating from road side food shops in KUET pocket gate, Fulbarigate, Khulna. Khulna University of Engineering & Technology (KUET) is a public engineering university of Bangladesh emphasizing education and research on engineering and technology. This is a renowned university for the study of engineering in Khulna, Bangladesh. Pocket gate is an entrance in south side with the Fulbarigate and Khulna bypass link road of its campus. Waste is known as the amount of something which is remaining after the useable and beneficial components have been removed and that has no longer satisfactory or useful. It may damage the healthy environment, spreading odor, make the site unpleasing to see and seriously, it is very harmful if the initiatives are not started. Growth of population, increasing urbanization, rising standards of living due to technological innovations have contributed to an increase both in the quantity and variety of solid wastes. It is increasing as the population is increasing day by day and the use of different materials is also increasing so that the unused portions is now at the top (UN Data, 2012).

It is very important to know how and where the waste is being managed. The importance of solid waste management is increasing day by day as it is an asset for producing energy, clearing environment, maintaining balance ecosystem which is already adopted in developed countries Globally, the estimated quantity of solid wastes expected to be generated annually by the year 2025 is about 19 billion tons (Elagroudy & Zayat, 2018). Management of solid waste reduces or eliminates adverse impacts on the environment and human health and supports economic development and improved quality of life. So it is necessary to find the impact of socio, economic and environmental for it. A part of management can be done by reusing the reusable portion from the waste which is collected in a healthy and safe environment. Bangladesh is generally faced with the rapid corrosion of environmental and sanitation conditions due to the conventional system of collection, transportation and the unconscious dumping of municipal solid wastes (Rahman, Haque and Morshed, 2017).

Every day food shops like tea stall, small restaurants, and hotels are generating a large amount of waste products in this area. But there is no proper waste management and dumping system here. So the waste creates pollutions, road side blockage which have a bad impact on KUET students and also on the local people. A questionnaire survey is conducted to determine the amount of waste generates per shop per day, which types of waste is generating and also about their waste management and dumping system.

The findings of this study suggest that the waste has a very bad impact on the adjacent environment as it creates air, water pollution and that's why it has a negative impact on KUET students as well as the local people. Road side waste dumping causes road blockage, in rainy season it also blocks the water drainage system and causes water logging in the area.

1.2 Literature Review

The term waste is any solid, liquid or gaseous substances or materials which being a scrap or being super flows, refuse or reject, is disposed of or required to be disposed as unwanted (Adewole, April 2009). According to The United Kingdom's Environmental Protection Act 1990, waste includes any substance or article, which requires to be disposed of as being broken, worn out, contaminated or otherwise spoiled. Waste can be divided into different categories like recyclable general waste, non-recyclable general waste, household waste, hazardous waste etc. Waste can be segregated as bio degradable waste and non-bio degradable waste. Bio degradable waste includes organic waste like kitchen waste, vegetable waste, paper etc. Non-bio degradable wastes are segregated into recyclable (plastics, glass, metal etc.), toxic waste (paints, chemicals, blubs etc.) and C-soiled (hospital waste such as cloth with blood and other body fluids) (S S H Alequzzaman M., 2006).

Waste management involves the collection, transportation, processing, recycling or disposal and monitoring of waste materials. It relates to refused materials produced by human activity, and is generally undertaken to reduce their effect on health, environment or aesthetics. Waste management is also carried out to recover resources from it. This has brought awareness to people that the solution lies in using waste as a resource rather than to be destroyed (Colon, 2006). Waste management involves the use of solid, liquid, gaseous or radioactive substances with different methods and fields of expertise for each of these. It concerned with the generation, on-site storage, collection, transfer, transportation, processing and recovery, and ultimate disposal of solid wastes (Vasisth, 2011).

In March 2005 JICA developed a case study on solid waste management of Dhaka city. The objective of that study were to formulate master plan concerning solid waste management in Dhaka City with the target year of 2015 and to develop capabilities and management skills of the DCC personnel through the technology transfer during the course of the Study.

2. STUDY AREA AND METHODOLOGY

2.1 Study Area

Khulna is the 3rd largest city of Bangladesh. Khulna University of Engineering & Technology (KUET) is a public engineering university of Bangladesh emphasizing education and research on engineering and technology in Khulna city. Pocket gate is an entrance in south side with the Fulbarigate and Khulna bypass link road of its campus. Which is located in Teligati, Khan Jahan Ali thana, Khulna district and between 22.9005° N, 89.5024° E.

Study area at a glance

Table 1: Study Area at a Glance

Tea stall	2
Restaurant	2
Grocery Shop	3
Distance from Fulbarigate	0.85 Kilometers
Distance from ZeroPoint	14.4 Kilometers

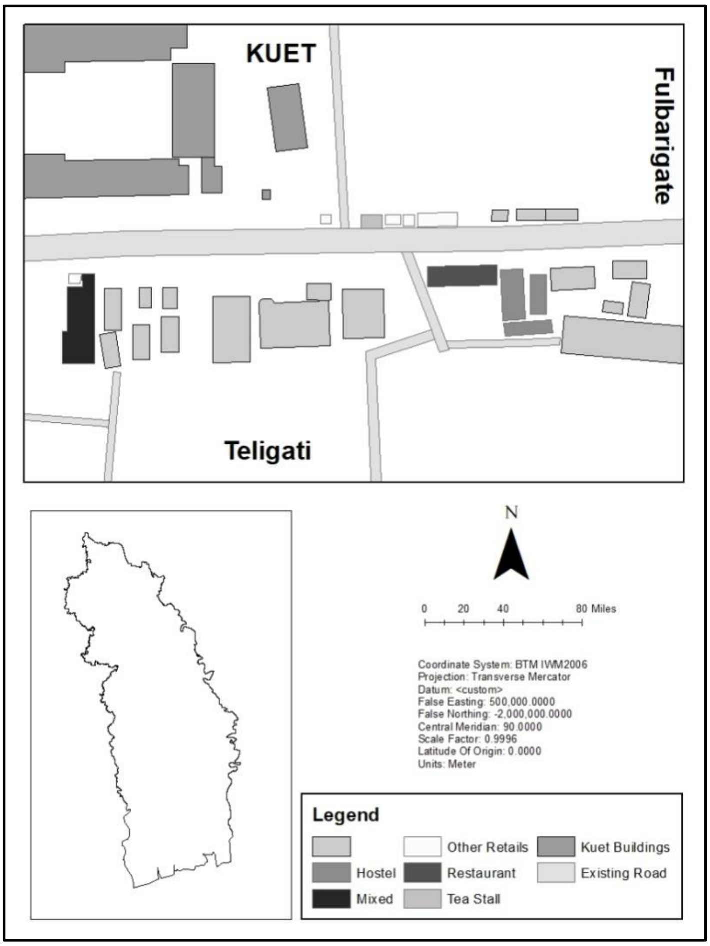

Figure 1: Map of Study Area, Source: Author 2017

2.2 Methods

Some report and other sources were reviewed for gathering knowledge. The practical field observation and field based data collection of solid waste generation, collection, transportation of solid waste management situation through questionnaire and interviews. During the survey some factors were also considered such as income level, education which can affect waste generation.

The primary data has been collected though the field survey and owner, manger, workers of 6 road side shop were interviewed with the help of questionnaires. Questionnaire measured shop existing solid waste practices as well as individual knowledge, concerns, willingness to participate on solid waste. The secondary data has been very useful for this research. The secondary data was collected from the various sources. Firstly, studies which involved the consultation of reports, articles, documents and Case studies. Some map was collected from various sources *(KCC, LGED, and KDA).*

For calculating the satisfactory index, a questionnaire survey was conducted among 50 people to know about the satisfactory condition about waste disposal system, water logging problem, air pollution, water blockage, water logging diseases. The satisfactory value is between 0-5. Where 0 indicate excellent, 1 indicate better, 2 indicate good, 3 indicate bad, 4 indicate worse and 5 indicate worst. Satisfactory index of each attributes is calculated by at first multiply each value by the number of respondents for the value then adding all the value. At last this value is divided by the total number of respondent.

3. ANALYSIS & INTERPRETATION

In the pocket gate there were no waste collection facilities. Waste is generally dumped in the road side when the waste buckets become full. In the all shop the storage of waste is done in one way or the other. Storage containers like plastic buckets are kept in the shop in order to store waste.

3.1 Solid Waste Generation

In study area shops are categorized into three different types on the basis of types of shops. These shops are tea stall, restaurant and grocery shop. There are two tea stalls, two restaurants and three grocery shops.

Among these three tea stall produces higher amounts of waste (0.63kg) per day where the grocery shop produces low amount of waste (.39kg) per day among the three type shops. And restaurant produces 0.51 kg waste per day.Figure 2 represent the yearly waste generation from the Shops.

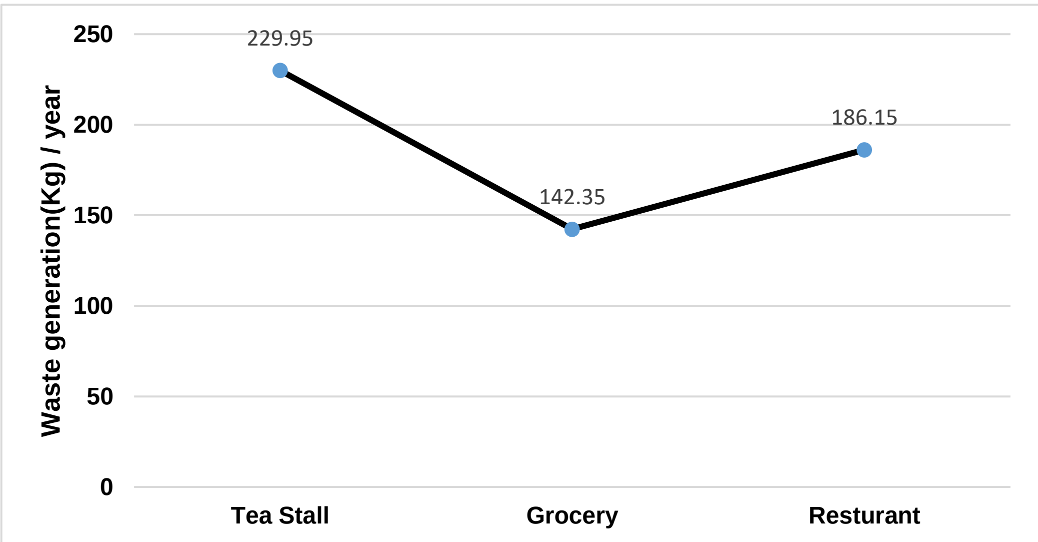

Figure 2: Yearly Waste Generation from Shops,   Source: Field Survey 2017

3.1.1 Tea Stall

In this area there are two tea stall. They are named as Babu Tea Stall & Liton Tea Stall. Among this two tea stall Babu Tea Stall produce more amount of waste per day than Liton Tea Stall. The figure 3 shows the amount of waste generation per day from the tea stalls.

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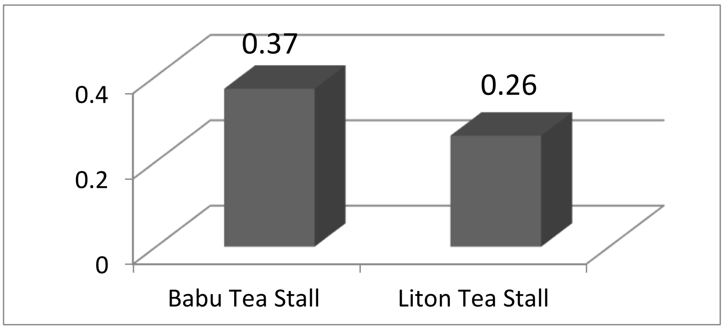

Figure 3: Waste Generation from Tea Stall,
Source: Field Survey 2017

3.1.2 Restaurant

Food Club and Sadia Hotel is the two main restaurants in the study area. Among this two restaurants, Food Club produces higher amount of waste than the Sadia Hotel. Figure 4 shows the waste generation per day from the restaurants.

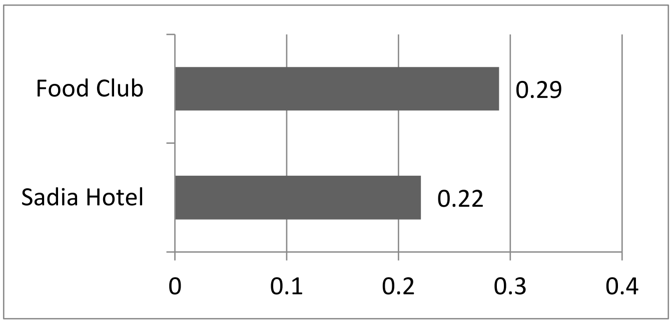

Figure 4: Waste Generation from Restaurant,
Source: Field Survey 2017

3.1.3 Grocery Shop

In the study area there are three grocery shops. These are Sakib Shop, Student Corner and Rafiq Store. Among the three shops Student Corner produces higher amount of waste per day. The amount of waste generation from the grocery shops is shown in figure 5.

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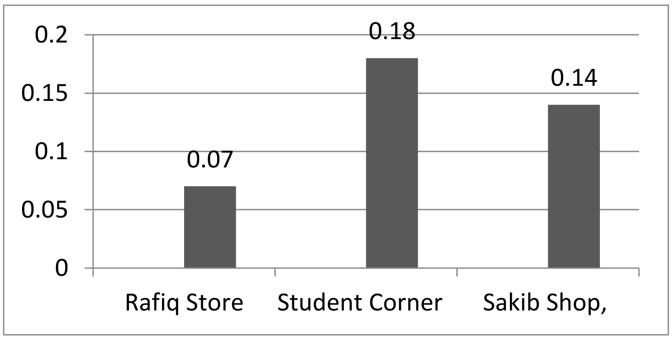

Figure 5: Waste Generation from Grocery Shop,
Source: Field Survey 2017

3.2 Segregation of Waste

The segregation condition in the study area is very poor. No shop has their own segregation system. All waste is dumped into a bucket. Then the wastes are dumped beside the road side area. The figure 6 represents the presence of segregation system in the shops.

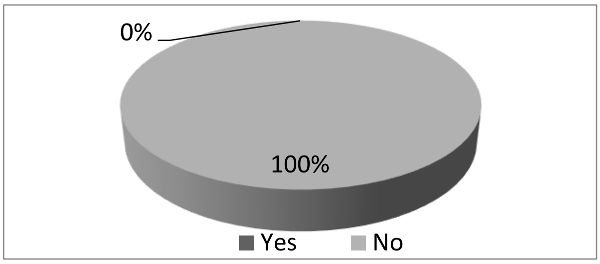

Figure 6: Segregation System, Source: Field Survey 2017

3.3 Satisfaction Index

In the user opinion survey respondents are asked to give their opinion on different attributes of waste management system in pocket gate on a scale of 0 to 5. Where 5 indicates the best excellent and 0 indicate the worst performance.

User opinions are taken about waste disposal system, water logging problem, air pollution, road side blockage, Water logging Diseases.

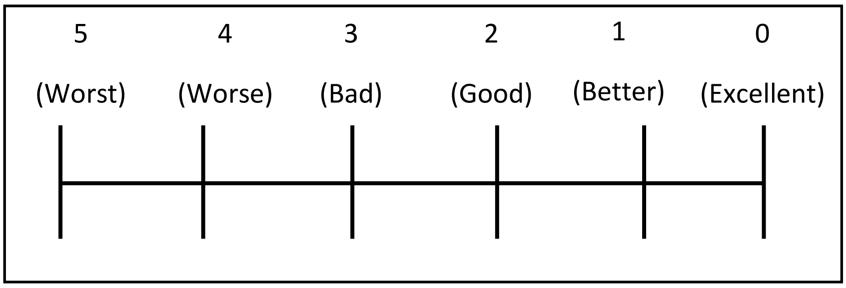

Figure 7: Scale of Satisfaction Level, Source: Author, 2017

Table 2: Value of Different Attributes

Attributes	**Scale**					
	5	**4**	**3**	**2**	**1**	**0**
Waste disposal system	9	22	16	3	0	0
Water logging problem	18	11	13	5	2	1
Air pollution	20	17	12	1	0	0
Road side blockage	31	14	5	0	0	0
Water logging Diseases	12	6	8	14	7	3

Source: Field Survey, 2017

$$\text{Satisfaction Index on Waste disposal} = \frac{5*9 + 4*22+3*16+2*3+1*0+0*0}{50}$$

$$= 3.74$$

Satisfaction Index of other attributes of waste management system in pocket gate

Table 3: Satisfaction Index of Different Attributes

Attributes	Satisfaction Index
Waste disposal system	3.74
Water logging problem	3.7
Air pollution	4.12
Road side blockage	4.52
Water logging Diseases	2.98

Source: Field Survey, 2017

From the above table 3, it is seen that the condition of air pollution and road side blockage is worst in the study area for lack of proper waste management system. The waste disposal system is not satisfactory and water logging problems are occurred due to it. On the other hand it is seen that water logging diseases are not spread at a high rate but it also affect the KUET students as well as the local people.

4. CONCLUSION

Population in Khulna city as well in Bangladesh is increasing rapidly and waste generation is also increasing. Depending on the education level, income level, house type, waste generation varies. Waste generation types are changing due to the adaption and availability of various packaging product (e.g. food etc.). It is found that none of the food shop has segregation practice at the early level of waste management in road side and also waste pickers do not have any different selected place to dump different waste in separate space. Source-segregated waste is essential for better management, so food shops should be motivated accordingly. Segregation practice at initial level in houses can increase the effectiveness of waste management and can make it easy to waste picker to manage the wastes and waste collection for recycling can be easier. Environmental significance of the wastes beside the road is negatively increasing. So, a better waste dumping place should be proposed to accumulate the wastes.

ACKNOWLEDGEMENT

Special thanks to the local people of Pocket gate and the students of KUET for their participation and coordination at the time of conducting survey. Without their co-operation and help this research could not be up the mark.

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DESIGN AND CONSTRUCTION OF AN APPROPIATE SYSTEM FOR THE TREATMENT AND REUSE OF GREY WATER

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ABSTRACT

Due to the increasing rate of population in the world, the demand of fresh water is also increasing. So a balance should be made between the demand of water and its supply. Therefore, wastewater recycling or management is gradually getting importance. Grey water is defined as any kind of domestic waste water, excluding sewage. The aim of this paper is to develop a treatment unit for reusing grey water. To achieve this,one sample of grey water has been collected from Rokeya hall, KUET, Khulna .The characteristics of grey water in terms of different water parameters have been tested. A Treatment unit consisting of a sand filter containing Sylhet sand and a roughing filter containing brick pieces and charcoal has been constructed. After filtration the characteristics of sample have been tested again. Comparing the values of treated grey water with the available permissible values of water reuse, it is found that it can be used for irrigation purpose.

Keywords: *Grey water, Waste water, Laboratory analysis, Treatment unit*

1. INTRODUCTION

Due to the increasing rate of population growth, the demand of fresh water is also increasing all over the world. But the source of fresh water is scarce. So a balance should be made between the demand and the supply of fresh water. Earlier wastewater treatment was popular only in developed countries but nowadays wastewater recycling or management is gradually getting popular in the low and middle income countries too. Appropriate treatment system of wastewater can reduce the scarcity of fresh water. Bangladesh is a South Asian country. The total population in Bangladesh was estimated at 159.9 million people in 2016 (Bangladesh population n.d.). But the area of Bangladesh is 1, 47,570 sq. km. So it can be clearly seen that the availability of fresh water is scarce in terms of vast population. The key concern is to create a proper balance between demand and supply of fresh water. In order to overcome the increasing demand, the concept of treatment and reuse of wastewater is a good solution. Grey water is one kind of wastewater originating from bathtub, shower, washing machine, kitchen sink etc. Grey water can contain large numbers of disease-causing organisms (human pathogens such as bacteria, viruses and protozoa). Grey water can also include a number of contaminants including fats and oils, food scraps, nutrients, salts, sodium, phosphorus, detergents, cleaning products, sunscreens and personal care products. Common tests that are generally conducted to judge the characteristics of grey water are pH, total dissolve solid (TDS), total suspended solid (TSS), color, turbidity, biological oxygen demand (BOD), chemical oxygen demand (COD), hardness, conductivity (EC), chloride, nitrate, sulfate, total coliform (TC) etc. In this study the parameters tested are conductivity, pH, chloride, hardness, nitrate, TDS, COD, color, sulfate, turbidity, BOD5, TSS etc. The generated amount of grey water depends on the factors such as existing water supply service, number of household members, life style, typical water usage patterns etc. To meet the demand of fresh water for the large number of population, the idea of the treatment of grey water has been developed. The appropriate reuse of grey water largely depends on both the source of grey water and the level of treatment. Septic tank, constructed wetland and intermittent sand filter are identified as the most suitable processes for decentralized treatment due to the simple operation and maintenance facilities as well as cost effectiveness of these systems (Ahmed and Arora, 2012) A research has been conducted to find out possible treatment method to make the grey water reusable. It has been conducted in the lab of Civil Department of Khulna University of Engineering & Technology.

2. METHODOLOGY

2.1 Study area

KUET campus has been selected as the study area for this research. KUET is situated in Khulna district of Bangladesh. Rokeya Hall of Khulna University of Engineering & Technology (KUET) has been selected to collect sample. Filter has been constructed and sample has been tested in the laboratory of Department of Civil Engineering, KUET. The location of the study area is presented below in the Khulna city map. Aerial view is also shown.

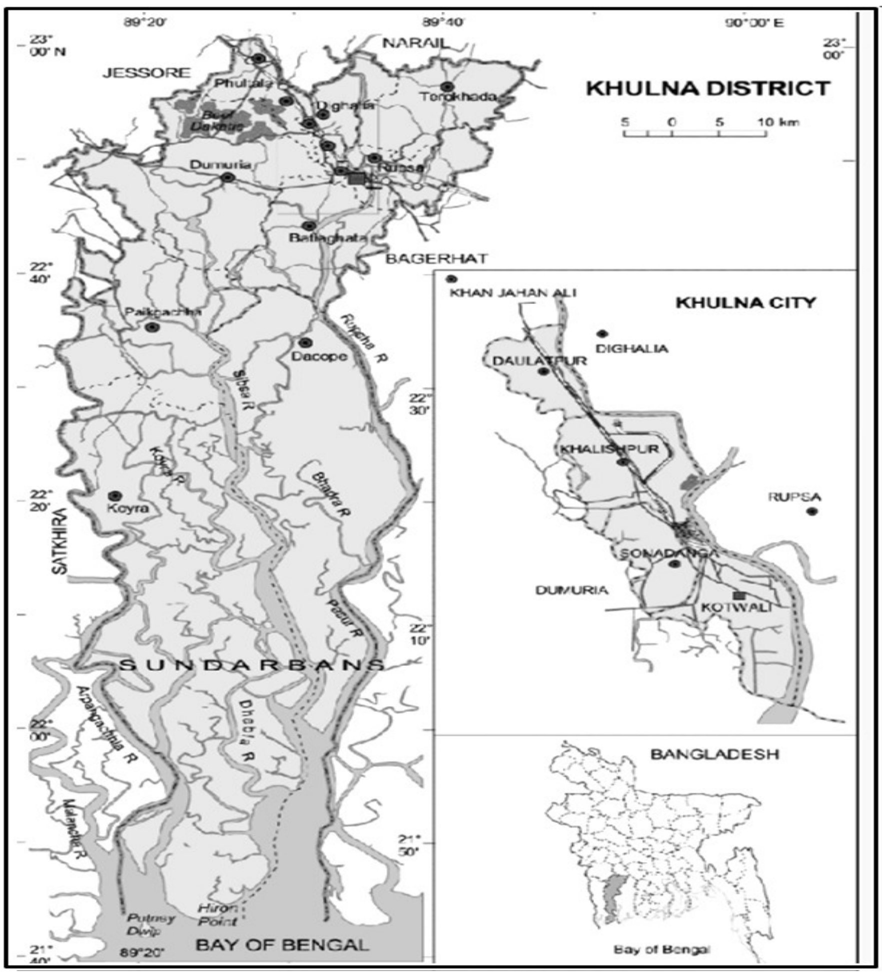

Figure 1: Khulna District (Map of Khulna n.d.).

2.2 Collection of Grey Water

Only one sample of grey water has been collected. It has been collected from tank in a plastic bottle from Rokeya hall, KUET, Khulna. The treatment method of grey water largely depends on the collected sample of grey water.

Figure 2: Sample of grey water

2.3 Arrangement of filter media

Filtration mechanism has been applied to treat the water. The filter which has been constructed in the lab for this study purpose consists of two parts. One is sand filter and another is roughing filter. Sand filter is one kind of simple filter containing sand. This filter is relatively inexpensive to build, but do require highly skilled operators. Roughing filter consists of one to three compartments in which gravels of different sizes are arranged. In this filter the portion which is known as sand filter contains 6" thick layer of Sylhet sand. And the portion which is known as roughing filter contains three layers. First layer contains 1.5" thick layer of brick pieces (size 0.5"-1"). Second layer contains 1.5" thick layer of brick pieces (size 1"-1.5"). Last layer contains 2" thick layers of charcoal. The function of sand, brick pieces and charcoal are to remove and retain contaminants. Various filter media with varying thickness has been adopted with a view to checking the effectiveness of the filter. It takes few seconds to run the filter, About 2 litres of influent can be treated at one time.

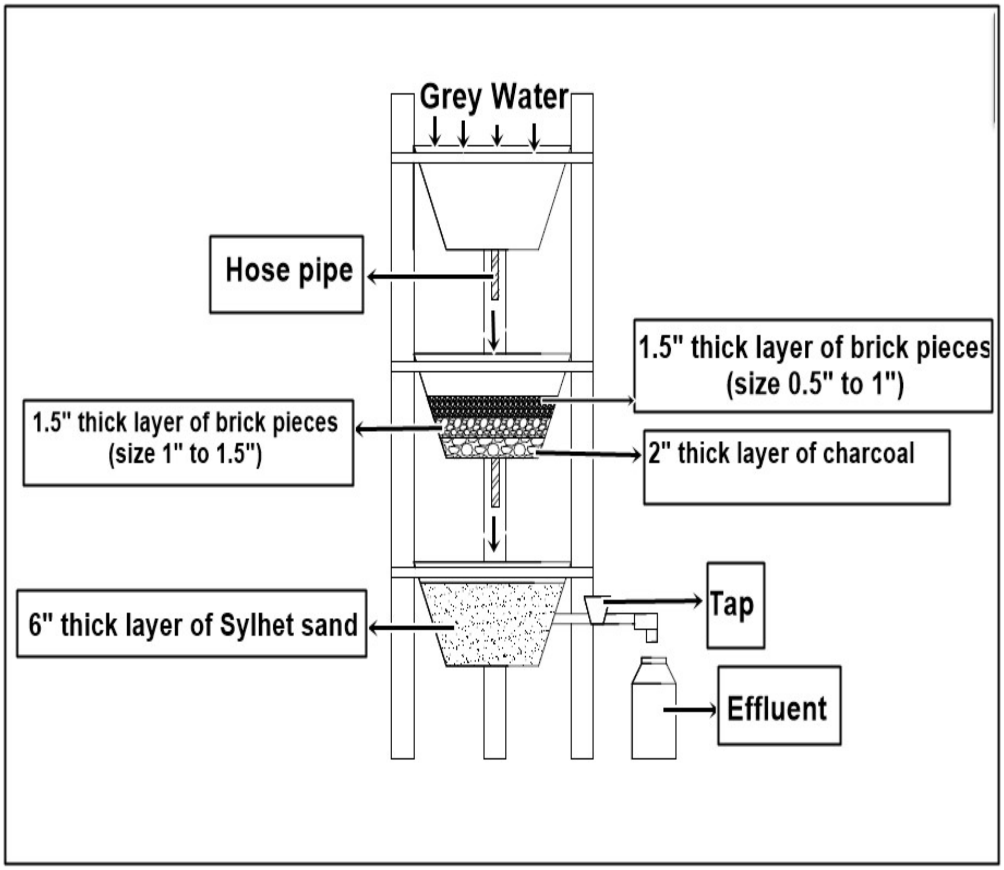

Figure 3: Linear representation of filter

Figure 4: Constructed filter

2.4 Laboratory Analysis

In the laboratory, total 11 parameters have been determined for the sample before and after the treatment. After that the values of treated water have been compared with the permissible values of reusing. Measurement of pH is carried out either by calorimetrical or by electrometrical method. The electrometric method is more accurate but expensive and calorimetric method is less accurate but cheap. Here electrometric method has been used. Pure water does not have any color. The color of water is tested either by color compactor or by spectrometer. Here it is done by spectrometer. Turbidity is a measure of the cloudiness or murkiness of water due to suspended particles. The standard method for turbidity test needs Nephelometry and Jackson turbiditimeter. Here it is conducted by nephelometry method. Conductivity indicates the presence of ions within the water. Conductivity has been measured electrochemically. In laboratory Biochemical Oxygen Demand (BOD) is measured by DO meter. For the determination of chemical oxygen demand (COD), $K_2Cr_2O_7$ is taken in pipette and ferrion indicator is used as reagent and then titration is conducted until reddish color forms. Chlorides are widely distributed in nature as salts of sodium (NaCl), potassium (KCl), and calcium ($CaCl_2$). Here chloride was determined by Mohr method. Sulfate in water was measured electrochemically by using a spectrometer. Nitrate in water was also measured electrochemically by using a spectrometer. The total dissolved solid content in water is obtained by specific conductance measurement.

3. RESULTS AND DISCUSSIONS

3.1 Results of the characteristics tests of grey water before and after the treatment

For collected sample of grey water, values of pH, Color, Turbidity, Conductivity, BOD, COD, Chloride, Sulfate, Nitrate, TDS, TSS before treatment were 7.32, 1065 Pt-Co, 26.1 NTU, 4.78 μS/cm, 201.5 mg/L, 1230 mg/L, 1980 mg/L, 56 mg/L, 4.5 mg/L, 3260 mg/L, 325 mg/L respectively and after treatment the values of pH, Color, Turbidity, Conductivity, BOD. COD, Chloride, Sulfate, Nitrate, TDS, TSS are 7.80, 290 Pt-Co, 11 NTU, 3.56 μS/cm, 112.84 mg/L, 110 mg/L, 535 mg/L, 80 mg/L, 0.44 mg/L, 299 mg/L, 95 mg/L respectively. Comparing the values of treated grey water with the available permissible values of water reuse, it is found that it can be used for irrigation purpose. After treatment the liquid is waste water, as it is not suitable for drinking purpose. The permissible values for irrigation are taken from different sources. The permissible limits of pH, BOD, COD, Chloride, Sulfate, TDS, TSS for irrigation are 6.5-8.4, 50 NTU, 2000 μS/cm, 110 mg/L, 150 mg/L, 2000 mg/L, 250 mg/L, 100 mg/L, 500 mg/L, 100 mg/L respectively for irrigation (Islam, 2012) .The permissible limits of Conductivity, Turbidity are 2000 μS/cm, 50 NTU for irrigation (Sultana, 2015).

Table 1: Tabular from of Results

Water Quality Parameter	Unit	BD Standard for drinking (ECR'97)	Irrigation Permissible Limit	Values Before Treatment	Values After Treatment
pH	-	6.5-8.5	6.5-8.4	7.32	7.80
Color	Pt-CO	15	-	1065	290
Turbidity	NTU	10	50	26.1	11
Conductivity	μs/cm	-	2000	4.78	3.56
BOD	mg/L	.2	110	201.5	110
COD	mg/L	-	150	1230	112.84
Chloride (Cl^-)	mg/L	150-600	2000	1980	1535
Sulfate ($SO4^{2-}$)	mg/L	200	250	56	80
Nitrate (NO_3^-)	mg/L	10	100	4.5	.44
Total Dissolved Solid	mg/L	1000	500	3260	299
Total Suspended Solid	mg/L	10	100	325	95

3.2 Graphical Representation of Results

The values of different types of pH changes slightly after the filtration. The value of pH slightly increased. This is because the sand filter may contain some alkalinity. The treated values are within the limit. Grey water contains high turbidity, but after filtration in roughing filter the turbidity is found less, and it is within the limit for the use in irrigation. After the treatment, the value of conductivity is decreased, the value of conductivity is within the standard limit for irrigation. After filtration the value of nitrate is decreased because of the roughing filter.

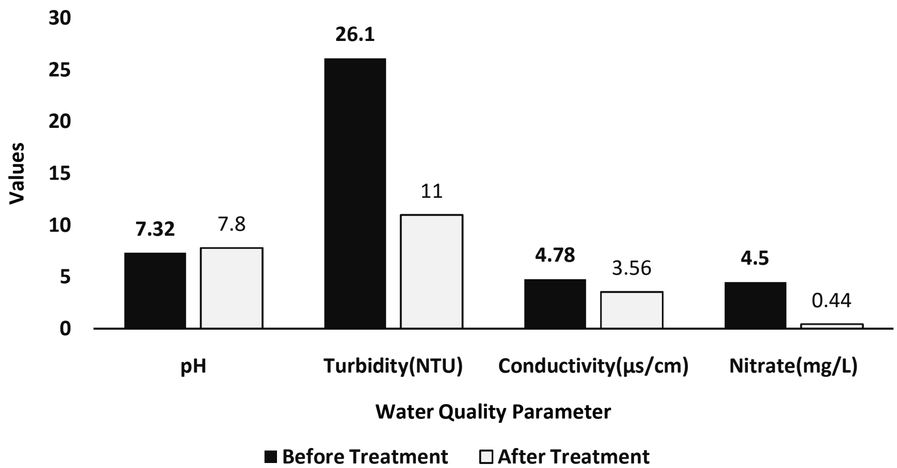

Figure 6: The variations of pH, Turbidity, Conductivity, Nitrate before and after treatment

The value of BOD is significantly reduced in the roughing filter, as large chain of organic can not pass through the small pore of aggregate. The value of COD is significantly reduced in the roughing filter. The value of chloride after treatment is found within the reusable limit. The value of sulfate increases after treatment, it may be because of the supply water which is used for the treatment contains lot of sulphate.

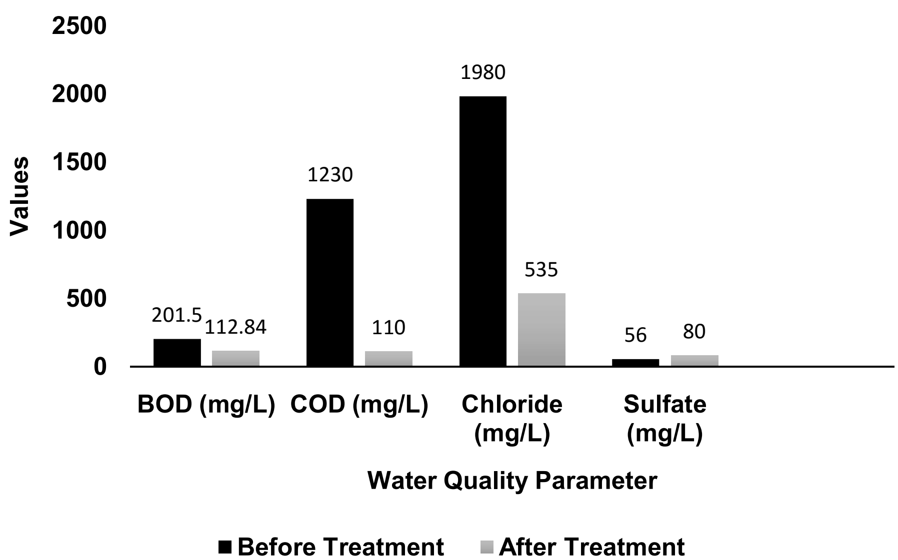

Figure 7: The variations of BOD, COD, Chloride, and Sulfate before and after treatment

The color is removed in roughing filter, as it is absorbed by brick chips. The TDS value decreased after treatment TDS was mostly removed by sand filter. The value of TSS is also increased.

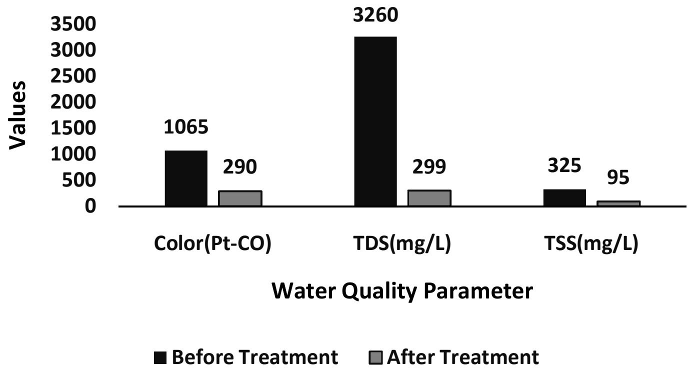

Figure 8: The variations of color, TDS, TSS before and after treatment

4. CONCLUSIONS

Different characteristics of grey water in terms of eleven different water parameters have been tested by collecting sample of grey water. A treatment filter has been constructed. The filter has two parts. One part contains Sylhet sand another contains different size of brick pieces and charcoal. After the treatment the water parameters have been tested again. The removal efficiency of color, BOD, COD, TDS, TSS etc have been observed. Comparing the parameters of treated grey water with the available standard values, it has been decided whether it can be reused or not. Most of the parameters are found to satisfy the permissible limit for the reuse in irrigation, but this treated grey water is not suitable for drinking. This treated can be applied directly to the soil. However, root crops which are eaten should not be watered with this water. Treated grey water can be used on flat area. Finally a treatment unit has been proposed.

ACKNOWLEDGEMENTS

The authors are grateful to the laboratory attendants of the Civil Engineering Laboratory for their assistance.

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PERFORMANCE EVALUATION OF UASB FOLLOWED BY DHS REACTOR TREATMENT PROCESS AND ITS COST IN TREATING TEXTILE WASTEWATER

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ABSTRACT

This study evaluates the potential of the combination of Up-flow Anaerobic Sludge Blanket (UASB) and Down-flow Hanging Sponge (DHS) in textile wastewater treatment system, especially for developing countries. A pilot scale UASB (446 m^3) and DHS was installed in a textile wastewater treatment site and constantly monitored for six months. Capacity of the ETP is 60 m^3/hour and design HRT of UASB is 6 hour. Removal efficiency of COD from UASB varied at 53-62 percent, BOD varied at 36-62 percent and color at 40 to 73.33 percent. DHS reactor increased water quality by removing COD (12%-20%), BOD (24%-32%), color (46%-72%), turbidity (64%-82%) and TSS (64%-82%) without any external aeration process. This treatment process has significantly less efficiency in removing TDS and EC. The chemical cost estimated at 1.66 taka/m^3, energy consumption 0.75 kw/m^3 which represents a very low cost and less energy consumption textile wastewater treatment process. Methane gas was also detected by gas detector from UASB. The sponge medium of DHS reactor was required to remove once in five year operation period of the ETP. The whole treatment process has significantly less biomass yield, sludge removal was required only twice in five year operational period of the ETP.

Keywords: *Up-flow anaerobic sludge blanket reactor, down-flow hanging sponge reactor, biomass yield, removal efficiency.*

1.INTRODUCTION

The up-flow anaerobic sludge blanket (UASB) is a high rate anaerobic bioreactor which is a single tank process. Wastewater enters the reactor from the bottom, and flows upward. A suspended sludge blanket filters the treats the wastewater as the wastewater flows through it. The sludge blanket comprised of microbial granules which is small agglomerations of microorganisms that, because of their weight, resist being washed out in the up-flow. The microorganisms in the sludge layer degrade organic compounds. The sludge blanket provides very high concentration of active biomass in the reactor. Thus extremely high SRT could be maintained irrespective of HRT.

After several weeks of use, larger granules of sludge form which, in turn, act as filters for smaller particles as the effluent rises through the cushion of sludge. Because of the up-flow regime, granule-forming organisms are preferentially accumulated as the others are washed out.

The technology is relatively simple to design and build, but developing the granulated sludge may take several months. The reactor UASB has the potential to produce higher quality effluent than Septic Tank, and can do so in a smaller reactor volume. It is a well-established process for large-scale industrial wastewater treatment and high organic loading rates.

The main advantage of anaerobic treatment process are it has less energy consumption as no aeration is required, energy is generated in the form of methane gas, less nutrient requirement, requirement of higher organic loading rate.

The small amount of excess sludge production of anaerobic treatment systems compared to conventional aerobic wastewater treatment system is one of the most significant benefits of anaerobic systems. 0.5 kg of excess biomass yield is obtained from 1 kg aerobic degradation of soluble BOD on the other hand less than 0.1 kg of excess biomass is yielded from 1 kg anaerobic degradation of 1 kg soluble BOD.

A down-flow hanging sponge (DHS) reactor is used for post-treatment of the effluent from an up-flow anaerobic sludge blanket (UASB) reactor and has provided excellent treatment performance. The principle of DHS reactor is similar to trickling filter. In this case sponge medium is used. The advantage of sponge medium is it has high porosity (90% porosity) which increases entrapped biomass. This provides higher solid retention time (SRT). Higher solid retention time provides ample time for autolysis of sludge within the system(Tandukar, 2006). Thus DHS reactor has negligible excess sludge production. No excess sludge withdrawal is required for DHS reactor. UASB is an anaerobic reactor, so it has less excess biomass yield. As a result the whole treatment.

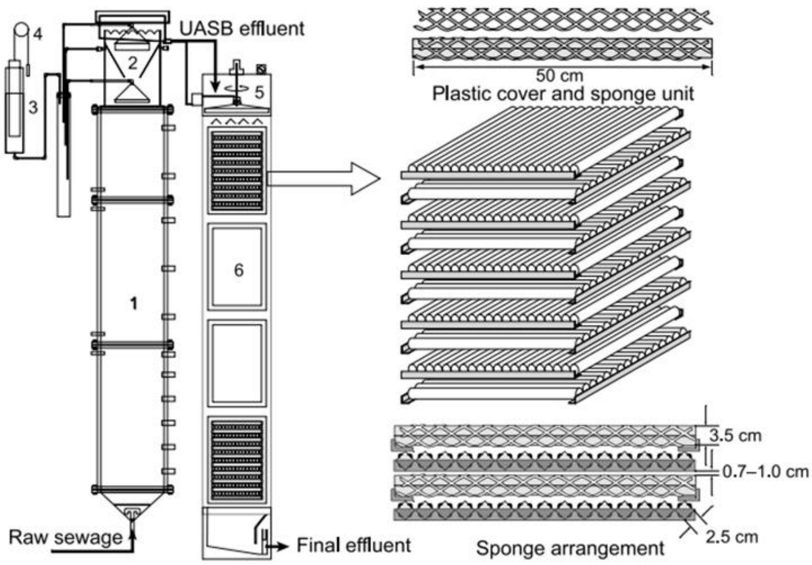


Figure 1: UASB bioreactor combined with DHS reactor

2. METHODOLOGY

An effluent treatment plant which has UASB reactor and followed by DHS reactor was monitored for six month. Wastewater sample were collected from each unit of the treatment plant and different pollution parameters were tested (environmental lab, BUET) to assess the performance. Wastewater sample were collected in the operational period of the industry. Methane gas could also be detected from UASB by gas analyzer. The cost and energy consumption of the ETP was estimated as well.

2.1 General information of the textile industry

The industry is situated in Ashulia, Dhaka near TuragRiver. It's a dyeing industry and has a production capacity of 5.5 ton/ day. Its water consumption is 440-550 m3/day and source of water is ground water.

2.2 General information on the ETP

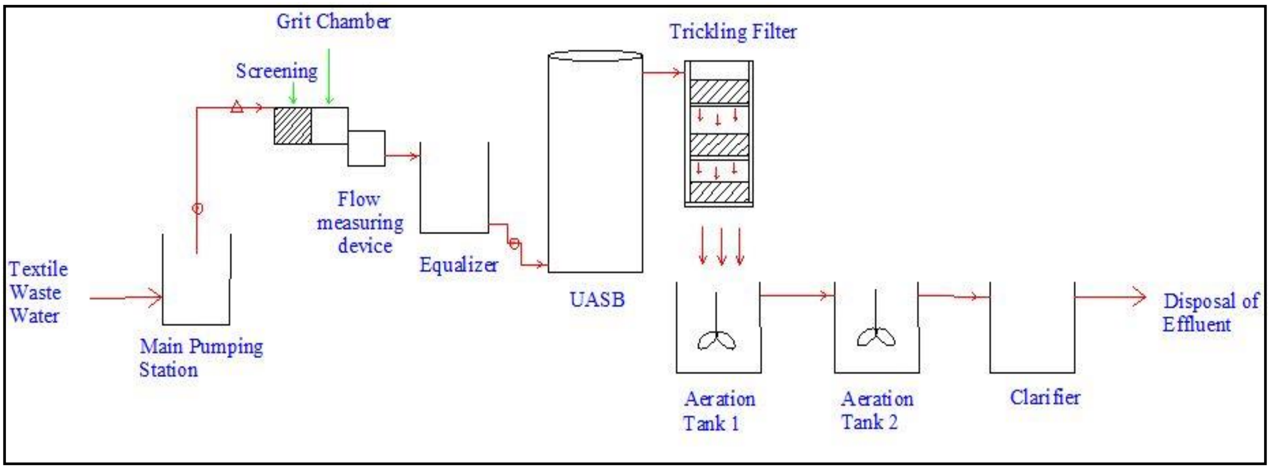


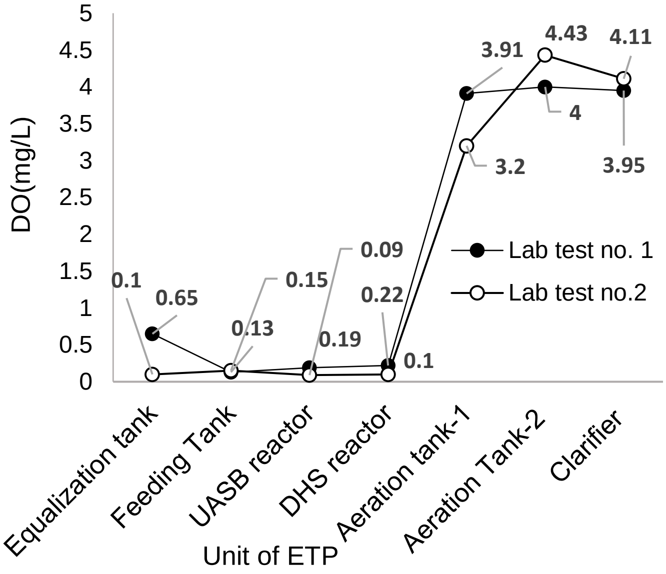
Figure 2: Schematic diagram of the ETP.

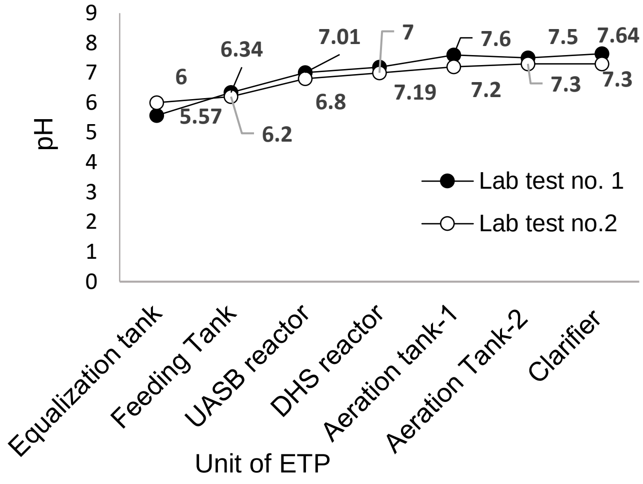
Table 1: Size, hydraulic retention time and capacity of each unit of the ETP

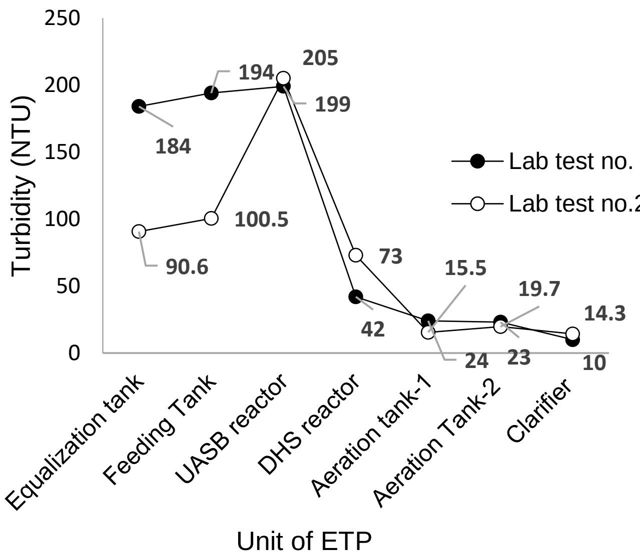
Treatment process unit	Capacity (m^3)	Size(length*width*height) (m*m*m)	Theoretical Hydraulic retention time(hour) (HRT)
Equalization tank	105	4*3.5*7.5	1.75
Feeding tank	75	4*2.5*7.5	1.25
UASB reactor	405	6*5*13.5	6.75
DHS reactor	94	4.5*3*7	1.56
Aeration tank-1	84	4*3*7	1.4
Aeration tank-2	195	6*5*6.5	3.25
Clarifier	102	6*3.7*4.5	1.7

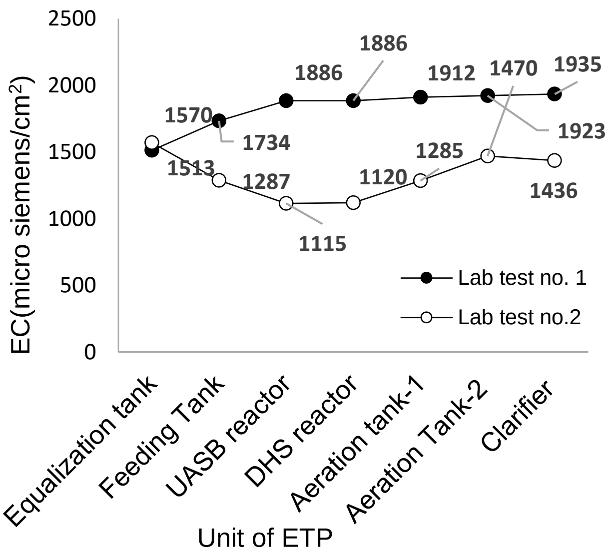
3. EXPERIMENTAL RESULTS

3.1 Pollution parameter profile of the UASB combined with DHS treatment process









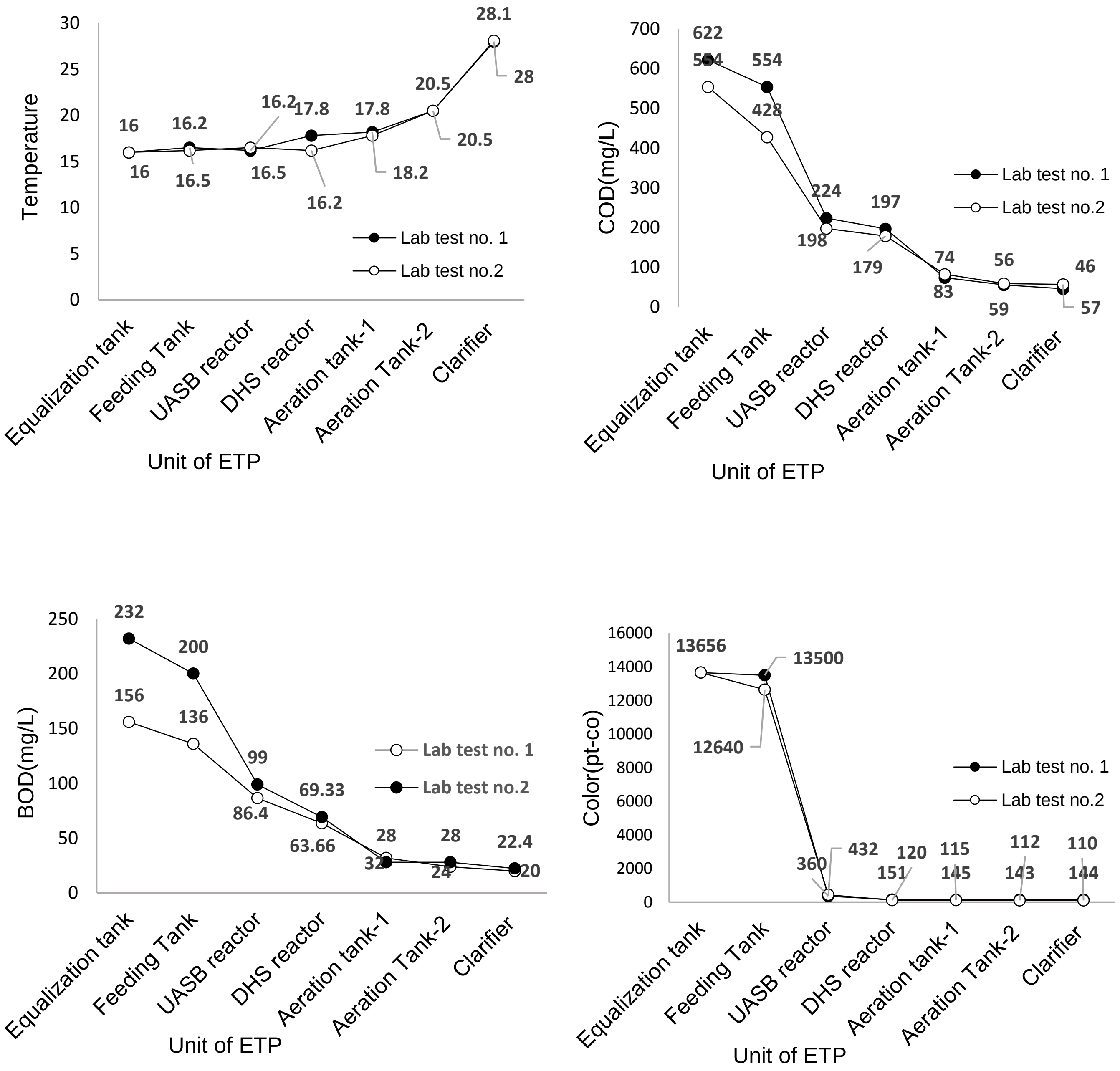
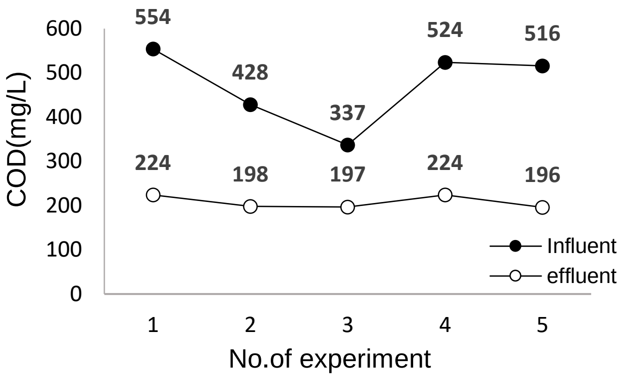
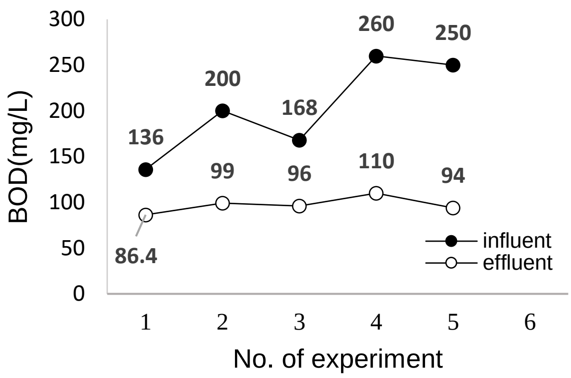


Figure 3: Dissolved oxygenFigyu, pH, turbidity, electric conductivity, temperature, chemical oxygen demand, biological oxygen demand and color profile of UASB combined with DHS treatment process for two laboratory test.

3.2 UASB performance assessment





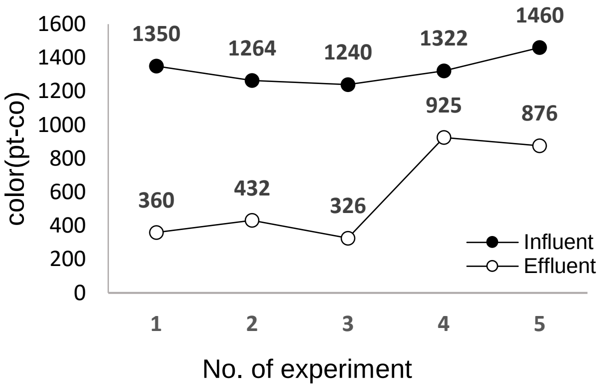


Table 2: Summary table of UASB removal efficiency.

UASB performance evaluation

Parameter	**Removal efficiency(%) range**
COD (mg/L)	53-62
BOD(mg/L)	36-62
Color(mg/L)	40-73

Figure 4: Variation of Chemical oxygen demand, biological oxygen demand and color in the influent and effluent of UASB.

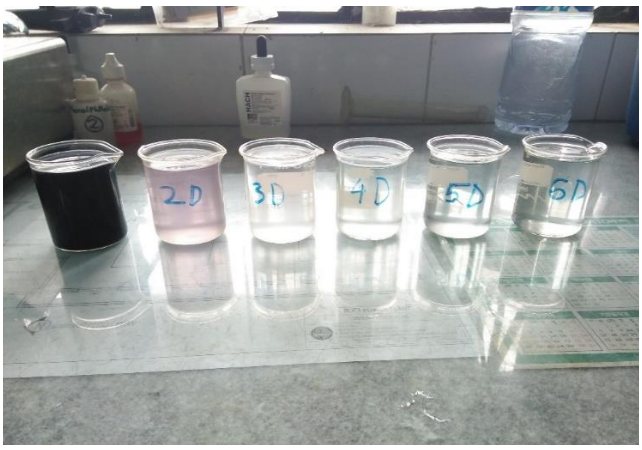


Figure 5: Wastewater sample of each unit of ETP

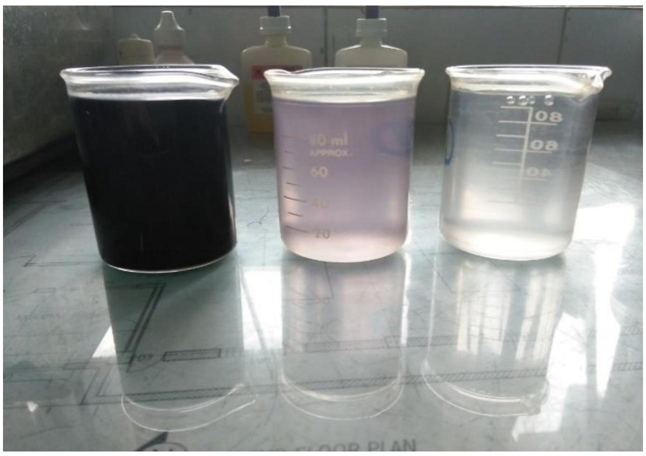
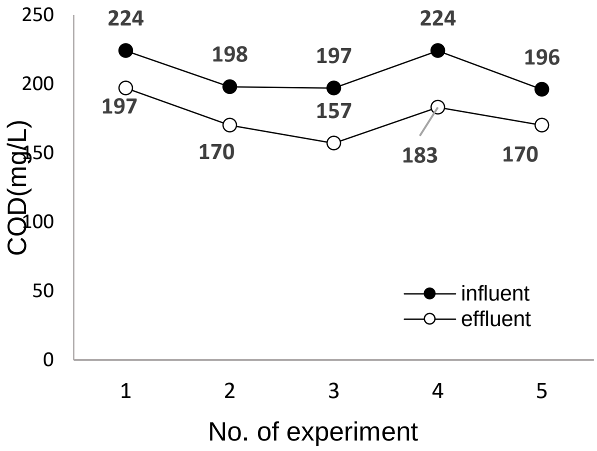
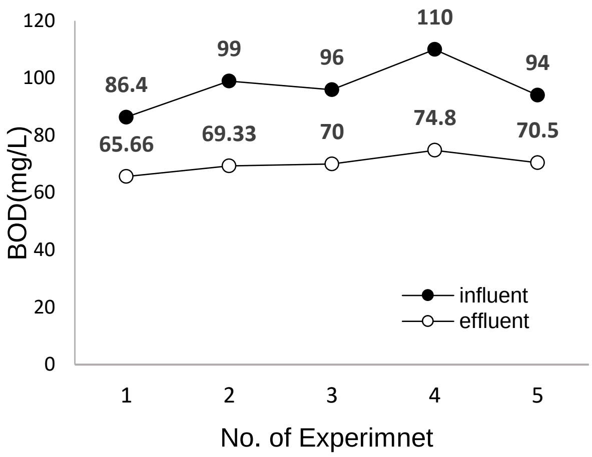
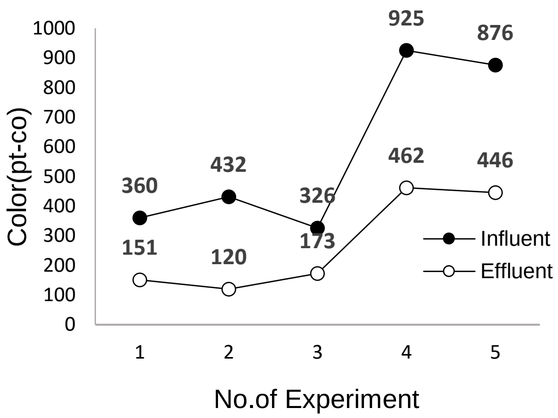


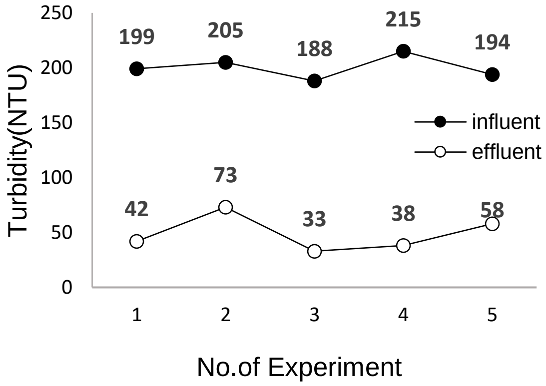
Figure 6: Color variation of wastewater sample of equalization tank, UASB reactor and DHS reactor.





3.3 DHS performance assessment





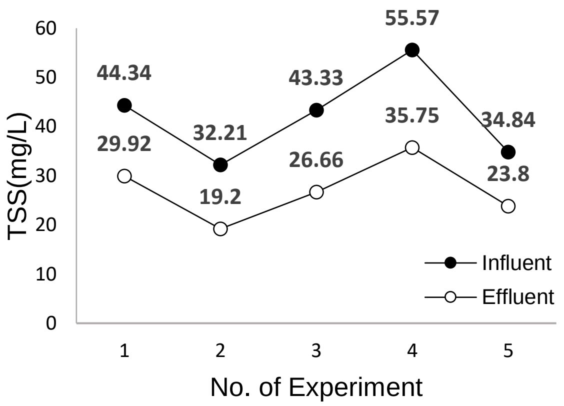


Figure 7: Variation of COD, BOD_5, color, turbidity and TSS in influent of DHS reactor and effluent of DHS reactor

Table 3**:** Summary table of DHS reactor removal efficiency.

DHS performance evaluation

Parameter	**Removal efficiency(%) range**
COD (mg/L)	12-20
BOD(mg/L)	24-32
Color(mg/L)	49-72.22
TSS(mg/L)	64-82
Turbidity (NTU)	64.39-82.44

3.4 Performance assessment of the UASB combined with DHS treatment process

Table 4: Inlet and outlet wastewater sample laboratory test result.

Parameters	**Inlet**	**Outlet**		**ECR'97**			**Minimum Detection Limit (MDL)**
			Removal Efficiency (%)	**Inland surface water**	**Public sewerage system connected to treatment at 2nd stage**	**Irrigated Land**	
pH	6.0	7.3		6.0-9.0	6.0-9.0	6.0-9.0	0
Color (Pt-Co)	1365	110	91.94	-	-	-	0.01
Turbidity (NTU)	90.6	14.3	84.21	-	-	-	0.01
DO (mg/L)	0.1	4.11		4.5-8.0	4.5-8.0	4.5-8.0	0.1
BOD5(mg/L)	232	22.4	90.4	≤ 50 (at 20°C)	≤ 250 (at 20°C)	≤ 1000 (at 20°C)	0.2
COD(mg/L)	554	57	89.7	≤ 200	≤ 400	≤ 400	0.2
EC(µS/cm)	1570	1436		≤ 1200	≤ 1200	≤ 1200	0.1
TDS (mg/L)	1285	982		≤ 2100	≤ 2100	≤ 2100	5
TSS (mg/L)	85	18	78.8	≤ 150	≤ 500	≤ 200	5

3.5 Cost estimation of The ETP

Chemical Cost
Textile wastewater is highly alkaline. Acetic Acid is used to control pH. Acetic Acid is used 40 kg/ day. Acetic Acid costs 60 taka/kg.
Total cost = (40*30*60) taka/month
= 72,000 taka/month
Mechanical Cost
Wastewater enters UASB bioreactor from bottom and flows upward. To maintain the upward velocity of fluid from equalization tank to UASB reactor three 5.5 kw/hour pump is used. Three 2.2 kw/hour pump is used to flow the waste water from equalization tank to Feeding tank and 22 kw blower is used for aeration process.

Energy consumption=3*5.5*24+3*2.2*24+22*24
= 1082.4 kw/day

Table 5: Summary of different type of cost of the treatment process.

Table 5: Summary of cost

Type of cost	**Cost (taka/m^3)**	**Remark**
Chemical cost	1.66 tk/m^3	Acetic acid is used to control pH
Mechanical cost	0.75 kw/m^3	3, 5.5 kw/hr pump 3, 2.2 kw/hr pump 2, 22 kw blower
Operational cost	1 staff/shift	Three shift

4. CONCLUSIONS

Results indicate that COD, BOD_5, TSS and turbidity removal efficiency of the DHS combined with UASB reactor treatment process are 89%, 90%, 78% and 84%. 91 percent color removal is achieved from this treatment process without any addition of de-coloring agent. The effluent water quality of this treatment indicates a potentiality of reuse in the industry itself and irrigation purpose.

UASB reactor removal efficiency of COD, BOD and color in treating textile wastewater is 53-62, 36-62, and 40-73.33. UASB reactor and DHS reactor has no contribution in decreasing or increasing turbidity, TDS and EC.
DHS is generally an aerobic reactor without any external aeration system but our lab test shows that dissolved oxygen level of DHS is 0.19 mg/l and 0.09 mg/l which indicates that DHS is in anaerobic condition and this might be the reason why it has color removal (46-72) efficiency. DHS has high turbidity (64-82) and TSS (64-82) removal efficiency. DHS has less efficiency in removing COD (12-20), BOD (24-32) in case of textile wastewater compared to municipal wastewater. Unlike sand bed filtration medium DHS reactor doesn't require regular backwashing or other maintenance. Sponge medium is removed once in 5 year of operation of the ETP.

EC and TDS profile has tend to increase as the treatment process proceeds. The average temperature of the ETP 19^0C is which is good for UASB reactor. Performance of UASB usually decreases when temperature falls and during heavy rainfall. Methane could be detected from UASB reactor.

The whole treatment process has significantly less biomass yield. Sludge removal is required only once in 2 years of operation. The UASB combined with DHS treatment process has higher pollution load removal efficiency with less biomass yield and less chemical consumption.

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AIR QUALITY ASSESSMENT DURING OPERATION PHASE OF PADMA BRIDGE

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ABSTRACT

Air quality management is essential to ensure clean air. Padma Bridge will be the largest bridge in Bangladesh with enormous traffic volume which may decrease the surrounding air quality due to the air pollutants emission from motor vehicles. The air pollutants such as CO, NO_x, SO_2, VOC_s, PM_{10} emission from motor vehicles are estimated in this study considering the peak operation phase of Padma Bridge. Air quality modeling using HYSPLIT dispersion model is also performed for determining plume movement, air pollutants concentration and deposition having archived meteorological data. This study revealed that the plume of air pollutants during winter season will be mostly towards south-east and south-west direction covering the areas of Shreenagar, Shibchar, Mawa, kobutorkhola, Kawadi and Padma River. Air pollutants such as CO (3.1 ton/yr) and NOx (2.2 ton/yr) emission from motor vehicles were estimated. The maximum increasing concentration due to the motor vehicles emission for CO, NOx, VOCs, SO_2 and PM_{10} were calculated as 3.8 $\mu g/m^3$, 2.69 $\mu g/m^3$, 0.633 $\mu g/m^3$, 0.213 $\mu g/m^3$ and 0.192 $\mu g/m^3$, respectively. Air Quality Index value (196) indicates unhealthy condition for which general people in addition to the peoples having breathing difficulty can pose at risk due to the long term exposure of air pollutants.

Keywords: *Air quality, Air Pollutants, Dispersion model*

1. INTRODUCTION

Air is an obligatory element in the environment to all living being is vulnerable to degrade in quality affecting human health as well as environment. The Padma Bridge is a multipurpose road-rail bridge across the Padma River under construction in Bangladesh. The bridge will be used as a communication route and motor vehicles are one of the major sources of transportation. The number of vehicles on the Padma bridge will be significant and vehicular emission is also a concern. Air dispersion model can present how air pollutants can disperse in the ambient atmosphere. Models are important tools for air quality management. They are used to estimate the downwind concentration of air pollutants emitted from emission sources. As the motor vehicular emission is increasing the concentration of pollutants, it is necessary to report daily air quality by Air Quality Index (AQI) to determine the air quality to know how clean or unhealthy the air is. For these pollutants, EPA has established national air quality standards to protect public health.

Vehicular emission is one of the most dominating sources of air pollution. Globally vehicular emission from transportation sector is a major source of air pollution and threat to human health and environment. From light-duty, gasoline-powered vehicles, the most important pollutant emissions are volatile organic compounds (VOCs), carbon monoxide (CO), and oxides of nitrogen (NOx), whereas for heavy-duty, diesel vehicles, NOx and fine particulate matter ($PM_{2.5}$) are of the greatest concern. VOCs and NOx react in the presence of sunlight to form ozone and photochemical aerosols. For this understanding the air pollutants emission from vehicle is essential to ensure the clean and healthier air by reducing the air pollutant emission.

The study is aimed at to demonstrate the vehicular emission and its distribution with change the space and time to estimate the air pollutants (CO, SO_2, NO_x & PM_{10}), their concentration and deposition generating from motor vehicles, to perform air quality modeling for evaluating the plume of air pollutants and To determine the air quality index and compare with the standard value.

2. RESEARCH METHODS

The main bridge will be located over the Padma River in the north-south direction starting at Mawa in the Dhaka side under Lauhajang upazila and ending at Janjira in the other side of the River under Shariatpur district where the source location is selected as 90.259534 E, 23.42407 N. The forecasted annual average daily traffic was collected up to year 2044 (Rahman, 2016). Air pollutants emission from motor vehicle was estimated from this equation using emission factor.

$$E_c = \text{No. of vehicle} \times \text{Distance} \times \text{Emission Factor}. \quad (1)$$

HYSPLIT dispersion modeling using archived meteorology was developed and the concentration and dispersion of pollutants were simulated and compared with the air quality data to find out the contribution of vehicular emission to the ambient air quality (CASE,2016). The month of January 2016 was selected for the availability of air quality monitoring data of emission from vehicle on Padma Bridge and dispersion modeling was done in this period. This period was selected because of winter season having more stable wind speed with lower velocity than other seasons which can provide maximum pollutant concentration in addition to availability of air quality monitoring data. During this period wind mostly moves towards the south, south-west and south-east direction (ARL,2016)..

AQI index value for this study was calculated for ambient concentration of CO, NO_x, SO_2, VOC_s, PM_{10} to check the ambient air quality for these air pollutants from the vehicular emission in addition with background data (ADB, 2010).The index is derived from the following formula:

$$AQI = (\text{Pollutants data reading} / \text{Standard limit}) \times 100 \quad (2)$$

3. RESULTS AND DISCUSSION

3.1 Emission Estimation of Motor Vehicles

The amount of SO_2, NO_x, CO, VOC_s, PM_{10} compounds were calculated from vehicular emission of Padma Bridge using emission estimation technique. Table 1 provides the mass of pollutants released from vehicle due to emission. Emission results show that by the year of 2044 (Rahman, 2016) vehicles will emit around 3168.331 kg/yr of CO, 2240.049 kg/yr of NO_x 527.755kg/yr of VOC_s, 177.659kg/yr of SO_2, 159.987 kg/yr of PM_{10}. The emission of CO is more than NO_x & SO_2. The emission of high CO indicates that the incomplete combustion of fuel. (Alam, 2016). The emitted sulfur dioxide and nitrogen oxides contact with water vapor and form nitric acid and sulfuric acid which can affect human health, animal life and the environment (Alam, 2016).

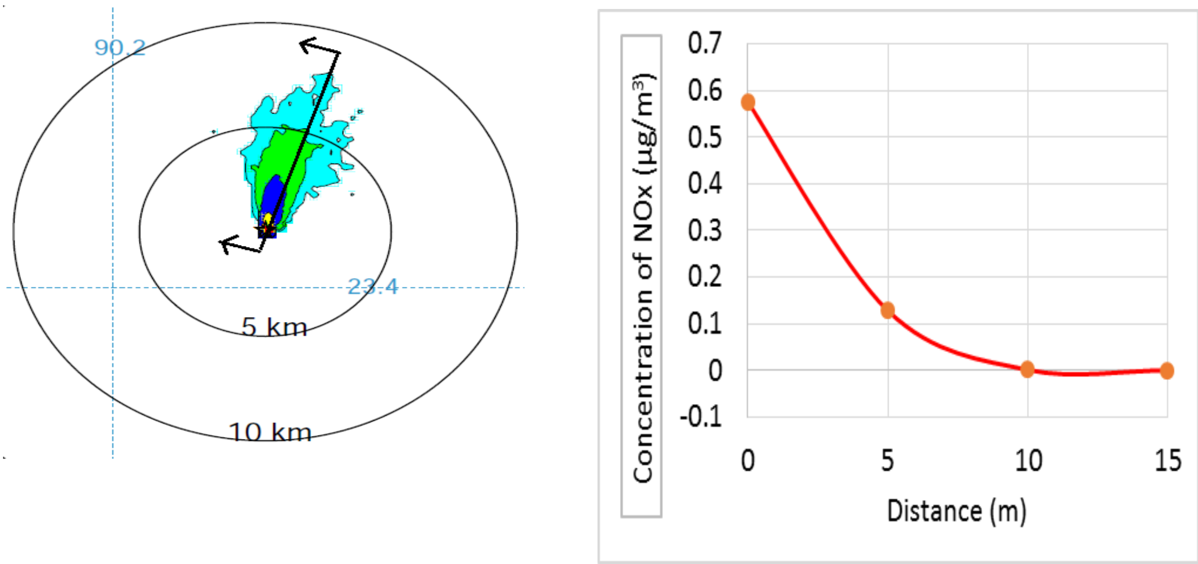
Table 1: Estimated Vehicular Emission

Compounds	Emission (Kg/yr)
CO	3168.3
NO_x	2240.0
VOC_s	527.8
SO_2	177.7
PM_{10}	160.0

3.2 Dispersion Modelling using HYSPLIT

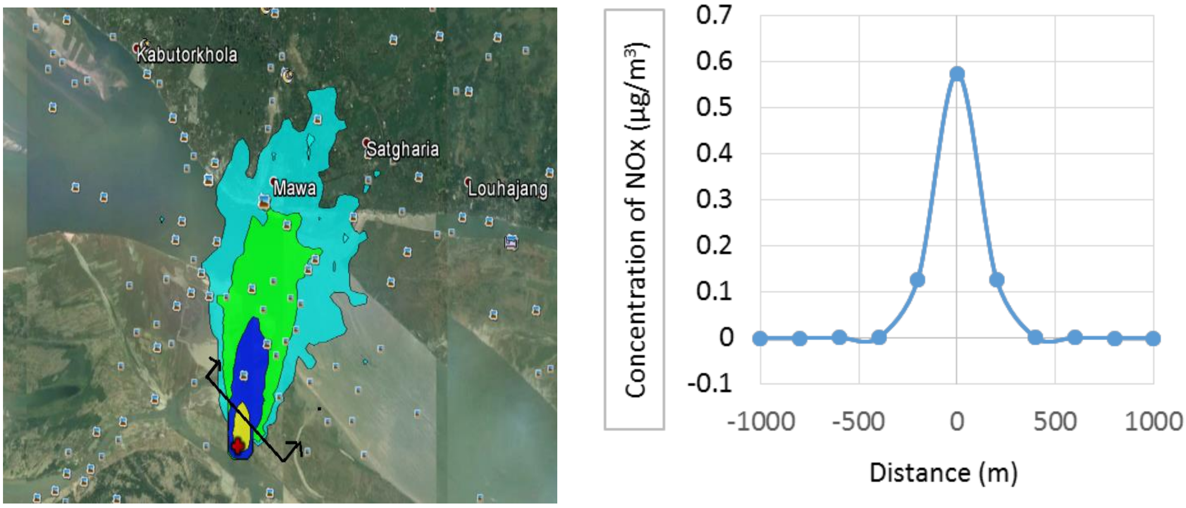
3.2.1 Validation of HYSPLIT Model

For the validation of HYSPLIT dispersion model with Gaussian plume distribution, graph was plotted by the value of pollutant concentrations with distance along the direction of plume distribution, a long section and a cross section transverse to long section of dispersion modeling.



(a) (b)

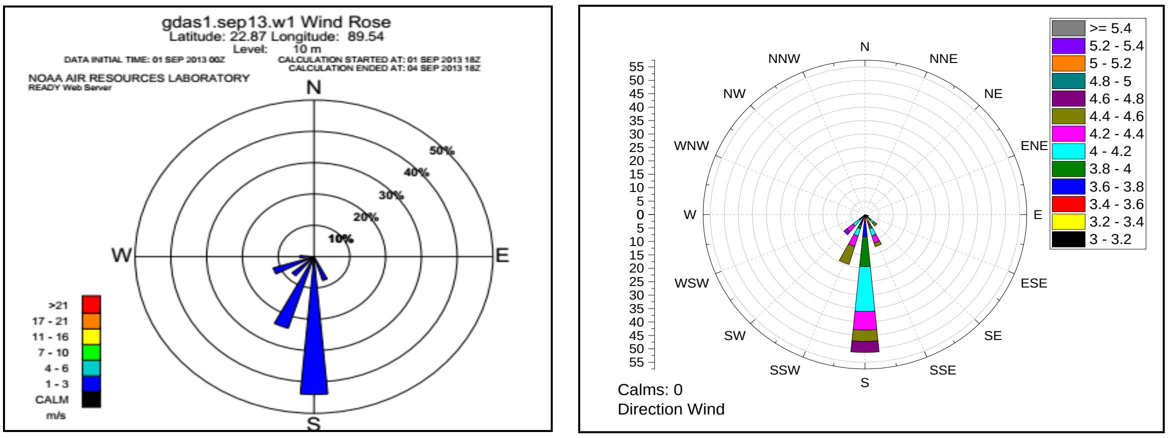
Figure 1: Spatial distribution of plume; (a) Typical dispersion map (b) Plume distribution along distance.



(a) (b)

Figure 2: Gaussian plume distribution; (a) Top view of pollutant dispersion, (b) Cross-section of plume distribution

Figure 1 and 2 showing the pollutant distribution after emission. From the graph, the concentration of NOx is decreasing continuously with the increment of distance. The mass of pollutants get dispersed along with the direction of wind movement. In the meantime, the pollutant mass get deposited on the earth surface. Thus, with the passage of time the covering area of dispersion increase and the pollution concentration decrease. From the HYSPLIT model result, both plume distribution results are similar to the Gaussian plume distributions. HYSPLIT windrose validation was checked with local windrose model on the same date 1st September, 2013 in figure 3 (Alam, 2017).



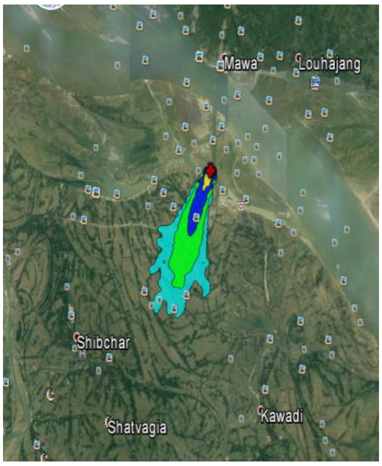
(a) (b)

Figure 3: Windrose for 1st September 2013 to 3rd September 2013; (a) generated by HYSPLIT, (b) windrose with regional air monitoring data

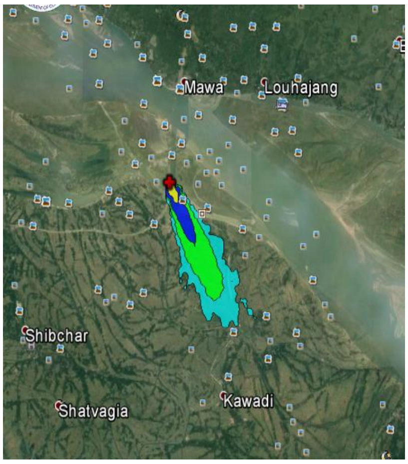
3.2.2 Concentration of Air Pollutants

The plume dispersion for every pollutants in HYSPLIT, is constant under the same meteorology and time as the model run under certain mathematical formula simulated in the model. The generated air pollutants from vehicles, the dispersion models are showing their path of dispersion after emission. The dispersion map in figure 1 showing the plume dispersion is concurrent with the meteorology that is wind speed and wind direction. In this approach, the plumes spread in between 15-20 Km from the source and the time of evolution of the area exposed above a particular concentration limit are considered. With the variation of time and distance, dispersion results from different simulations show variation in plume distribution pattern and concentration. Differences are seen in both plume movement and its aerial spread in each case. The plume travelled mostly in the direction of South-West and South-East direction. The highest concentration was near to the point of interest in all cases within 20 Km of radial distance.

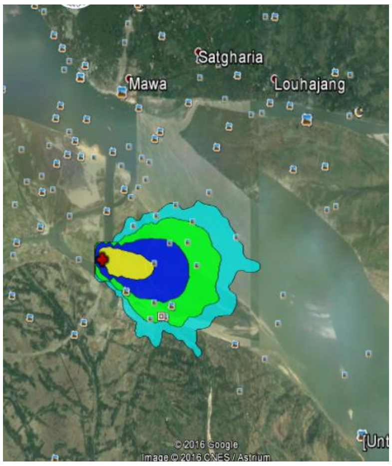
From the analysis of model results, it is seen that for 01 January, the plumes moved towards shibchar 0.958 µg/m^3 and the plume emission dispersed to a distance 10 Km. On January 02, the plumes move towards Kawadi and for 03 and 04 January, towards Padma River.



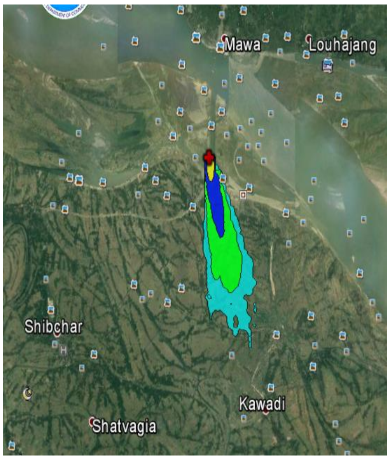
(a) 01 January



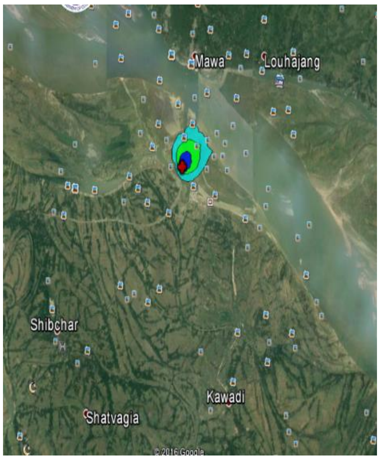
(b) 02 January



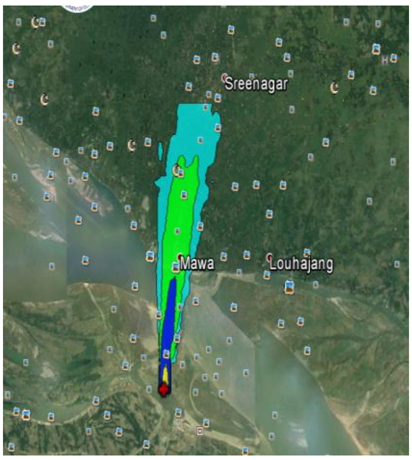
(c) 03 January



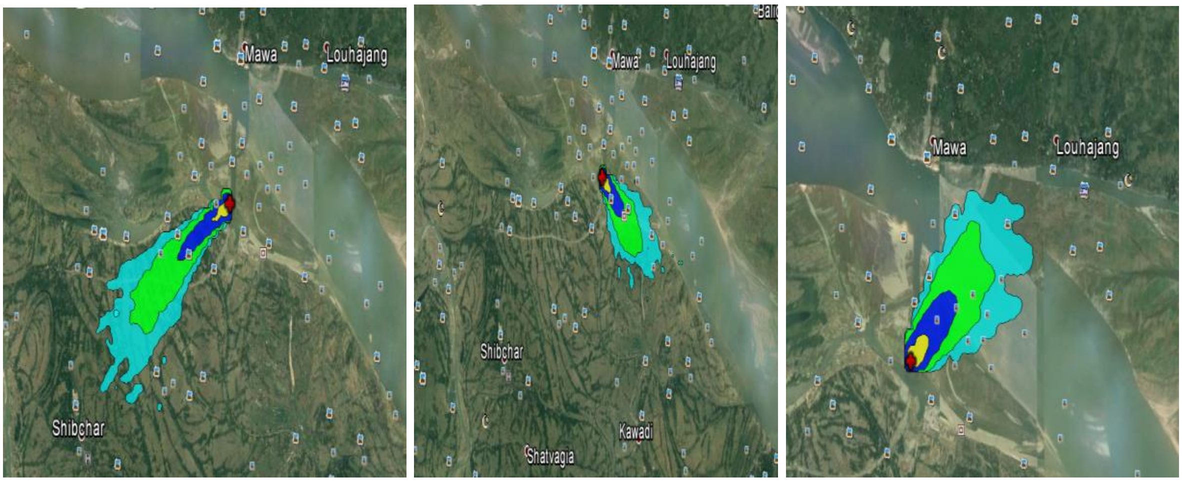
(d) 05 January



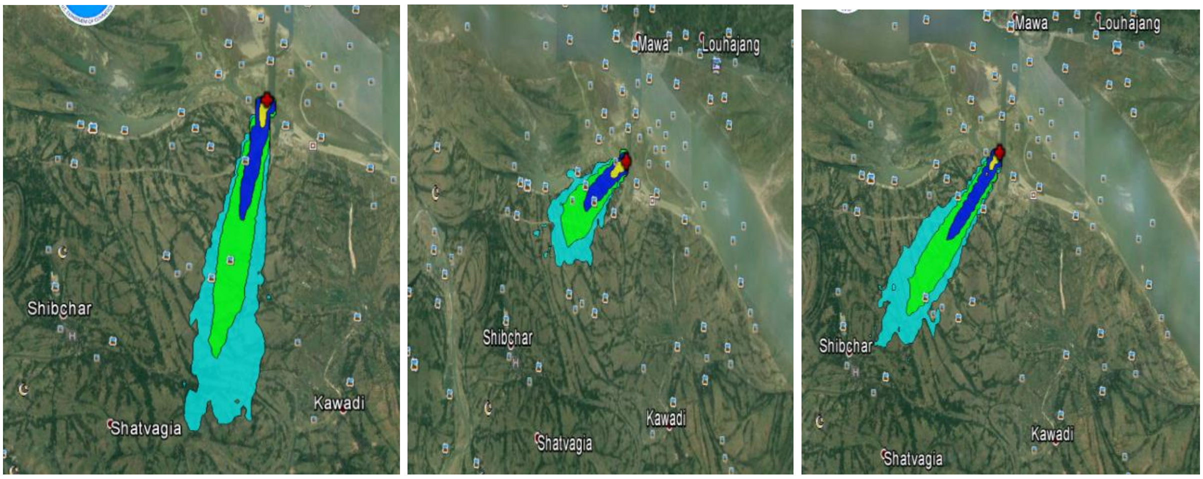
(e) 08 January



(f) 09 January



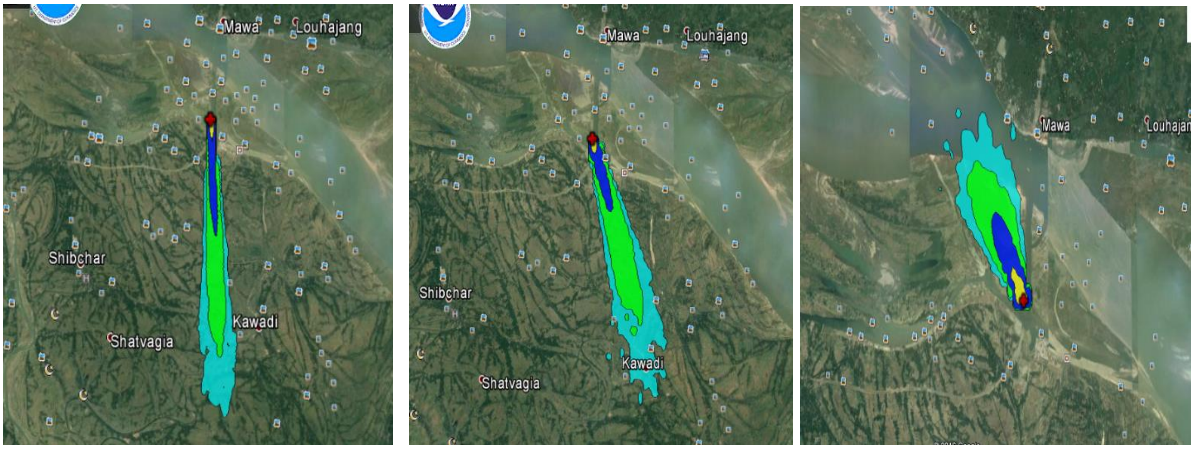
(g) 10 January (h) 12 January (i) 16 January



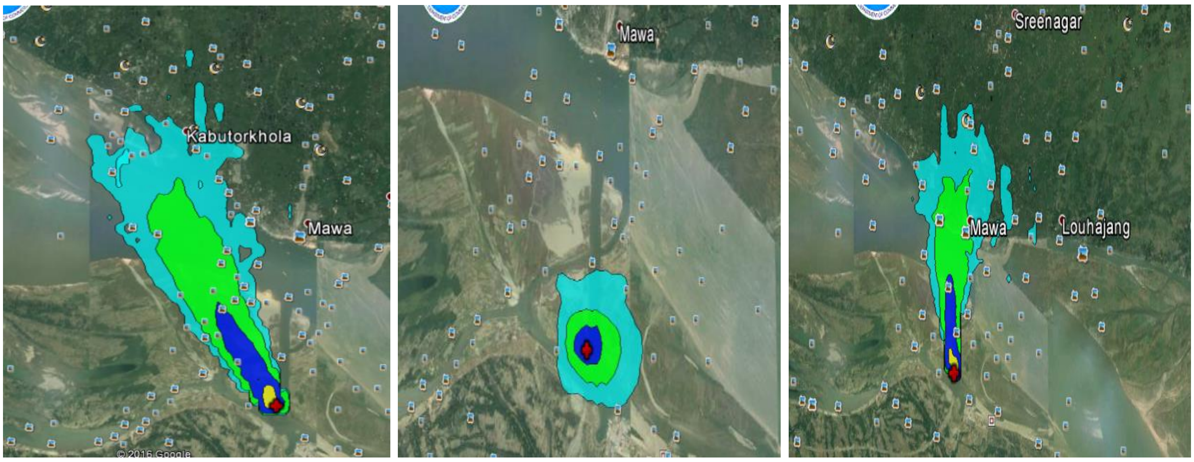
(e) 17 January (f) 19 January (g) 20 January

Figure 4: HYSPLIT generated air pollutants concentration NOx (µg/m^3) integrated for 1 hour period.

From January 05 to 07 the plume moved towards kawadi and for January 08, the concentration is maximum 2.69 µg/m^3. On january 09, the plume moved towards Sreenagar, 10 km away from the source with concentration 0.345 µg/m^3. 10 and 11 January plumes were in the direction of Shibchar. From 12-15 January plumes were towards the river bank, on 16 January on the river and 17 January was to the Shatvagia with maximum concentration of 0.908 µg/m^3. 19-20 January plumes were towards shibchar 0.832 µg/m^3.



(a) 21 January (b) 23 January (c) 27 January



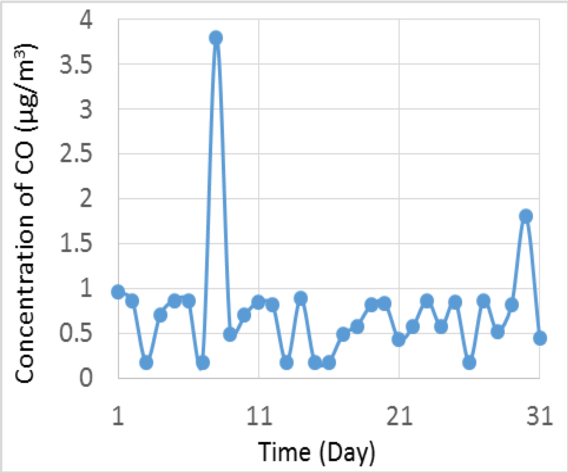
(d) 28 January (e) 30 January (f) 31 January

Figure 5: HYSPLIT generated air pollutants concentration NOx (µg/m^3) integrated for 1 hour period.

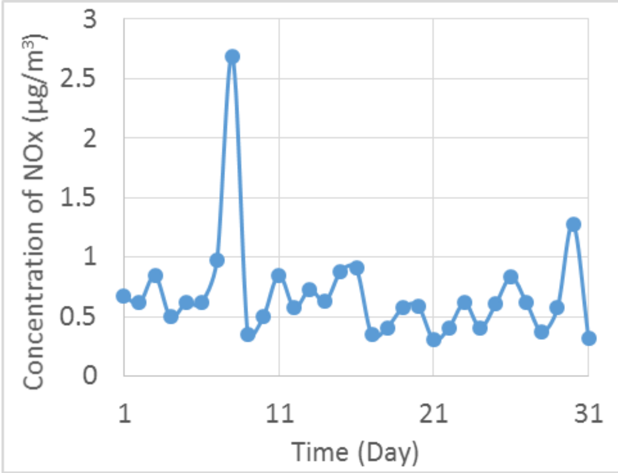
January 21 and 22 showing the plume crossing in between Kawadi and Shatvagia with maximum concentraion 0.868 µg/m^3 with the range 20 km from the point of interest. For 23 to 26 January plumes are moving towards Kawadi. January 27 and January 28 showing that air pollutants are to the river and Kobutorkhola. January 30 having a concentration of 1.81 µg/m^3. For January 31, the concentration is 0.32 µg/m^3 towards Mawa, in the range between 10 km from the source.

3.2.3 Temporal Variation of Concentration

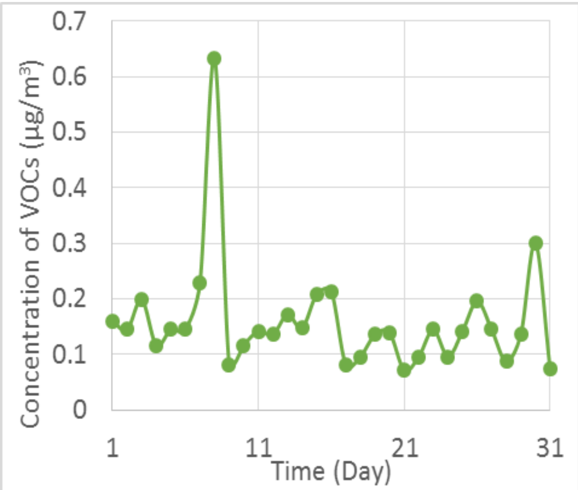
The variation of concentration of the air pollutants with time was obtained by concentration vs time curve by plotting the 31 days concentration of January 2016.



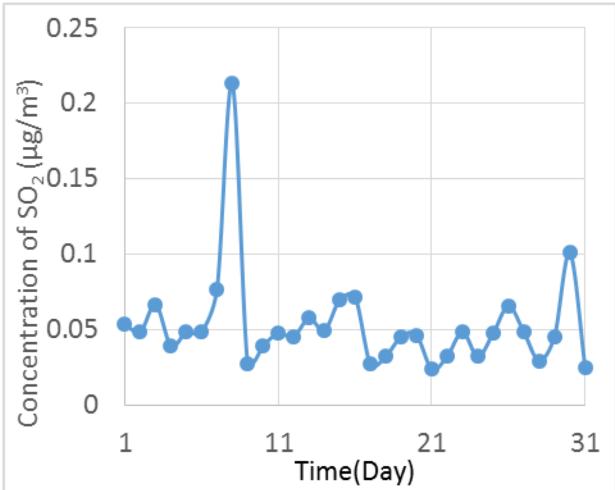
(a)



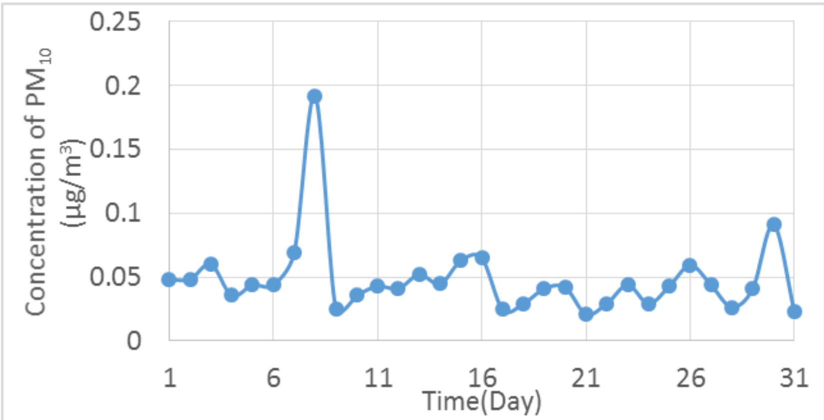
(b)



(c)



(d)



(e)

Figure 6: Variation of concentration with time (a) CO (b) NOx (c) VOCs (d) SO_2 (e) PM_{10}

The concentration of CO largely varied in between 0.5 µg/m^3 to 1 µg/m^3 showed in Figure 6 (a). The maximum concentration was found 3.8 µg/m^3 on 8th January, 2016 and the minimum concentration was 0.434 µg/m^3 on 17th and 21st January. The variation of NOx concentration from Figure 6 (b) are from 0.5 µg/m^3 to 1 µg/m^3. On 8th January maximum concentration of that month is 2.69 µg/m^3 and minimum is 0.345 µg/m^3 on 17th and 21st January.

From figure 6 (c), the VOCs concentration changes in between 0.1 µg/m^3 to 0.2 µg/m^3. On January 8 the maximum concentration of VOCs is found 0.633 µg/m^3 and minimum on 17th and 21st January was 0.00813 µg/m^3. In Figure 6 (c) and (d), the maximum concentration of SO_2 and PM_{10} were found 0.213 µg/m^3 and 0.192 µg/m^3 respectively on January 8. Minimum concentrations for SO_2 and PM_{10} were 0.00274 µg/m^3 and 0.00246 µg/m^3 respectively.

3.3 Air Quality Index

Air Quality Index (AQI) provides the understanding of air pollution level at which air can be polluted and the associated health effects that might concern. Background data of criteria air pollutants were obtained from Padma Bridge EIA report (EIA, 2010) was used to calculate the AQI values of CO, NOx, SO_2, and PM_{10} The maximum concentration of PM_{10} was fall in unhealthy condition For NOx, SO_2, CO the AQI values were obtained as good category.

Table 2: Air Quality Index

Air pollutants	Concentration µg/m^3	AQI Index value	Category	Color	Cautionary Statement
PM_{10}	294.1915	196	Unhealthy	Orange	General public at risk; sensitive groups at greater risk
SO_2	54.913	15	Good	Green	Little potential to affect public health
NO_x	26.785	26	Good	Green	Little potential to affect public health
CO	3.789	9.5	Good	Green	Little potential to affect public health

4. CONCLUSIONS

The forecast of estimated emission from the release of pollutants from motor vehicle by the year 2044 when the vehicles will be maximum, was found for CO 3168 kg/yr, NOx 2240 kg/yr, VOCs 527.7 kg/yr, SO_2 177.7 kg/yr, PM_{10} 160 kg/yr. CO and NOx was found higher in amount than the other pollutants. Air dispersion modeling showed that the plumes were heading dominatingly towards South-East and South-West direction and dispersion was within 20 km from the source of interest. The concentration of the pollutants was found maximum on the bridge road. The maximum concentrations for CO, NOx, VOCs, SO2, PM_{10} were found 3.8 µg/m^3, 2.69 µg/m^3, 0.633 µg/m^3, 0.213 µg/m^3 and 0.192 µg/m^3 respectively and the minimum concentrations were 0.434 µg/m^3, 0.345 µg/m^3, 0.00813 µg/m^3, 0.00274 µg/m^3 and 0.00246 µg/m^3 respectively. The Air Quality Index was evaluated for the estimated emission from vehicle in addition with the background data obtained from Padma Bridge EIA report. AQI found unhealthy due to PM_{10} concentration.

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DETERMINATION OF NOISE LEVEL AT RAJSHAHI MEDICAL COLLEGE HOSPITAL AND NEARBY ROAD

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ABSTRACT

Noise pollution's adverse effect on human is undeniable and it is particularly detrimental for patients in hospitals as it averts their healing process. Since public hospitals in Bangladesh are exposed to a noticeable sound pollution, this study seeks to reveal the intensity of internal noise and impact of nearby roads noise of Rajshahi Medical College Hospital. In this study, noise level was measured in 11 different types of wards and their nearby roads during 2 work-days and 1 holiday from 8am to 8pm at a 30 minute interval by a digital sound level meter. By analyzing the data for both maximum and minimum noise levels, the average noise level yielded nearly double of allowable limit (WHO standard: 45 dB). The maximum noise levels measured in Child, Medicine, Nephrology, Cardiology, Neurosurgery, Orthopedic, Neuromedicine, Surgery, Gynecology, Burn unit, and Post-operative ward were of 81.3 dB, 82.3 dB, 77.5 dB, 79.3 dB, 80.5 dB, 81.2 dB, 74.8 dB, 78.4 dB, 79.4 dB, 78.3 dB, 75.7 dB, respectively. Even the ICU's maximum average noise level was found to be of 74.2 dB, which is far above the WHO standard (35 dB). It was observed that rather than noise from nearby roads, the noise pollution was occurring mainly due to an excess of patients, screaming, instrumental alarm, meal-time noise, moving trolleys etc. The study suggested that the facilities should be vigilant about enforcing rules regarding patient capacities and building codes, and adopt building designs that favors patients' privacy and reduce noise levels. Furthermore, attendants and visitors should exercise more self-restraint.

Keywords: *Noise level, pollution, hospital, indoor, WHO standard*

1. INTRODUCTION

For the time being after air and water pollution noise is figured out as the third most hazardous pollution of big cities according to World Health Organization (WHO) statement. Noise can be described as an intolerable amount of sound which has a detrimental effect on environment. Kryter (1985) defines noise as "an audible acoustic energy that adversely affects the physiological or psychological wellbeing of people". The general meaning of 'NOISE' is an over loud or disturbing sound, which breaks the calmness of the atmosphere (Shahid and Bashir, 2013). When the level increases to an irritable level, it can be considered as "noise pollution" in the atmosphere (Philimoni, et al., 2011; Stanchina and Hijlem, 2005; Crmiel, et al., 2004). At present the environment has reached suchlike a position that it is hard to overlook sound pollution problem. Some places where people are exposed to a lot of sound pollution problems are industries, hospitals, roads, educational institutions, recreational areas and so on. By and large, lack of urban planning increases the exposure to unwanted sounds. This is why understanding noise pollution is necessary to curb it in time.

It is reported that the hearing ability of the inhabitants of the City has reduced during the last ten years (Ahmed, 1998). About five to seven percent of the patients admitted to the Bangabandhu Seikh Mujibur Rahman Medical University, Dhaka are suffering from permanent deafness due to noise pollution (Ahmed, 1998). Many studies have revealed that extended exposure to noise pollution may cause auditory and non-auditory disorders, such as temporary or permanent hearing loss, sleep disruption, vertigo, agitation, weariness, hypertension, gastrointestinal system problems including gastric and duodenal ulcer, cardiac arrhythmia, nervous, myocardial infarction and ischemic heart diseases and psychic disorders and so on (Bond and Michael, 1994; Pathak, et al., 2008; Belojevic, et al., 2008; Babisch, 2000, 2006; Babisch, et al., 2005; Lundberg, 1999; Griefahn, 1990; Clark and Stansfeld, 2007).

The patient in hospitals receives far more bad impact by noise as it slower the healing process. Nightingale (1860) acknowledged noise as a health risk when she wrote "Unnecessary noise is the most cruel abuse of care which can be inflicted on either the sick or the well". According to the study of Researchers from the University of Chicago's Pritzker School of Medicine, 42% of patients reported being woken up by noise and many reported sleeping significantly less than normal while in the hospital. Patients exposed to the loudest average nighttime noises slept an average of 76 minutes less than patients exposed to the quietest noises. Some of world renowned organizations which have been working on noise level of hospitals for a long time are WHO, American National Standards Institute (ANSI) and United States Environmental Protection Agency (US EPA). They have fixed certain standard which a hospital should not exceed. The WHO's standard is 40 dB(A) whereas the ANSI's standard is 25-43 dB(A) depending on type of room again the US EPA's standard is 45 dB(A). But it is a matter of fact that almost all the hospitals in the world specially that of the Indian subcontinent fail to maintained those standard level.

Rajshahi Medical College Hospital (RMCH) is the only tertiary level hospital in this area, situated in the heart of Rajshahi city. The hospital receives a large number of patients from areas including whole Rajshahi division and the northern part of Khulna Division. This institute started its journey in 1958 with only 550 beds but now is able to accommodate around 1700 patients on a daily basis. Nowadays owing to population growth the numbers of patients are also increasing which creates a heavy pressure on this hospital. As a consequence, like other unmanageable situations, crowd, screaming, shouting are increasing day by day that hampers proper treatment environment in the hospitals. Therefore, the aim of this study is to ascertain the present condition of noise level and its causes in RMCH and to alert the hospital authority to take essential steps as well as people in general to be careful which will help to create a proper environment for the patient.

2. METHODOLOGY

2.1 Site Selection

The indoor noise level measurement was done in different wards of RMCH to ascertain the scenario of noise pollution. The wards were selected in such a way that all important wards were accounted for in measuring sensitivity, type of treatment, types of patients, number of patients, age of patients, surroundings, etc. So, the selected 11 wards were the Children, Medicine, Nephrology, Cardiology, Neurosurgery, Orthopedic, Neuromedicine, Surgery, Gynecology, Burn, and Post-operative wards. Furthermore, the ICU's noise level was determined as it is the most sensitive zone. Moreover, Noise of the frontal road was also measured to compare the indoor and outdoor noise level.

2.2 Operational Procedure

A portable digital sound level meter was used to measure the sound level at maximum and minimum levels. The sound pressure is detected in decibels (dB) in this instrument with expansive measuring limit from 30 dB(A) to 130 dB(A) having exactitude level of ±1.5dB. The measurement was performed at the middle of each ward at a 30 minuets interval from 8:00 am to 8:00 pm during two working days and one holiday. To measure the sound level, holding the digital sound level meter in hand 'ON' button of it was pressed and it started. The maximum sound level was locked by pressing 'MAX' button which would be replaced when the higher value appeared. Within the time span the minimum value was also recorded and that time the sound level meter was not locked.

The overall situation of the wards was observed and perceptions of patients and doctors were noted. The noise level of nearby road was also measured during those periods. The collected data was analyzed for average of maximum and minimum noise level with their standard deviations.

3. RESULTS AND DISCUSSION

The average values of maximum and minimum noise level in decibel (dB) for three days from 8:00 am to 8:00 pm were determined for 12 wards of Rajshahi Medical College and Hospital. The average of average maximum noise of different wards varies from 71.68 dB to 75.41 dB. The results are graphically represented in Figure 1 and 2:

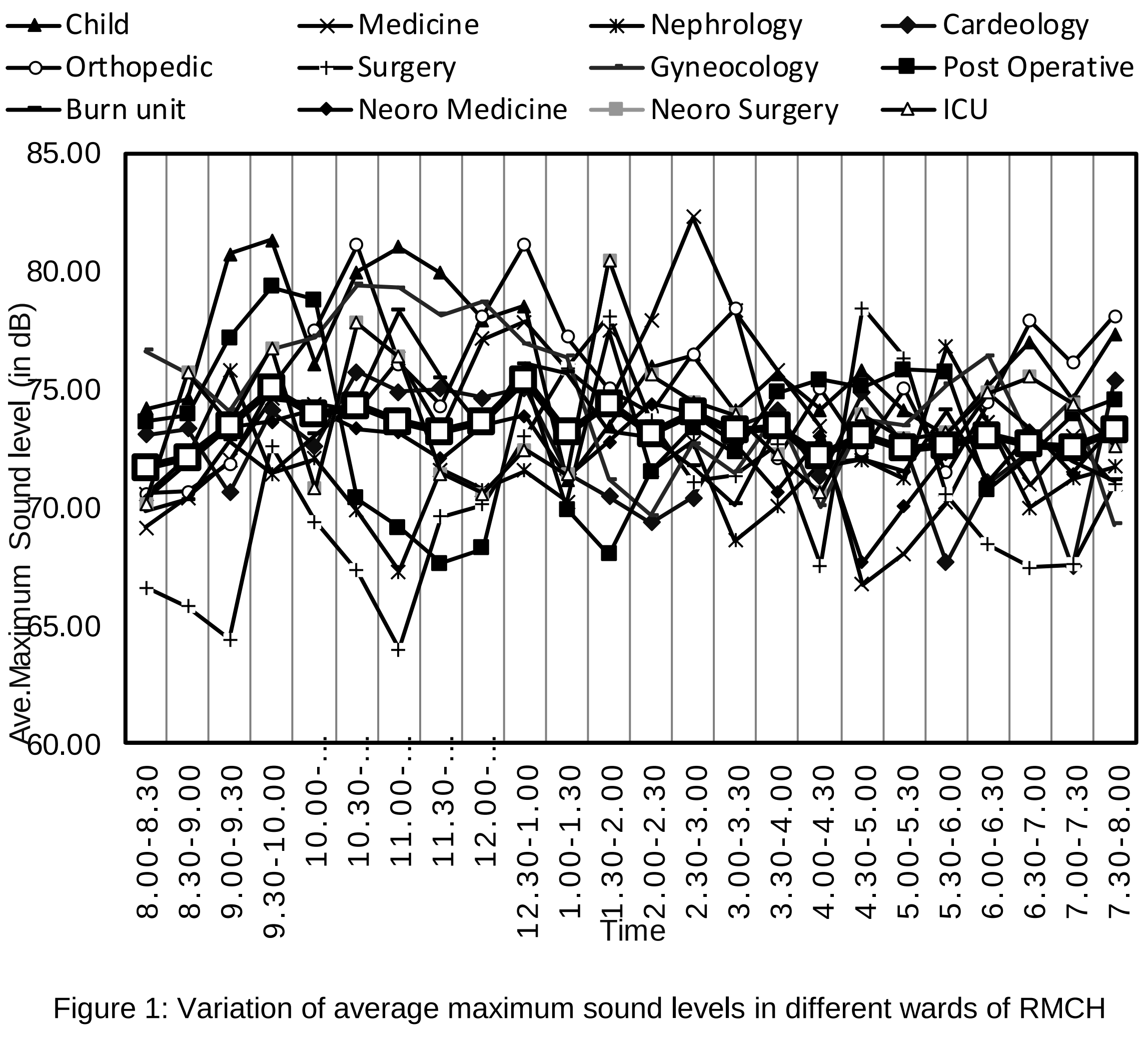

Figure 1: Variation of average maximum sound levels in different wards of RMCH

Child Care Unit (Ward No. 24) was full of child patients of different ages. Hence, the sounds of children crying and screaming resulted in a relatively high noise level at this ward at most of the times. Figure 1 shows that the maximum noise level in this ward is 81.3 dB whereas the minimum is 60.4 dB (Figure 2). The maximum noise level is usually seen at 9.30 a.m.to 10.30 a.m. in the morning.

In Medicine ward (Ward No. 17), the patients were generally quiet but the large gathering of visitors produced significant noise pollution. The following figure (figure 2) shows that the ward has a maximum noise level of 82.3 dB between 2.30 p.m. to 3.00 p.m. and its minimum noise level is about 60.3 dB.

Almost all the beds in Nephrology ward (Ward No. 21) were full of patients. The maximum and minimum noise level was 77.5 dB and 62.4 dB respectively in this ward. The maximum noise was found to be between 1.30 p.m. to 2.00 p.m.

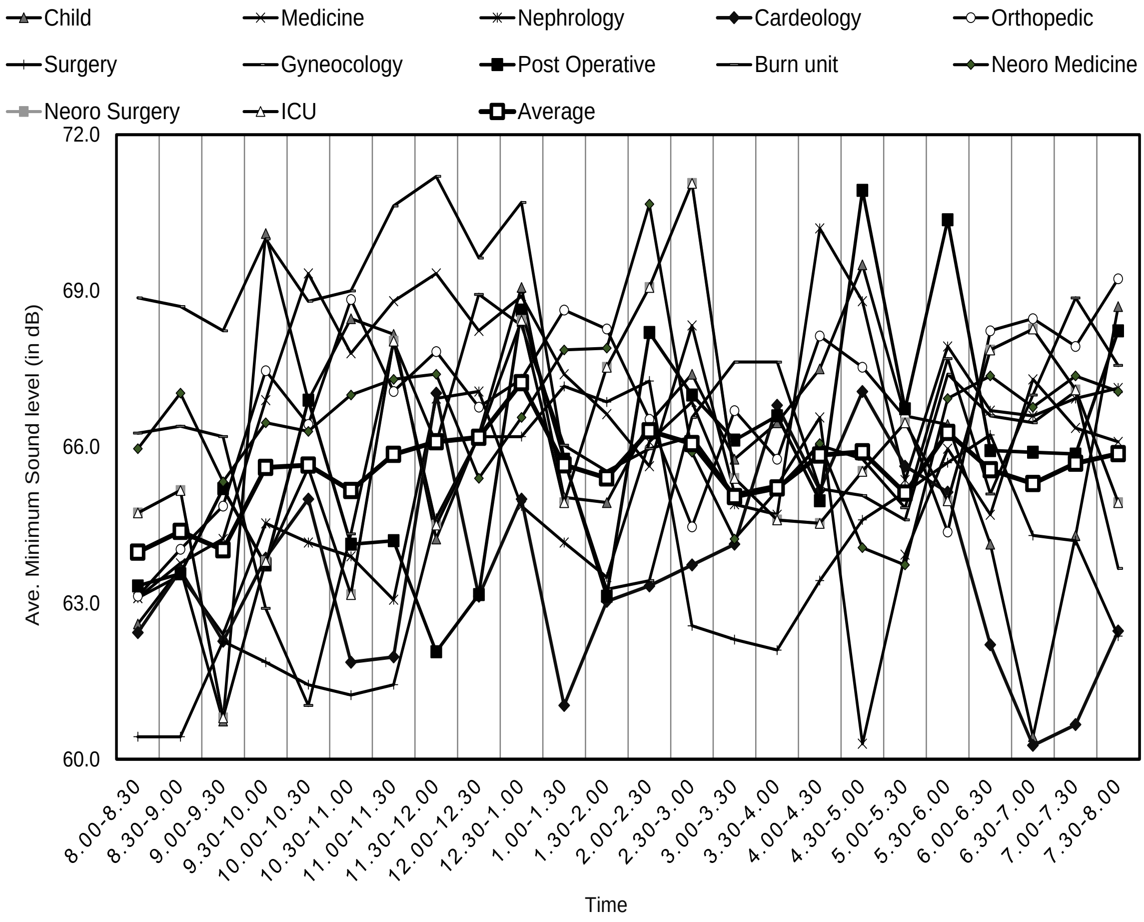

Figure 2: Variation of average minimum sound levels in different wards of RMCH

Since the Cardiology ward (Ward No. 7) serves patients of heart disorders, it is quite a sensitive unit. Despite that, the average maximum noise level was measured to be of 79.3 dB (in the morning at 10.00 to 10.30 a.m.). Furthermore, the minimum was 62.1 dB.

The Orthopedic ward (Ward No. 1) serves for the patients having bone fractures and related injuries face significant sound levels during doctor's visiting hours. From figure it is observed that the maximum noise level in this ward is 81.2 dB, occurring between 10.30 to11.00 a.m. in the morning, the average minimum noise level being 63.1 dB.

In Surgery ward (Ward No. 6), many patients were howling and screaming due to surgical pain. The average maximum noise level in this ward is found to be of 78.4 dB and the average minimum noise level is 60.4 dB. The maximum noise level was at the afternoon between 4.30 to 5.00 p.m.

In Gynecology ward (Ward No. 22), the average maximum noise level is measured to be of 79.4 dB during the morning (11.00 to 11.30 a.m.) whereas the minimum noise level was 63.3 dB.

Mourning of visitors and screaming of patients due to pain after operation were common observations in Post-operative rooms. The average maximum noise level at this ward was recorded at 75.7 dB at evening between 7.30-8.00 p.m. and the minimum noise level was 60.2 dB.

The maximum and minimum noise level in the Burn Unit's (Ward No. 29) is 78.3 dB and 61.0 dB respectively, where the maximum noise level was observed during 11:00 to 11:30 a.m. interval.

In the Neuromedicine ward (Ward No. 7), gathering of people (including patients, visitors) was high due to its large room size. Figures show that the maximum noise level was 74.8 dB (between 9.00 to 9.30 a.m. in the morning), whereas the minimum was 63.7 dB.

The Neurosurgery ward had many patients who were admitted due to accidents and many of their visitors were lamenting profusely. So the noise level can be significantly high in this ward. The Figure 1 and 2 represent that the average maximum noise level in this ward is observed to be of 80.5 dB at the noon during 1.30 to 2.00 p.m. The minimum noise level in this ward does not go below 60.8 dB.

ICU is a special department of this hospital with 10 beds which provides intensive treatment to patients in critical health conditions. All the beds were attached with several instruments which were creating alarm sounds quite frequently. In figure it is observed that the maximum and minimum noise level in this unit is 74.2 dB and 61.6 dB respectively.

The World Health Organization recommends that average patient room noise levels remain around 30 decibels. According to Medscape Medical News, the recommended maximum noise level is 40 decibels. However, from Figure 1 and 2, it is clear that the noise levels in every ward both for maximum and minimum noise levels are far above the standard limit. For ICU, the WHO's guideline is 30 dB for maximum noise level and any ICU should not cross this limit. But the ICU in this hospital fails to maintain this standard for both maximum and minimum noise levels.

It was observed that the noise was mainly due to the admission of patients beyond capacity, conversations and gossiping between personnel, particularly attendants, care givers, staffs and nurses. Furthermore, screaming of patients (especially the children), doctor's discussions with the patients, moving of trolleys containing wastes, medicines and foods, instrumental alarms, lamenting of the relatives in the event of a patient's death, mobile phones, crowding of people during meal time, classes for interns within the wards, old electric devices such as old fans contribute to the high level of sounds in RMCH.

After consulting with the doctors at the wards, it was known that the noise level has been imparting several negative impacts on the patients' health. It impedes their healing process, seesaws heart rate and blood pressure; causes sleep disturbance as well as prolonging their stay time in the hospital. Besides the doctors, nurses and all other staffs are physically and psychologically disturbed and exhausted due to this extreme level of noise.

On the other hand, noise levels at the frontal road of RMCH was also measures in same way and the variations of noise levels in maximum and minimum are presented in Figure 3. From the figure it is observed that noise level is lower at the morning time and it is gradually increasing as day grows up. At 10:30 am the noise level exceeds 90 dB and reached to the highest at above 100 dB during 3:00 to 3:30 pm and similar observation was also mentioned by Bari, et al., (2017).

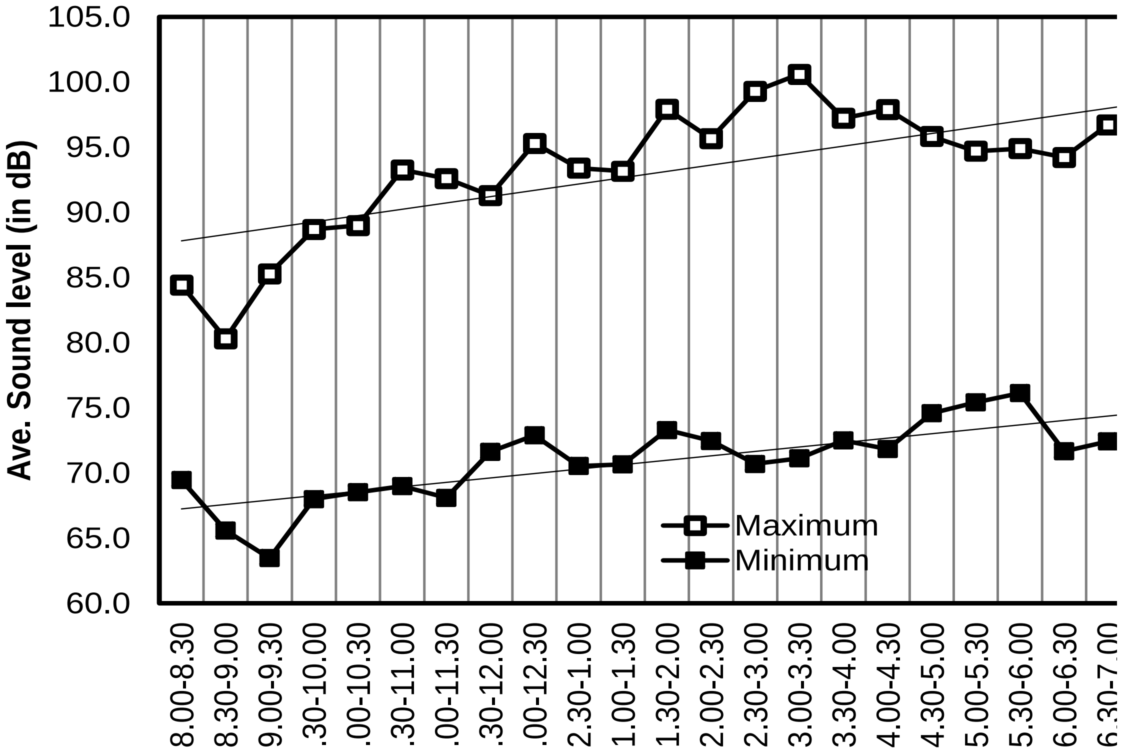

Figure 3: Variation of average maximum and minimum sound at frontal road of RMCH

Furthermore, the average minimum noise level of the nearby road during the same periods was observed that the trend of increasing of noise level is following almost same nature. The average minimum noise level is varying between 65 to 75 dB at the nearby road. However, sound from road side was not found inside the hospital wads at any time. Although, the maximum allowable noise level around the hospital is 60 dB while the average minimum noise level is also exceeds that limit.

This pollution can mitigate by two ways: one is by modifying the infrastructure by maintaining proper building code and the other is by adopting proper management by employing a standard code of conduct for doctors, caregivers, patients and visitors. Some of these changes could be expanding the hospital to reduce gathering of people, creating awareness among the visitors, ensuring attendants stay calm, replacing the alarm system of the instruments by visual light or permitting alarms only for critical readings, replacing the old electric devices (such as fans) with new ones, creating a habit of keeping mobile phones in silent modes within hospital grounds, training the nurses and other staffs perform their duties and keep away from gossiping and vain talk, increasing the number of beds to stop quarrelling of the patient's attendants for bed, and create a more systematic method of distributing food. Moreover, the authority and administrative department of the hospital should introduce some rules to reduce noise level and provide proper monitoring about maintaining the rules as well as punishment for breaking them.

4. CONCLUSIONS

From the above discussion, it can be inferred that the whole hospital environment is exposed to an intolerable amount of sound pollution that does not originate from the nearby road's noise. The adverse effect of this phenomenon on the patients, doctors, nurses and other people visiting to the hospital is undeniable. It is high time that the hospital's authority of RMCH should consider the excessive noise level as a serious health hazard and should take necessary steps to reduce it.

ACKNOWLEDGEMENTS

The authors thank to the Dr. Mostofa Kamal, ICU consultant, RMCH for giving permission and necessary help to take the reading of ICU. The authors also thank all the doctors, nurses, staffs and patients of RMCH for their co-operation.

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SCENARIO OF BANGSHI RIVER WATER OF SAVAR POURASHAVA AND PLANNING FOR A SUSTAINABLE MANAGEMENT

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ABSTRACT

A study was carried out on the Bangshi river near Savar Pourashava in Dhaka. The study was aimed to determine the present condition of surface water source, seasonal variation of water pollution and to find out the causes and mitigation measures for pollution. A Total of 7 samples were collected in each season September 2016 and January 2017 from Bangshi river and Karnapara canal connected with the river. Major physical parameters to evaluate water quality were pH, Dissolve Oxygen (DO), Biochemical Oxygen Demand (BOD), Total Dissolve Solids (TDS), Faecal Coliform, Turbidity, concentration of PO_4, NO_3-N and NH_4-N. 'River Pollution Index' by EPA and 'National Sanitation Foundation Water Quality Index' were also used to evaluate the water quality. Highest value of turbidity, total solid and BOD_5 of the river water were found to be 223 NTU, 691 mg/L and 2.72 mg/L respectively, lowest DO was 3.18 mg/L, highest concentration of NH_4-N, PO_4 and NO_3-N were 2 mg/L, 2.54 mg/L and 1.9 mg/L, respectively. The 'River Pollution Index' was found 'Moderately polluted' during dry season where in the rainy season it was 'Slightly polluted'. Similarly NSF-WQI showed that the water quality was 'Medium' and 'Bad' in September 2016 and January 2017, respectively. The main causes found for the pollution were untreated industrial waste, solid waste and untreated sewerage. Establishing effluent treatment plant (ETP) for every industry, sewage water treatment, proper solid waste management and strict law enforcement by Municipality authority can overcome the problem of pollution of Bangshi river.

Keywords: *River Pollution Index, Savar Pourashava, Seasonal variation, Water management*

1. INTRODUCTION

Everything originated in the water, and everything is sustained by water. All life on earth depends on water (Gupta, 2007). Water is the primary source of life on earth. Two third of the earth's surface is covered with water and the rest is land (Fry, 2005). But today pollution of water sources around the world has become a major problem. The environment is heading towards a potential risk due to unsafe disposal of industrial and domestic waste water. Water pollution affects drinking water, rivers, lakes and oceans all over the world. In many developing countries, it is usually a leading cause of death, by people drinking from polluted water sources. Polluted drinking waters are a problem for about half of the world's population. Each year there are about 250 million cases of water-based diseases, resulting in roughly 5 to 10 million deaths (Expedition, 2014). More than 80% of sewage in developing countries is discharged untreated, polluting rivers, lakes and coastal areas. Many industries – some of them known to be heavily polluting (such as leather and chemicals) – are moving from high-income countries to emerging market economies. Although rural populations in Asia are projected to remain stable over the next 20 years, urban populations are likely to increase by 60% before 2025, which affect prospects for water scarcity (Fry, 2005). Water pollution by different chemicals and toxic metals is a worldwide issue. All countries have been affected, though the area and severity of pollution vary enormously. In Western Europe, 1400000 sites were affected by different chemicals agents and heavy metals (McGrath, 2001), of which, over 300000 were contaminated, and the estimated total number in Europe could be much larger, as pollution problems increasingly occurred in Central and Eastern European countries (Gade, 2000). Water pollution is also severe in India, Pakistan and Bangladesh, where small industrial units are pouring their untreated effluents in the surface drains, which spread over near agricultural fields. In recent time, the environment has become hostile, posing threat to health and welfare due to release of pollutants from industries and urban sewage (Ntengwe, 2006). In Bangladesh, there is a progressive increase in industrial wastes and due to the rapid industrialization such waste products have been causing severe contamination to the air, water and soils, thus polluting the environment. Rivers surrounding Dhaka city are mostly affected by pollution. Several studies have been done about the Buriganga, Turag, Dholeshwari, Shitalakhya, Balu and Bangshi river. These rivers are in the most affected area. Surface water of Bangladesh is polluted in various ways. The important sources of surface water pollution are industrial wastes, agricultural inputs including fertilizers and pesticides, sewage slugs and domestic wastes etc. (Dara, 2006). Polluted water cannot be used for drinking, domestic and agricultural purposes because it has inherent health risk (Goel, 2006). Savar is known as a rapid growing industrial city near Dhaka. Most of the garment factories of the country are situated here. Besides countries largest tannery processing zone has also recently been transferred to Savar. These industries are generating a large amount of waste water every day. The dumping source of the waste water is mainly the nearby rivers. So this is contributing to the pollution of the river water. The study is aimed to determine the water quality parameters and compare these parameters with standard ones to evaluate the pollution status of Bangshi river. Seasonal variations of the parameters are also observed. The final objective is to find out the possible sources of pollution and to propose for mitigation measures to improve the present condition.

2. METHODOLOGY

Different locations of the Bangshi river were visited to observe the pollution scenario and to find out the sources of pollution. Pictorial views of pollution scenario were collected from different disposal point, sewage point and industrial area which were adjacent to the Bangshi river to find out the causes and sources of pollution of the river water and observe the present pollution scenario of the river. The water samples were collected in two seasons. First time samples were collected in September 2016 after the monsoon. Second time samples were collected from the same place in January 2017 during winter season. Sampling location has been selected from this initial survey with the help of GPS shown in Table 1.

Table 1: GPS location of the sampling points

Sampling points	**Latitude**	**Longitude**	**Locations**
Point 1	23°48'9"N	90°14'45"E	Rajfulbaria
Point 2	23°49'5"N	90°15'28"E	Bank Town
Point 3	23°49'14"N	90°14'56"E	Bank Town
Point 4	23°49'46"N	90°14'52"E	Ulail
Point 5	23°50'17"N	90°14'40"E	Genda
Point 6	23°50'48"N	90°14'30"E	Monughat
Point 7	23°51'50"N	90°14'15"E	Savar Nama Bazar

The depth of the sampling was fixed at 1 ft for avoiding the surface interference. The water samples were collected from 7 different points along the Bangshi river and Karnapara canal at a regular interval of 1.0 km between each sampling point except from point 1 and point 7 which are taken 2 km away from adjacent points. The GPS position were taken from each point and it was shown in the google map in Figure 1. The samples were taken in plastic containers of 1000 ml capacity and prior sampling the bottles were washed with distilled water. The containers were completely filled with sample water to the brim. Later the containers were labelled and sealed carefully.

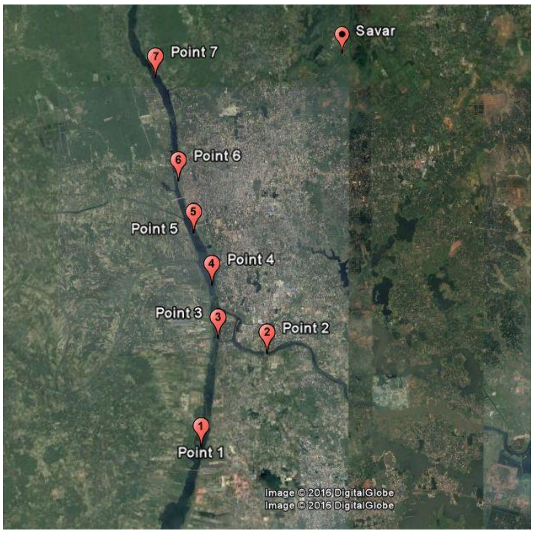

Figure 1: Sampling points shown on google map

The temperature of the sample was measured in the field with a thermometer. Water pH was measured by a pH meter (Model- SensIon: 156). Turbidity was measured by a digital turbidimeter (Model- Hack 2100p). Biochemical oxygen demand of water samples were determined in the lab by DO meter five days after sampling; the water sample was stored in incubator for 5 days. This standard method is recognized by U.S. EPA, which is labelled Method 5210B in the Standard Methods for the examination of water and wastewater. Nitrate and phosphate were measured using a Hack Spectrometer (Dr/4000). Nitra Ver 5 Nitrate Reagent Powder Pillow was used to measure nitrate content and Potassium Persulfate Powder Pillow was used to measure phosphate content. Concentration of ammonia was measured in 'Indophenol Blue Method'. Reagent Set for Water Analyser No.17A Ammonium, model LR-NH_4-A. Standard method was adopted for finding total solid and suspended solid content in water.

The current assessment of river quality by the E.P.A (The United States Environmental Protection Agency) is based on a comprehensive index known as "River Pollution Index", or RPI for short. RPI is an integrated indicator used to determine the level of pollution of a river. The index value is calculated using the concentration of 4 parameters in water quality: Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Suspended Solids (SS) and Ammonia Nitrogen (NH_3-N). Another commonly-used water quality index (WQI) was developed by the National Sanitation Foundation (NSF) in 1970. The NSF WQI was developed to provide a standardized method for comparing the water quality of various bodies of water. Nine water quality parameters were selected to include in the index. These parameters are dissolved oxygen, faecal coliform, pH, biochemical oxygen demand, temperature, phosphate, nitrate, turbidity and total solids.

3. RESULTS AND DISCUSSION

The location of sampling points was surveyed thoroughly before collecting samples. During the assessment of water quality of Bangshi river different point and non-point pollution sources have been identified. Pollutants are mainly generated in and around the city through domestic, commercial and industrial activities. Wastewater and sewage generated in the city are carried into the river system through numerous outlets. There were dumping points of solid waste near the river banks shown in Figure 2. These waste were directly in contact with river water.

Figure 2: Municipal waste dumping site at river side

Domestic waste are high in organic content and they increase the BOD of the water and decrease DO level. Industrial waste gets dissolved in water and also some of it remain as suspended solid. A lot of drains running through the municipality end at the river. So almost all the domestic waste and runoff generated inside Savar Municipality is carried by the Bangshi river. A number of industries were situated near river side. The waste generated in some of those industries were directly dumped into river without any treatment. Several locations were spotted where sewerage water and Industrial waste water were falling into river shown in Figure 3.

Figure 3: Sewerage water and Industrial waste water falling into river

The data regarding the pH of the sites shows almost invariance maintaining neutrality of water through the period. The pH values of water samples of the study area varied between 6.80 and 7.20 in January and in September it varied between 7.70 and 7.80 Shown in Figure 4. Although the pH values of water samples were found within the standard limits for drinking, irrigation and aquaculture, it dropped down significantly in the dry season. Because in dry season the discharge of the river decreases, but the amount of waste disposed to the river remains same. So it slightly lowers the pH of the river water in dry season.

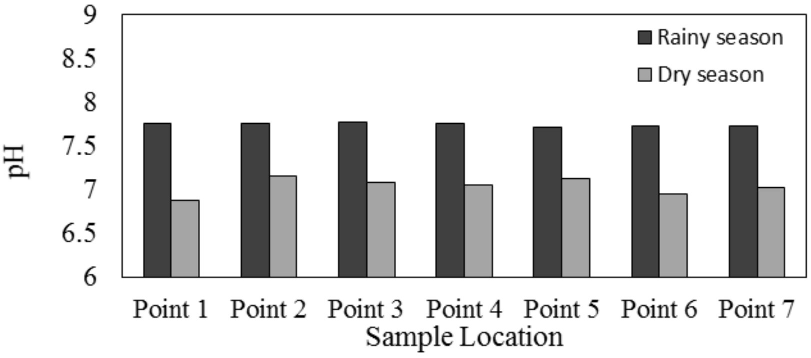

Figure 4: pH variation of Bangshi river at two seasons

The turbidity value varied from 70 to 145 NTU in January and from 132 to 223 NTU in September shown in Figure 5. The turbidity level was higher than the standard limit 10 NTU set by ECR, 97 throughout the year. The turbidity of the sampling area was found unsuitable for drinking, domestic, irrigation and industrial purposes.

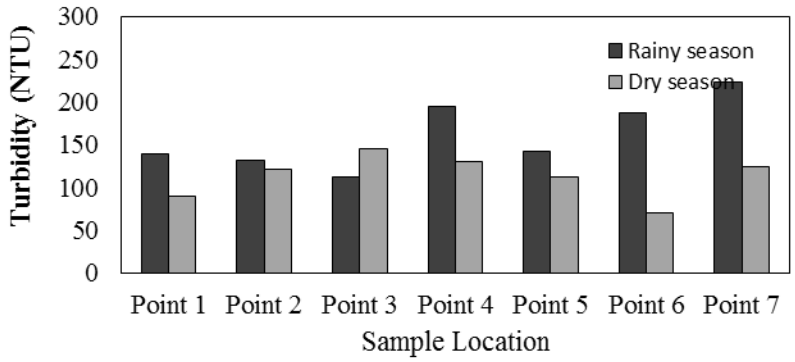

Figure 5: Turbidity of different points at two seasons

The DO value varied from 3.18 to 4.25 mg/L in January and from 6.00 to 7.05 mg/L in September shown in Figure 6. The optimum DO in natural water is 4-6 mg/L, which is essential for supporting aquatic lives. Although the amount of Dissolved Oxygen found in water samples during rainy season was sufficient, the DO level in dry season was too little for well aquatic environment.

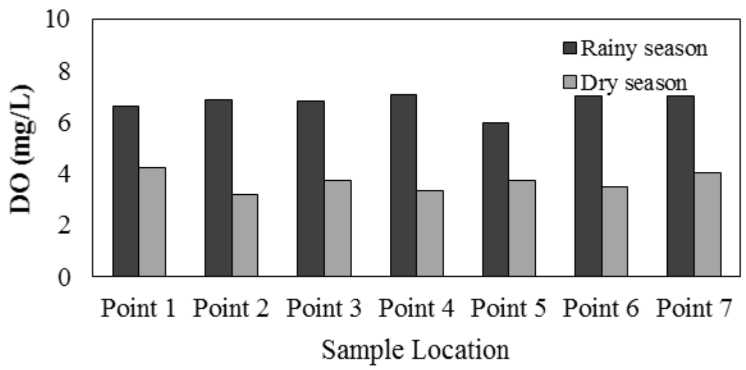

Figure 6: DO concentration in different location at two seasons

The optimum value of BOD_5 for surface water is 6 mg/L or less (ECR, 97). Higher values indicate water pollution. The BOD_5 of the study areas varied from 0.48 to 1.09 mg/L in the month of September and from 2.06 to 2.72 mg/L in the month of January shown in Figure 7.

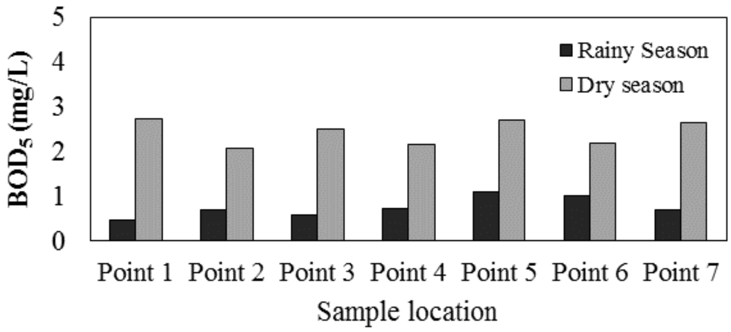

Figure 7: BOD_5 concentration of different points at two seasons

The phosphate concentration increase significantly during dry season shown in Figure 8. The average phosphate concentration during rainy season was 0.60 mg/L where the average rises up to 1.57 mg/L during dry season that is almost 3 times than the result found during September. It is very high than the allowable limit 0.1 mg/L (USEPA, 2000).

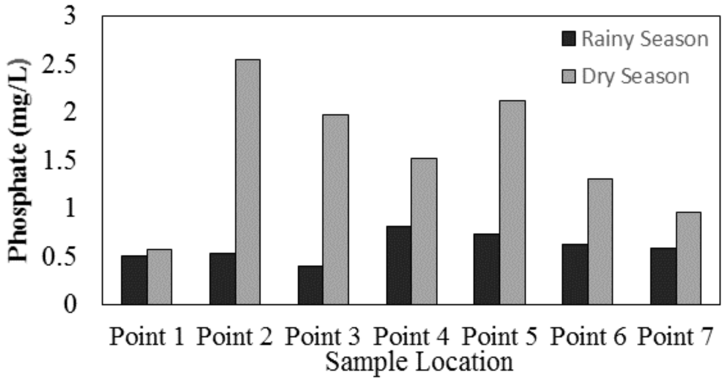

Figure 8: Phosphate concentration in different location at two seasons

The highest nitrate concentration found during dry season and rainy season was 1.9 mg/L and 0.3 mg/L, respectively. The allowable limit for nitrate concentration is 10 mg/L stated in ECR, 97. So the nitrate concentration was under acceptable limit. The current USEPA recommendations for faecal coliform for body-contact recreation is fewer than 200 colonies/100 mL; for fishing and boating, fewer than 1000 colonies/100 mL; and for domestic water supply, for treatment, fewer than 2000 colonies/100 mL (USEPA, 2000). The drinking water standard is less than 1 colony/ 100ml. The highest number of faecal coliform was found during dry season 73 N/100ml. So the water is safe for all purposes except drinking. The highest amount of total solid is observed during dry season which is 693 mg/L. The EPA standard for total solid is 1000 mg/L, so the result is favorable. The ammonia nitrogen concentration increase significantly during dry season shown in Figure 4.22. The average ammonia nitrogen concentration during dry season was 1.40 mg/L where it has been reported toxic to freshwater organisms at concentrations ranging from 0.53 to 22.8 mg/L.

There are water quality standards for surface water for water supply stated by ECR, 1997. As we can see in Table 2 all the four parameters during September 2016 were inside standard limit. But during January 2017 all the parameters excluding pH crossed the standard limit for surface water for water supply by disinfection process. So costly treatment is needed to use the river water for supply during dry season.

Table 2: Comparison between test result and Bangladesh water quality standards for surface water for water supply (ECR, 1997)

Water quality parameters	**(ECR, 97) values for water supply by**		**Bangshi river water**	
	Disinfection only	**Conventional treatment**	**September 2016**	**January 2017**
pH	6.5-8.5	6.5-8.5	7.77	7.15
BOD (mg/L)	2 or less	3 or less	1.09	2.72
DO (mg/L)	6 or more	6 or more	6	3.18
Total Coliform (N/100 mL)	50 or less	5000 or less	20 (Faecal Coliform)	73 (Faecal Coliform)

The seasonal variation of RPI is shown in Table 3. In rainy season the pollution status of the river was found 'lightly polluted' but in dry season the pollution status degraded to 'moderately polluted'. This happened primarily because in rainy season the discharge of river water was very high. So the amount of waste discharged into the river was little compared to the discharge of the river. But in dry season the river carry relatively less discharge so the amount of waste water discharged to the river can't be washed away by the slow moving current of the river.

Table 3: Variation of RPI at two seasons

	Rainy Season (September)		**Dry Season (January)**	
Sample Location	RPI score	Pollution status	RPI score	Pollution status
Point 1	2.25	Lightly Polluted	5	Moderately Polluted
Point 2	2.25	Lightly Polluted	5.75	Moderately Polluted
Point 3	2.25	Lightly Polluted	5.75	Moderately Polluted
Point 4	2.25	Lightly Polluted	5	Moderately Polluted
Point 5	2.75	Lightly Polluted	5.75	Moderately Polluted
Point 6	2.25	Lightly Polluted	5.75	Moderately Polluted
Point 7	2.25	Lightly Polluted	5.75	Moderately Polluted

The same thing happened for NSF-WQI. In rainy season the water was of 'Medium quality' but in dry season the water quality drops down to 'Bad quality' shown in Table 4. A lot of variation in NSF-WQI score is observed between rainy season and dry season. The average score in September was 68 whereas the average score in January was 49. So the water quality degraded in great extant from September to January.

Table 4: Variation of NSF-WQI at two seasons

	Rainy Season (September)		Dry Season (January)	
Sample Location	**NSF-WQI Scores**	**Water quality**	**NSF-WQI Scores**	**Water quality**
Point 1	69	Medium	54	Medium
Point 2	68	Medium	48	Bad
Point 3	69	Medium	48	Bad
Point 4	69	Medium	47	Bad
Point 5	66	Medium	47	Bad
Point 6	68	Medium	49	Bad
Point 7	68	Medium	51	Medium

Different types of approaches needed to restore and rehabilitate the river water quality. There are lot of industries already established near the river side. Also waste from industries located inside Savar Municipality are finally dumped into Bangshi river. So effluent treatment plant is a must for these industries. The domestic waste water should be treated properly so that they become environmentally safe. Adequate care should be taken to ensure that effective sewage treatment process is in place and that contaminated water does not get mixed with the environment in order to prevent water pollution. The municipal solid waste dumping site should be moved elsewhere at a distance from river side. Municipality authority can play a vital role in controlling the pollution of Bangshi river. Strict laws should be imposed on violating the Environmental Conservation Rules.

4. CONCLUSIONS

The water quality of Bangshi river was observed polluted not only by laboratory analysis but also by its physical appearance. The pH, BOD, DO and Faecal coliform value of Bangshi river water was found to be 7.77, 1.09 mg/L, 6.00 mg/L and 20 N/100 mL, respectively, which was satisfactory in rainy season but BOD 2.72 mg/L, DO 3.18 mg/L and Faecal coliform 73 N/100 mL was not satisfactory in dry season for inland surface water according to ECR, 97. Highest value of turbidity, total solid, NH_4-N, PO_4 and NO_3-N of river water was observed 223 NTU, 691 mg/L, 2 mg/L, 2.54 mg/L and 1.9 mg/L respectively. From the study, it may be concluded that Bangshi river water contained acceptable pH and concentration of NO_3, NH_4-N, DO and BOD during September 2016, whereas water turbidity, values of FC, TDS, SS and PO_4 exceeded the recommended limit for drinking and irrigation water. But in January 2017 only pH and nitrate were inside acceptable limit. The River Pollution Index and NSF-WQI for rainy season was found to be 'Lightly Polluted' and 'Moderate Quality' whereas in dry season it was found to be 'Moderately polluted' and 'Bad quality', respectively. From the results of the experiment it can be clearly stated that the concentrations of studied parameters were proceeding towards impermissible limit with the advancement of months, when the rainfall intensity was getting lower. But these values were generally low and fell within standard levels when rainfall intensity was higher. The scenario indicated that the Bangshi river received a huge amount of untreated sewage, municipal solid waste and industrial waste regularly through direct disposal. As the untreated effluent was directly discharged to the river, its water color was black and having noxious odor. Current pollution will be minimized if necessary approaches are properly implemented. So the authority of Savar Municipality needs to enforce laws and environment standards and regulation on polluting industries as they cause a tremendous threat to river water quality. This may involve identifying the sources of pollution, strict enforcement of laws to setup effluent treatment plant (ETP) in each industry to treat effluents before discharge in respect to recommended standard and also create public awareness about “save life of river”.

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ASSESSMENT OF SUPPLIED WATER QUALITY OF RAJSHAHI WASA (RWASA) IN BANGLADESH

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ABSTRACT

Recently, adequate and safe drinking water is a challenging issue in developing countries like Bangladesh. Poor quality of drinking water becomes injurious to human health. Rajshahi, the sixth largest city in Bangladesh, is facing drinking water scarcity. To overcome the scarcity, Rajshahi WASA is supplying water in Rajshahi city through a distribution network. However, according to peoples perception, the quality of water is very poor. The main objective of this study is to investigate the quality of water in those locations in the city where problems have arisen and to attempt to help and concern WASA about the condition of water quality. By surveying, defective areas, where poor quality of water was found, were selected and samples were collected from there according to the objection of local consumers who take up that water from Rajshahi WASA. Water quality parameters collected from different consumers against their sources (WASA point) were tested in the laboratory. These parameters include p^H, turbidity, iron (Fe), hardness and odor. From the lab test, it was noted that p^H of water in the selected areas was in allowable limt. However, in few wards, turbidity, iron, hardness, and odor deviated from their standard values. Health effect of iron includes warding off fatigue and anemia. Due to unpleasant odor of water, possible health effect including gastrointestinal illnesses (diarrhea, vomiting, cramps) may occur. Excessive turbidity, or cloudiness, in drinking water is aesthetically unappealing and may also represent a health concern. Water with excessive amounts of iron can have negative effects on the skin. So, Rajshahi City Corporation and Rajshshi WASA should take proper steps to improve water quality by proper treatment.

Keywords: *RWASA, quality assessment, physical parameter, chemical parameter.*

1. INTRODUCTION

Water is one of the most significant ingredients on earth as we use it to fulfill our daily necessities. Good drinking water quality is one of the most important elements to build human physiology and man's continued existence depends very much on its availability. An average man (of 53 kg – 63 kg body weight), requires about 3 litres of water in liquid and food daily to keep healthy. The importance of water to a human being cannot be over emphasized. A man can survive longer without food than without water. This fact apparently accounts for why water is regarded as one of the essential substances in life (Etim, Odoh, Itodo, Umoh, & Lawal, 2013). Increase in human population has exerted a vast pressure on the provision of safe drinking water especially in developing countries like Bangladesh. In Rajshahi, the water crisis was very high in the past few decades. To overcome the crisis of water in Rajshahi City Corporation, Rajshahi WASA was established in 2013 which provides water to the households of this city. But Rajshahi WASA could not serve satisfactory level of water quality to their consumers. But the water, they are distributing and the consumers are receiving, is being polluted in various ways as toxic and harmful elements. Possible cause of water pollution in Rajshahi city may be due to geological conditions, water treatment plants, pipe leakage of water treatment plants, corrosion of pipe of distribution system, due to increased human population, industrialization, the use of fertilizers in the agriculture and man-made activity it is highly polluted with different harmful contaminants(Sagar, Chavan, Patil, Shinde, & Kekane, 2015). Even many consumers complain that they face odor problem, hair fall problems due to use this water.

According to the World Health Organization (WHO), 89% of the world population consumes drinking water from improved drinking water sources .Improved drinking water sources include piped treated water connections, public standpipes and protected dug wells (Alam, Dafader, Sultana, Rahman, & Taheri, 2017). Therefore, it is necessary that the quality of drinking water should be checked at a regular time interval because due to use of contaminated drinking water, the human population suffers from various water borne diseases (Sagar et al., 2015). Moreover, water quality control is a crucial part of environmental pollution studies (Murino & Palmieri, 2017). A number of scientific procedures and tools have been developed to assess the water contaminants. These procedures include the analysis of different physical parameters such as pH, turbidity, conductivity and chemical parameters like iron, chloride .These parameters can affect the drinking water quality adversely if their values are in higher concentrations than the safe limits set by the World Health Organization (WHO) and other regulatory bodies (Rahmanian et al., 2015).From the investigation of public opinion and lab test water quality in RCC ,it is revealed that iron, turbidity, and odor is the major problems to deteriorate water quality .These three parameters deviate from their standard extremely.

This study represents the maximum and minimum values of physical parameters including turbidity, pH, odor and chemical parameters including hardness and iron against WHO standard and Bangladesh standard values. According to the analysis, if the parameters present in water is lower or higher than the required value the quality is deteriorated. The main purpose of this study is to investigate water quality with respect to locations where problems have appeared and to perform lab analysis about which of water quality parameters of defective locations deviate from their standard values. Furthermore, an attempt has also been made to concern and help Rajshahi City Corporation (RCC) and Rajshahi WASA by delivering noticeable information about the present condition of water quality in RCC and make them cautious to provide good quality water.

2. STUDY AREA

Rajshahi City-corporation is one of the six city-corporations located in the north-west part of Bangladesh. It lies between $24^0 21^/$ and $24^0 26^/$ north latitudes and between $88^0 28^/$ and $88^0 37^/$ east longitudes. The city is bounded on the east, north, and west by Paba Thana and on the south by the Padma River and the shape of the city is as like an inverted “T” with an area of about 47.78 sq. km (RCC). The maximum length along east-west direction is about 13 km and along north-south is 8 km (Rahman, 2004)

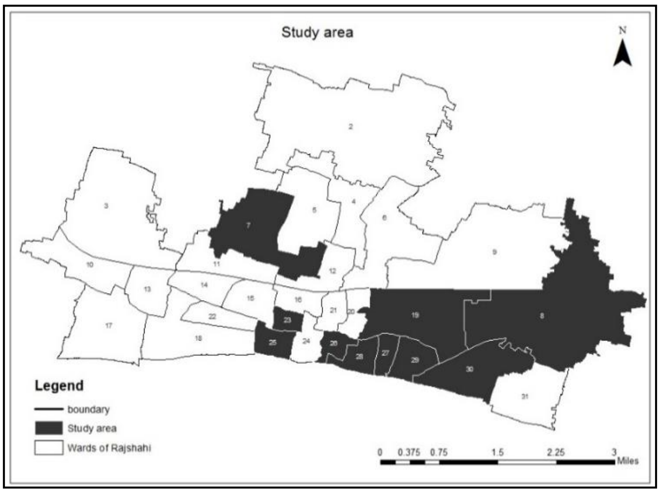

Figure 1: Study Area (prepared by author from Google Earth)

3. METHODOLOGY

3.1 Selection of sampling points

The criteria for selecting sampling points were based on the population density, geographical location, defective residential areas where problems have arisen are prosecuted in WASA by consumers against their sources. Out of 30 wards of RCC, 10 wards were selected for the present study based on public problems, which mainly covers the center part of the city. According to public objectives, 3 consumers (**S_1, S_2** and**S_3)** point were selected for each ward. All targeted locations are summarized in Table 1 and presented in Fig. 1.

Table 1: Water sample collection points (consumers and RWASA)

WASA Points(Source)	**Ward No**	**Source of consumer(3 sample collect from different consumers)**
Shipaipara pump	Ward 8	S_1 , S_2 , S_3
Dargapara pump	Ward 9	S_1 , S_2 , S_3
Shiroil colony jame moshjid	Ward 19	S_1 , S_2 , S_3
Ahammednagor	Ward 23	S_1 , S_2 , S_3
Talaimari shahidminar	Ward 25	S_1 , S_2 , S_3
Meherchandi alaka	Ward 26	S_1 , S_2 , S_3
Adorsho school	Ward 27	S_1 , S_2 , S_3
Kazla	ward 28	S_1 , S_2 , S_3
Khojapur ghorosthan	Ward 29	S_1 , S_2 , S_3
Binodpur	Ward 30	S_1 , S_2 , S_3

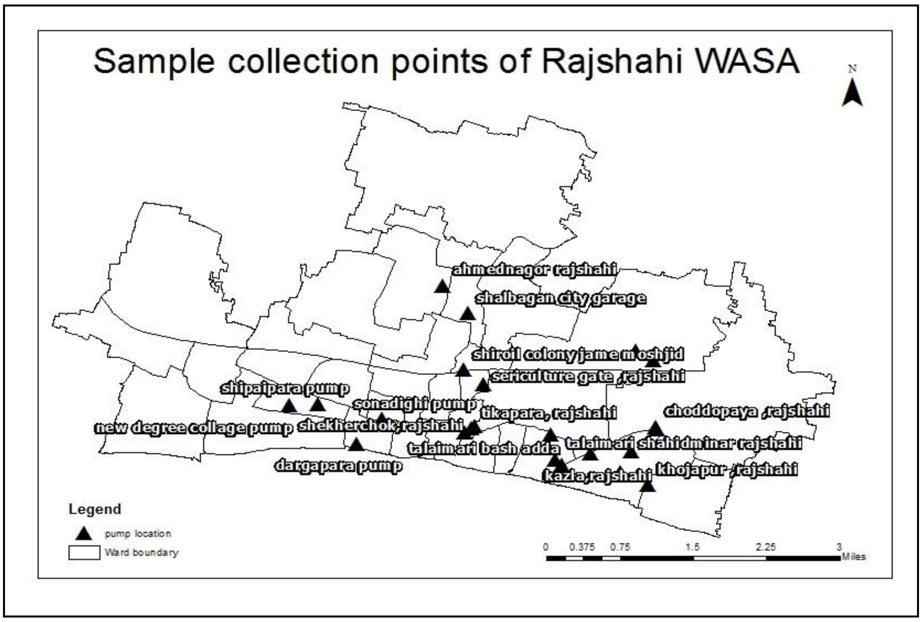

Figure 2: Sample collection points of Rajshahi WASA (Source: Google Earth)

3.2 Sample collection

All drinking water samples were taken from tap water of residential area from different consumers of different locations as well as from where consumers get those tap water in their households. The samples were marked according to their sources and consumers. The samples were collected in1-litre polyethylene (PE) bottles, which were pre-treated by washing with dilute HCl (0.05m) and later rinsed with distilled water. They were then air-dried in a dust free environment (Etim et al., 2013). Collected samples were promptly carried to the Environmental Engineering laboratory of the Department of Civil Engineering of RUET. These sample bottles were sealed and placed in a dark environment at a constant temperature range to avoid any contamination and the effects of light and temperature (Rahmanian et al., 2015).

4. ANALYSIS AND RESULTS

4.1 Analytical instruments

All physical and chemical parameter analyses are performed according to the standard methods for the examination of water.

4.1.1 Immediate analysis

Some physical parameters of water were measured as soon as possible after collecting the samples due to obtaining an accurate value. These parameters include Turbidity. All probes should be thoroughly rinsed and completely dried with lint- free wipes or compressed air. The recommended order for calibration of the individual probes on a multipara meter is p^H, and turbidity(WHO, 2008). Almost all these important water quality parameters were measured within four hours of collection.(Fahmida, Lemon, Islam, & Kader, 2013)

4.1.2 Lab analysis

Chemical parameters were performed by lab analysis. These parameters include iron, hardness .The concentration of Iron, hardness are determined by titration method. To investigate the quantity of iron in water some chemicals involve KCN, standard iron solution, 0.3N HCL, $KmnO_4$ (if necessary) were used. The p^H of the water samples was measured by using multi-parameter analyzer (Model DZB-718). The instrument used to determine turbidity is turbidity meter. The test to indicate hardness was done by soda reagent method in the laboratory. Required chemical included 0.02N H_2SO_4, Methyl orange indicator, and soda reagent. Iron in the sample was indicated by titration method in the laboratory. $KmnO_4$, KCN, iron solutions and distilled water were required.

4.2 Physical parameter analysis

4.2.1 PH level

pH is defined as one of the most important water quality parameters. pH value indicates the acidity or alkalinity of the water (Rahmanian et al., 2015). A sample is considered to be acidic if the pH is below 7.0. It is alkaline if the pH is higher than 7. Alkaline water shows disinfection in water (Alam et al., 2017). Both alkaline and acidic water harmful to people.

The normal drinking water pH range mentioned in WHO standards and BDS guidelines are between 6.5 and 8.5. The pH values of all the drinking water samples were found in the range between 6.5 and 8.5 (Fig- 3). So, pH of all samples should remain within allowable limit according to WHO standards and BDS guideline.

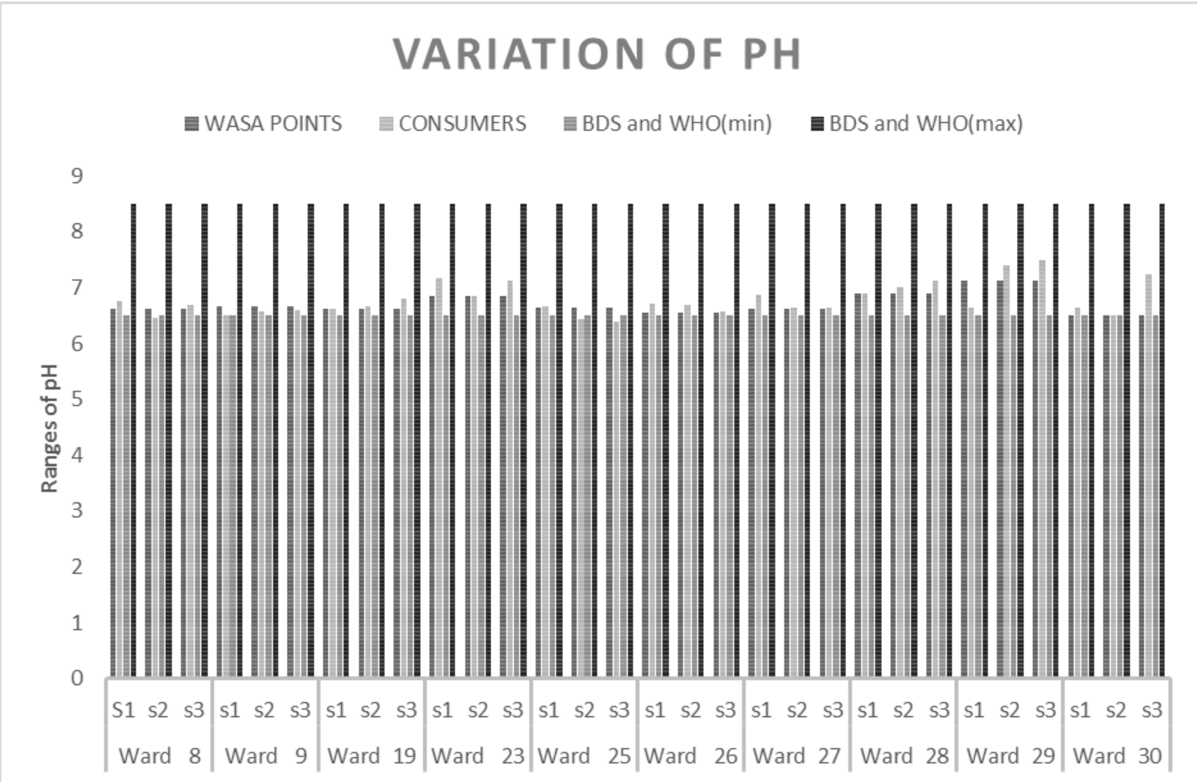

Figure 3: Variation of p^H

4.2.2 Odur

The odor is one of the most important parameters of water and water must be odorless(Hossain, Nahida, & Hossain, 2014). But this study result shows that about 90% sample found objectionable odor. The odor was determined by the threshold odor number (TON).Study results of all samples for odor are represented in (Fig- 3)

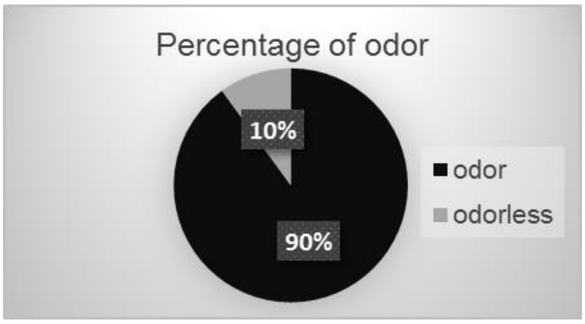

Figure 4: Percentage of odor

4.2.2 Turbidity

An excess amount of Turbidity of water is not suitable as it causes quick clogging of filtered. Turbidity is a measure of light transmission and indicates the presence of suspended material (Rajon & Bari, 2014). According to WHO standards & BDS guideline the allowable turbidity for drinking water is 5 NTU and 10 NTU respectively. Turbidity in excess of 5 NTU is usually objectionable for aesthetic reasons.

It is clear that from 40 samples, half of the samples collected from consumers exceed their WHO standards. Ward 25, 27, 29 & 30 exceed BDS value. Samples from both consumers and WASA in ward 8, 9, 19, 26 & 23 were within allowable limit according to BDS and WHO standards. The maximum turbidity was found 25.22 NTU in ward 25 from consumer and minimum found 0.52 NTU in RWASA point. It can be seen that there is a variation of turbidity for different collected samples which varies from almost 0-25.22. (Fig- 5).

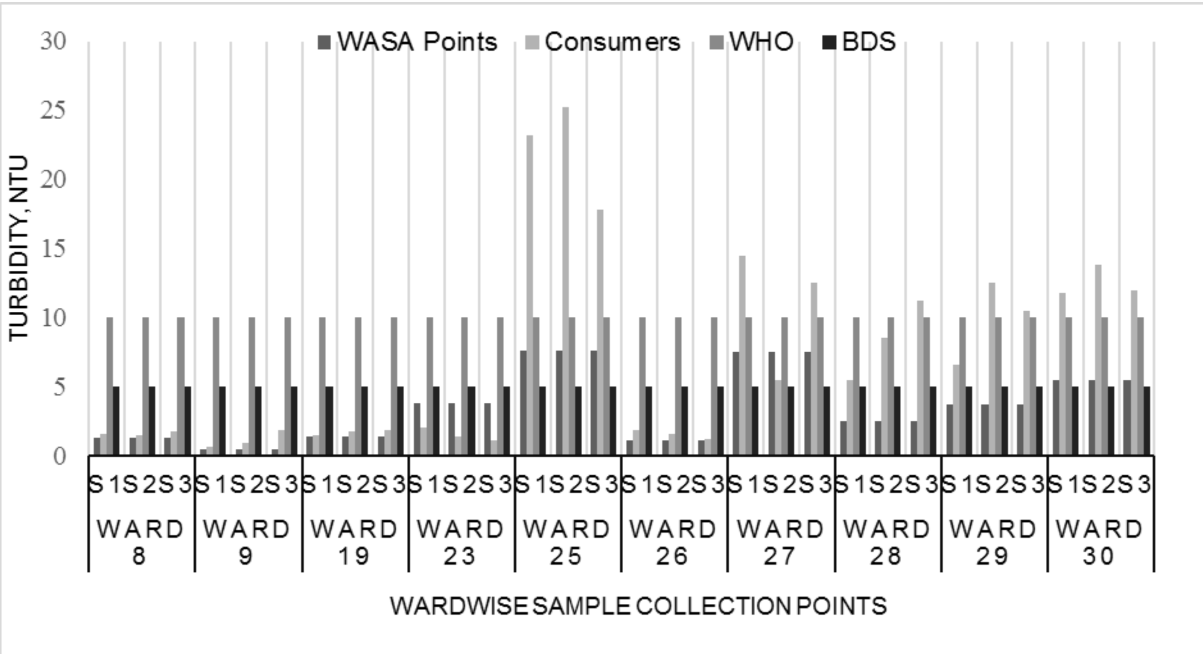

Figure 5: Variation of Turbidity

4.3 Chemical parameters analysis

4.3.1 Iron

Iron is one of the most important constituents of blood in human and another living organism. Iron is an essential element for human nutrition and metabolism, but in excess quantities results in toxic effect like hemochromatosis in tissues(Sagar et al., 2015). Iron enters drinking water supplies from natural deposits in the earth or from agricultural and industrial practice(Fahmida et al., 2013).

4 samples (ward 9 & 26) did not find objectionable iron but rest of the samples found objectionable iron deviated from BDS and WHO standards. The maximum value of iron found 3 mg/l in ward 29 from consumer deviated from BDS and WHO standards and minimum value found 0.02 in ward 9 from Consumer. About 90% samples exceed BDS (Bangladesh drinking water standards) and WHO standards (Fig- 6).

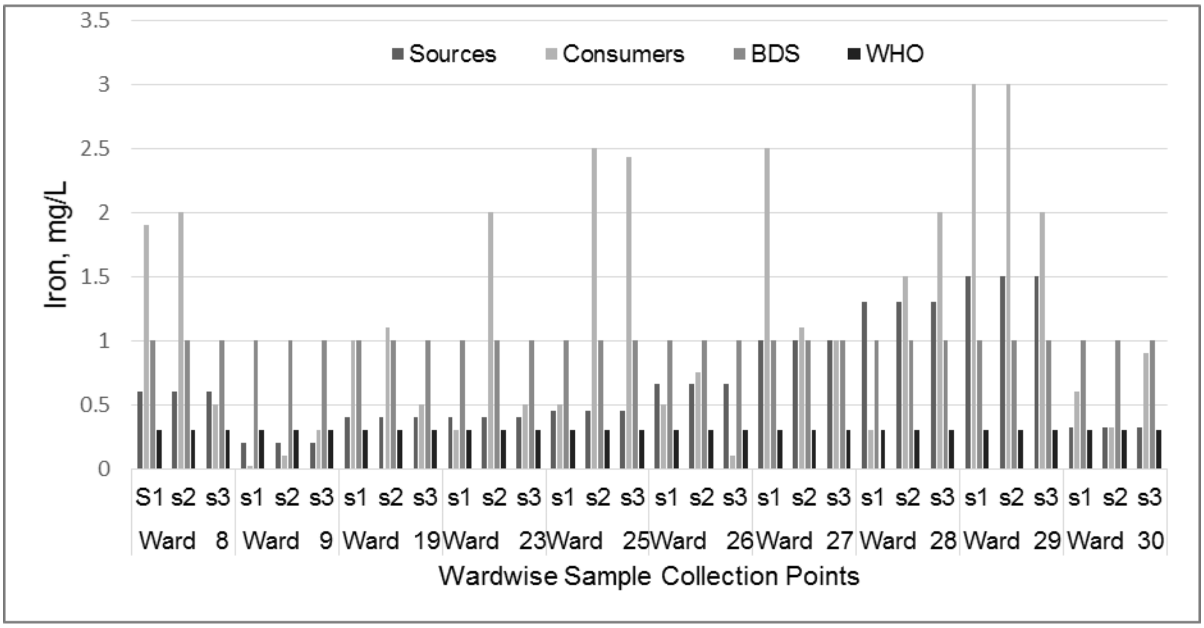

Figure 6: Variation of Iron (Fe)

4.3.2 Hardness (AS $CACO_3$)

Total hardness is the summation of calcium and magnesium hardness in mg/L As $CaCO_3$ (Sagar et al., 2015). Water can be classified as soft (<75 mg/L), moderately hard (75-150 mg/L), hard (150-300 mg/L) and very hard (>300 mg/L) according to the concentration of calcium and magnesium. It is an important criterion for determining the usability of water for domestic, drinking and many industrial applications. Water having hardness below 300mg/L is considered portable, but beyond this limits cause gastro-intestinal irritation (Alam et al., 2017).

Test results show that about 10% samples (ward 26,27 & 30) found very hard, 10% hard(WARD 23, 26 & 28), 45% moderately hard (ward 8, 9 & 25) and 35% soft water (ward 19). Maximum value from the test was 485 mg/L found from ward 27 consumer and the minimum value was 35 mg/L from WASA point. About all samples were within BDS and WHO standards (Fig- 5)

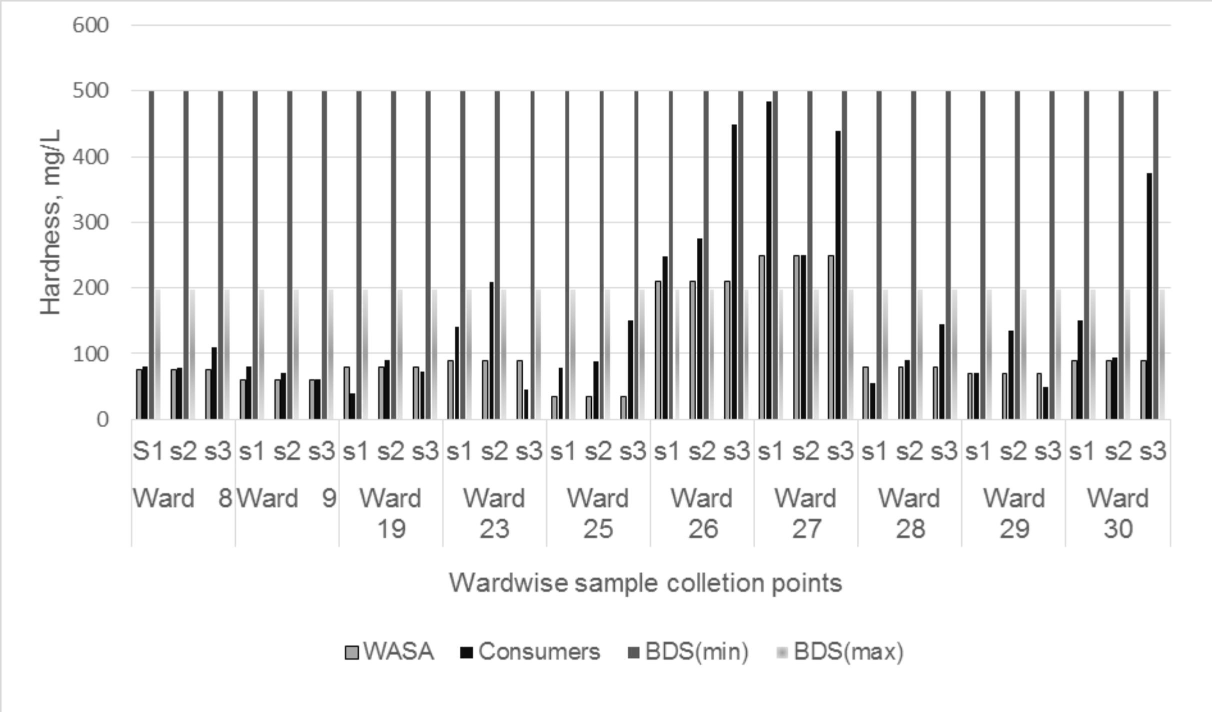

Figure 7: Variation of hardness

Table 2: Maximum and Minimum value of whole samples

Parameter	WASA(max)	Consumer (Max)	WASA (Min)	Consumer (Min)	BDS	WHO standards (2006)
pH	7.3	7.5	6.56	6.40	6.5-8.5	6.5-8.5
Turbidity(NTU)	7.5	25.22	0.52	0.70	10	5
Iron(mg/l)	2	3	0.2	0.02	0.3-1	0.3
Odor	odor	odor	odor	odor	odorless	Odorless
Hardness (mg/l)	150	485	50	200	200-500	500

4.4 Causes of poor quality of water and its health effect

The major source of iron may be the geologic formation of Rajshahi area or iron release from corroded iron pipes in drinking water distribution systems: effect of dissolved oxygen. Odor problems create due to Minerals such as iron or copper, may leach into the water from the pipes or due to Bacteria growing in pipe or from organic matter or bacteria that are naturally present in lakes and reservoirs during certain times of the year("Color ,taste and odor problems in drinking water," 2011). Turbidity is caused by particles suspended or dissolved in water that scatter light making the water appear cloudy or murky (MPCA, 2008).Particulate matter can include sediment - especially clay and silt, fine organic and inorganic matter, soluble colored organic compounds, algae, and other microscopic organisms. Excessive Iron in drinking water is classified as a secondary contaminant according to the EPA (Murino & Palmieri, 2017).

If iron levels are too high, serious health effects like iron overload can develop. Water with excessive amounts iron can have negative effects on your skin. It can damage healthy skin cells, which can lead to wrinkles. Iron leaves residue on anything it touches (Etim et al., 2013). If clean dishes with it, produce orange or dark red stains on plates and cutlery eventually. Excessive turbidity, or cloudiness, in drinking water is aesthetically unappealing, and may also represent a health concern. Turbidity can provide food and shelter for pathogens (Perlman, 2016). If not removed, turbidity can promote regrowth of pathogens in the distribution system, leading to waterborne disease ("Color ,taste and odor problems in drinking water," 2011). Due to unpleasant odor of water, possible health effect gastrointestinal illnesses (diarrhea, vomiting, and cramps) may occur. When People smell strong odors, it may get headaches or feel dizzy or nauseous(ATSDR, 2017). If an odor lasts a long time or keeps occurring, it also could affect mood, anxiety and stress level.(Sagar et al., 2015) So, drinking and domestic water must be free from physical and chemical contaminants.

4.5 Problems identification from consumers

From the overall investigation of all consumers and by surveying their opinions, it was found that about 46% people complain about facing odor problem, 30% for the iron problem, 17% for turbidity problem and 7% for hardness problem. Especially, in ward 29, 30 and 19, people suffer a lot due to Iron problem. People in ward 29, 30 25 complain that they found black colored water. In the ward, 25 people use turbid water. Almost all wards that were surveyed odor problem is severe. Few ward has some hardness problem.

Table 3: Percentage and frequency of different identified problems according to public objections

Ward no	Turbidity problem	Iron problem	Odor problem	Hardness	P^H
Ward 8	0 (0%)	1(33.33%)	2(66.67%)	0(0%)	0(0%)
Ward 9	1(33.33%)	1(33.33%)	1(33.33%)	0(0%)	0(0%)
Ward 19	0(0%)	2(66.67%)	1(33.33%)	0(0%)	0(0%)
Ward 23	1(33.33%)	1(33.33%)	0(0%)	1(33.33%)	0(0%)
Ward 25	1(33.33%)	0(0%)	2(66.67%)	0(0%)	0(0%)
Ward 26	0(0%)	2(66.67%)	1(33.33%)	0(0%)	0(0%)
Ward 27	0(0%)	2(66.67%)	1(33.33%)	0(0%)	0(0%)
Ward 28	1(33.33%)	1(33.33%)	0(0%)	1(33.33%)	0(0%)
Ward 29	1(33.33%)	2(66.67%)	0(0%)	0(0%)	0(0%)
Ward 30	0(0%)	2(66.67%)	1(33.33%)	0(0%)	0(0%)
sum	5(17%)	14 (30%)	9 (46%)	2 (7%)	0(0%)

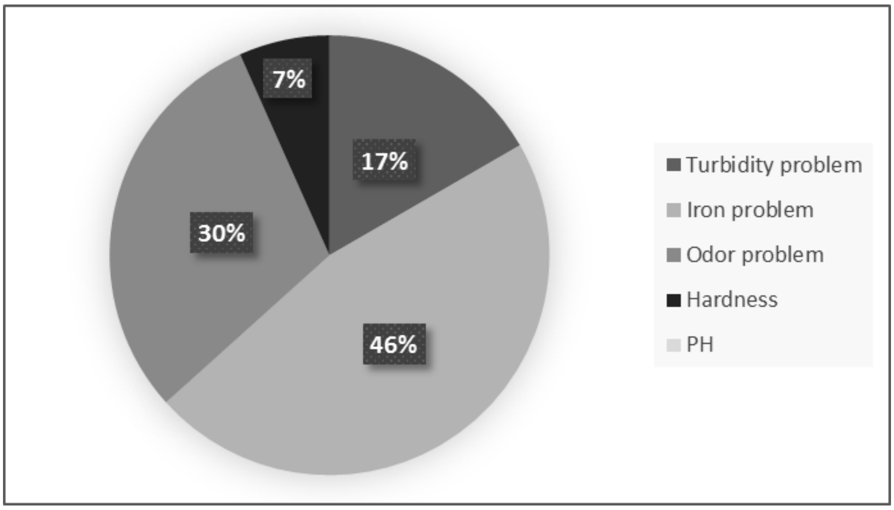

Figure 8: Different investigated problems by surveying consumers opinion

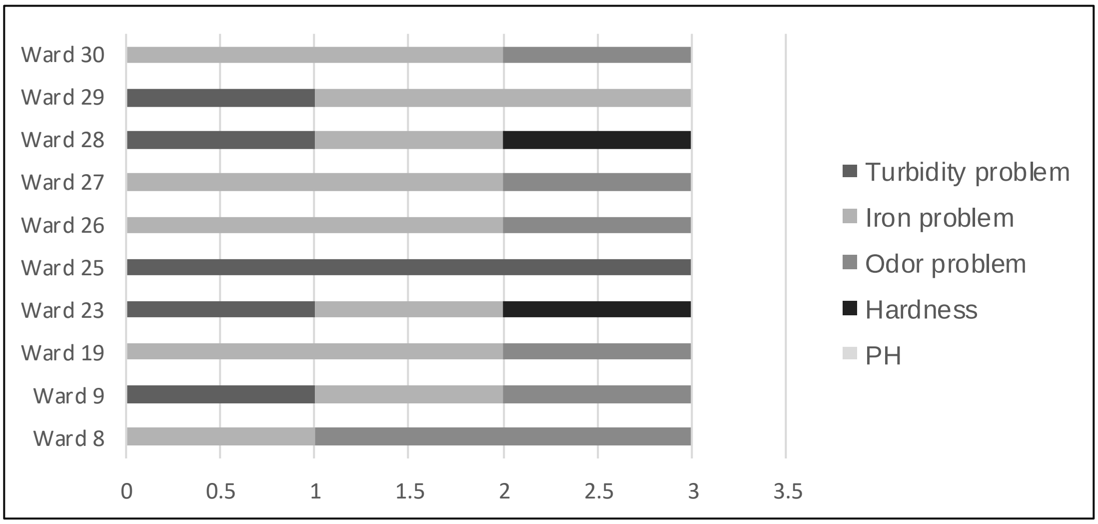

Figure 9: Ward-wise problem identification from public opinion

5. CONCLUSIONS

Rajshahi city householders are suffering from inadequate water supply as well as they suffer from various water related diseases. Water quality test of targeted sample exhibited that water quality of samples is not satisfactory. The p^H values of all the drinking water samples were found in the range between 6.5 and 8.5. So, P^H of all samples remains in within allowable limit according to WHO standards and BDS guideline. The hardness of all samples was within allowable limit for drinking purpose according to BDS guideline. But, the concentration of iron and turbidity in WASA point and household samples of the study area were very high. About 90% samples found to have an odor. In ward 25, turbidity over the tolerable range was found. But the drinking water must be clean and less turbid for sound health. 95% samples have been found to have iron from the lab test and they exceed WHO standard and BDS standard. So, the authority of RWASA should take necessary steps to improve the poor quality of water.

ACKNOWLEDGEMENTS

The authors are highly grateful to the authority of WASA and the department of civil engineering, RUET and Non-teaching staff for providing necessary laboratory facility, for his constant encouragement and support. .They are also highly indebted to the assistant engineer of WASA Md. Mahbubur Rahman, for his painstaking endeavor, to go through the manuscript.

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EVALUATION OF LANDSLIDE SUSCEPTIBILITY OF THE CHITTAGONG CITY USING THE METHOD OF MULTI CRITERIA ANALYSIS (MCA)

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ABSTRACT

Landslide has become a major concern for Bangladesh in the recent past. Even in medium rainfall, it is occurring with an increasing trend of frequency and causing huge damages to people, property, and resources. Chittagong division has become more susceptible to this hazard. In this study, we focused only on Chittagong City as it is one of the major metropolitan city having ample importance of its own. Here, the study is undertaken to assess the landslide susceptibility of the Chittagong City. Various open source spatial data and previous studies were used for the analysis and to show the huge possibility of remote sensing and GIS in the very field. Multi Criteria Analysis (MCA) method which is a heuristic approach was used to determine the Landslide Susceptibility Index (LSI). As per the experts of different discipline, seven key factors like slope, land use, and land cover etc. Are combined to assess the major criterion of the LSI and the higher value of LSI, indicates greater susceptibility. Finally, the susceptibility maps were generated for the region which will be essential to analyze the future landslide susceptibility of Chittagong City.The result of the study indicates a major portion of Chittagong City as susceptible to this hazard. With this study, appropriate landslide mitigation strategies can be taken by the local authorities and other stake-holders, concerned in disaster risk reduction and mitigation activists. Moreover, this study can also be advantageous for risk sensitive land use planning in the study area

Keywords: *Landslide, Susceptibility, Slope, Land use, GIS and Remote Sensing.*

1. INTRODUCTION

1.1 Background of the Study

The term ‘landslide’ is a geomorphic process by which soil, sand, and rock move downslope typically as a mass, largely under the force of gravity. But there are other contributing factors that affect the original slope stability [1]. Landslide is one of the most catastrophic natural disaster in hilly areas causing huge damages to mankind, properties and national economy. It also creates natural and ecological imbalance [2]. Chittagong Metropolitan Area (CMA) is highly susceptible to landslide hazard, with an increasing trend of frequency and damage. The major recent landslide events were related to extreme rainfall intensities having short period of time. Besides, rapid urbanization, growing population density, unplanned land use, cutting the hills i.e. illegal alterations in the hilly regions, indiscriminate deforestation, and agricultural practices are triggering the events of landslides in CMA [3]. In addition, the absence of strict hill management policy also worsen the situations. This has encouraged many informal settlements along the landslide-prone hill-slopes in Chittagong. Though these settlements are being considered as illegal, the settlers claim themselves as legal occupants. As a result, the conflict among the formal authorities, the settlers, and the local communities over the past few decades has also weakened the institutional arrangement for reducing the landslide vulnerability in Chittagong City [4].

Therefore determination of the landslide prone areas in CMA is a crying need for developing appropriate landslide disaster risk reduction strategies. Hence, an up-to-date and accurate landslide susceptibility maps can ensure safety to mass people and their property at risk and avoid the immense economic loss [5].

The susceptibility was measured in terms of Land Susceptibility Index (LSI) which is the relative spatial likelihood for the occurance of landslide. A heuristic approach has been used in the study to assess the susceptibility of the area named Multi Criteria Analysis. This might not be the guaranteed optimal approach but given the complexity, it is an approach to problem solving. The approach makes the options and their contribution to the different criteria explicitly and for the different criteria, measures those explicit relative weighting system. [6].

1.2 Study Area

Chittagong is the second largest both in size and importance and main seaport of Bangladesh, situated on the banks of the Karnaphuli River between the Chittagong Hill Tracts and the Bay of Bengal. It is situated within 22° 14' and 22° 24' 30" North Latitude and between 91° 46' and 91° 53' East Longitude[7]. The administrative boundaries divided Chittagong City into Chittagong Statistical Metropolitan Area, Chittagong Metropolitan Area, and Chittagong City Corporation. The study area for this research is Chittagong Metropolitan Area (Figure 1).

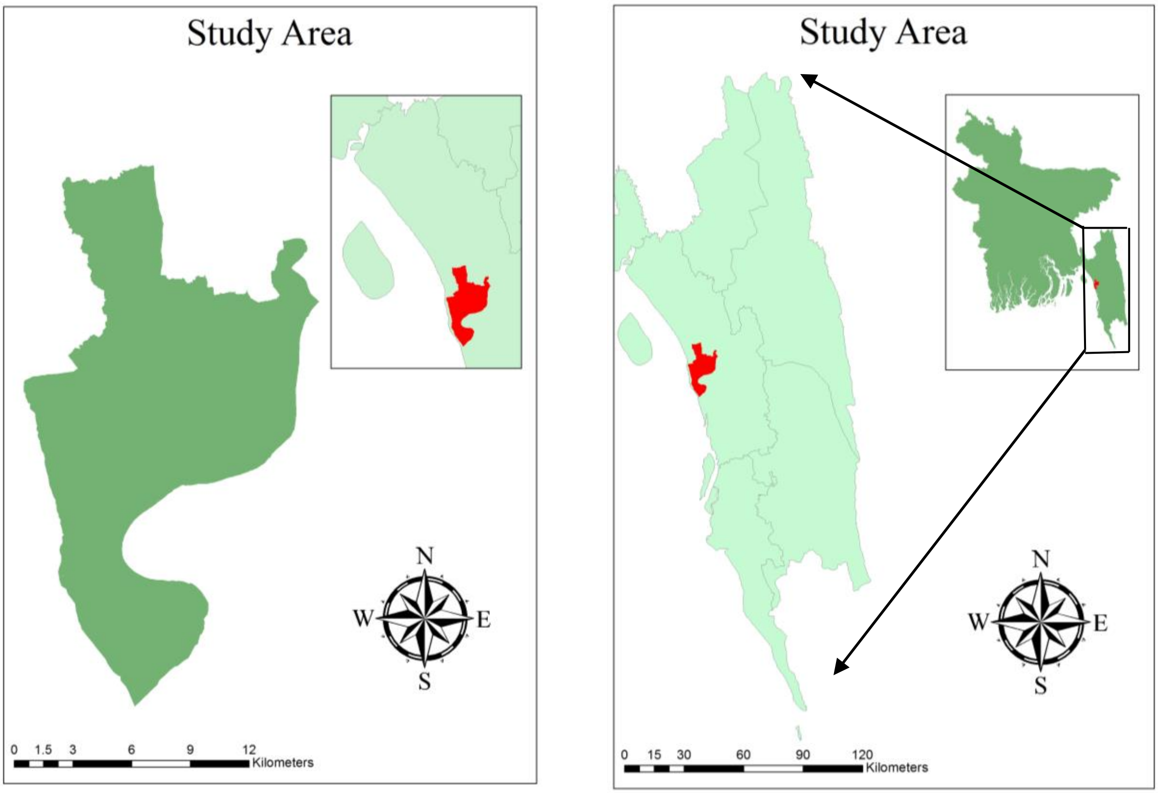


Figure-1 Map Showing the Chittagong Metropolitan Area and Chittagong City Corporation.

1.3 Objective of the Study

The aim of this research is to prepare the Landslide Susceptibility Mapping (LSM). The specific objectives of this research work are in the following:

(a) Landslide Susceptibility map generation.
(b) Preparing a handful materials for landslide mitigation strategies and risk sensitive land use planning.

2. LITERATURE REVIEW

Landslide hazard assessment is generally based on the concept that 'the present and the past are keys to the future'. For this reason, most landslide hazard analyses take into account an up-to-date landslide inventory which represents the fundamental tool for identifying the factors causing landslides [8]. Different types of Geospatial technologies like the use of GIS, Global Positioning System (GPS), and Remote Sensing (RS) are useful in the hazard assessment and risk identification. The use of GIS for landslide mapping is common in various studies. Remote sensing (RS) is also used for monitoring and mapping of landslides [9].Mapping the susceptible areas is an essential task for proper land use planning and disaster management. This results in Social and economic losses due to landslides [10].

Throughout the years, different techniques and methods have been developed and applied for generating landslide susceptibility maps. These can be produced using both the quantitative or qualitative approach [11].Qualitative approaches weight each factors affecting the landslides based on the practical experience and expertise of the researcher [11]. Qualitative methods simply portray the hazard zoning in descriptive terms [12]. However, in recent decades quantitative techniques have become more popular because of the developments in computer programming and geospatial technologies.

There are mainly four methods available to map landslide susceptibility, namely landslide inventory based probabilistic, deterministic, heuristic, and statistical techniques [12]. Within these techniques, the probabilistic and statistical methods have been commonly used in recent years. These methods have become more popular, assisted by GIS and RS techniques [8]. Moreover, GIS-based Multi Criteria Analysis (GIS-MCA) provides powerful techniques for the analysis and prediction of landslide hazards. The primary objective of this paper is to apply GIS-MCA techniques for the Landslide Susceptibility Mapping (LSM).

3. DATA COLLECTION AND METHODOLOGY

3.1 Data Source and Spatial Techniques

Open source web portal namely United States geological survey (USGS) was used for all the spatial data required in this particular study. JAXA (Japan Aerospace Exploration Agency) DEM having spatial resolution of 30 m X 30 m was retrieved from (http://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/index.htm) [13]. It was used for the preparation of various topographic parameters like slope, plan curvature, aspect, and relative relief of the current analysis. Geology information was taken from downloadable GIS data of Bangladesh which had been retrieved from U.S. Geological Survey Open-File Report. Retrieved from https://pubs.usgs.gov/of/1997/ofr-97-470/OF97-470H/linked_filepaths1.htm [14].

Slope, plan curvature and aspect maps were prepared from DEM file using spatial analyst tool of ArcGIS (version10.2). Before execution of these functions, a median filter was run over the entire DEM to minimize and remove artefacts. Next, the entire study area was divided by 30 m × 30 m grid size alongside each and individual grid filling with elevation range value for getting the relative relief map. This particular task had been done using geo-processing tools in ArcGIS (version 10.2). A vegetation map was generated by means of spectral enhancement techniques like NDVI. It comprises three major vegetation classes as high, moderate and low.

3.2 Parameter Weight Values

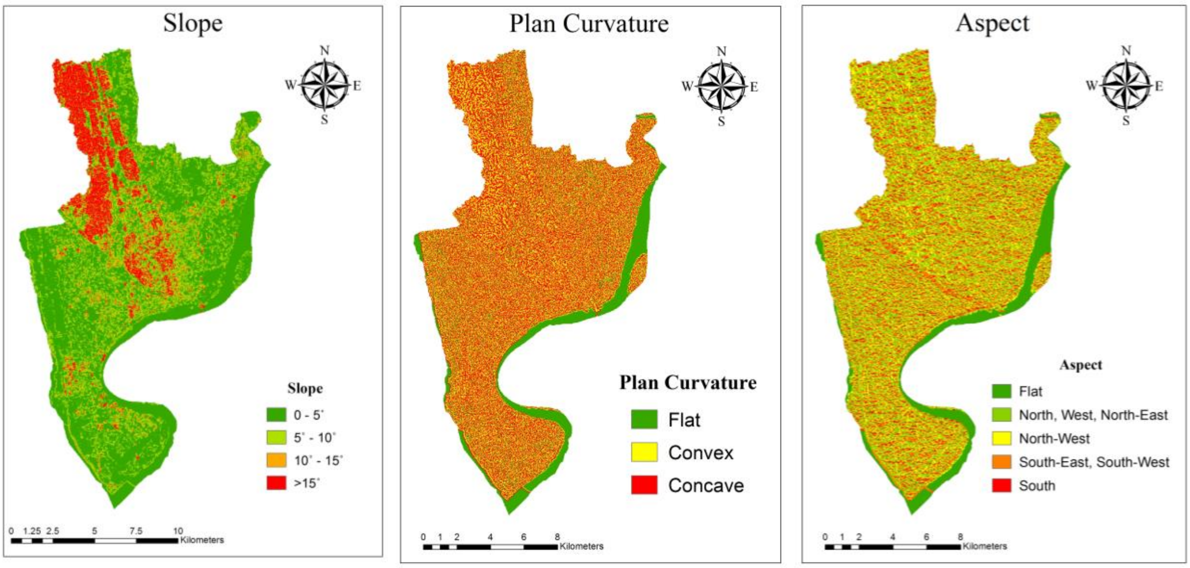
Landslide susceptibility parameters, their subclasses, and rating for individual parameters are given in Table 1.

Table-1 Weight and rank values for each and individual input parameters based on influence on landslide occurrence.

Parameter	Sub-Classes	Weight	Rank
[1] Slope	0°-5°	3	8
	5°-10°	4	
	10°-15°	6	
	> 15°	8	
[2] Plan Curvature	Flat	2	6
	Convex	3	
	Concave	6	
[3] Aspect	Flat	1	5
	North, West, North-East	2	
	North-West	3	
	South-East, South-West	7	
	South	8	
[4] Land Use/ Land Cover	River	2	4
	Urban	3	
	Vegetation	5	
	Roads	2	
[5] Geology	Beach, Dune Sand, Ocean and Wide River	1	3
	Vally Alluvium and Colluvium	3	
	Dihing Formation	4	
	Bhu-ban Formation	6	
	Tipam Sandstone	8	
[6] Relative Relief	< 15 m.	2	6
	15 m. - 25 m.	4	
	25 m. - 35 m.	6	
	35 m. - 45 m.	7	
	> 45 m.	8	
[7] Vegetation	High	3	3
	Moderate	5	
	Low	8	

The angle of the slope plays the most vital role in slope stability of a terrain. It is directly related to the landslides [15]. Moreover, residual soil gain more gravitation induced shear stress when the slope is potentially high resulting higher frequency of [16]. In this study, the entire study area was divided into 4 major slope classes. The past landslides put forward an observation that most of the slides were earth/debris flow, where natural slope angles were >15° [17]. This cognition led us to allotting higher weight value (i.e. 8) to this subclass. The other sub-classes are 0°-5°, 5°-10°, 10°-15° and their weight values are 3, 4 and 6 respectively.

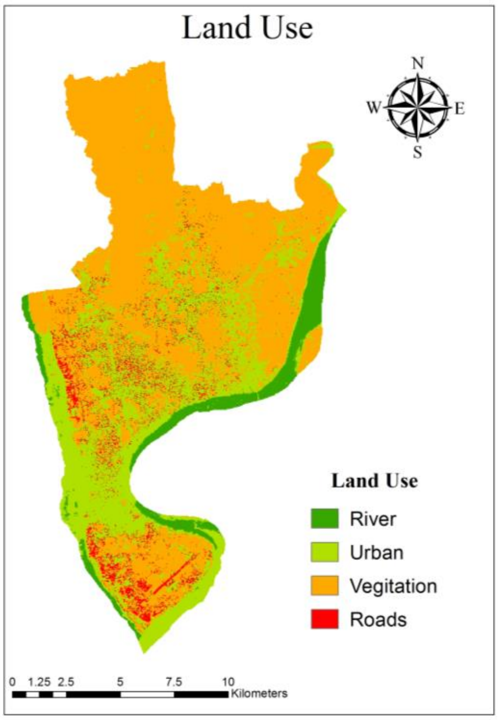
Plan curvature consists three sub-classes. Flat surface has no substantial influence in landslide thus given very low weight values as 2. Concave curvatures concentrate surface water and almost certainly trigger landslide activity, hence assigned high weight value as 6, on the other hand, in case of convex curvature surface water will diverge from slope toe thus imposing less threat to landslide, thereby, given low weight value as 3. Aspect infers exposure to sunlight and drying winds, those control the concentration of the soil moisture which may eventually control the occurrence of landslides [18]. The aspect map is divided into 5 classes as Flat; North, West, and North-East; North-West; South-East and South-West; South. Then, from the context that south, south east and south west facing slopes are more open to landslide in the studied area, higher weight values (i.e. 8, 7 and 7) were assigned to these classes, and rest of the subclasses were given lesser weight values within 1 to 3 since those are not likely to pose potential threat [19].



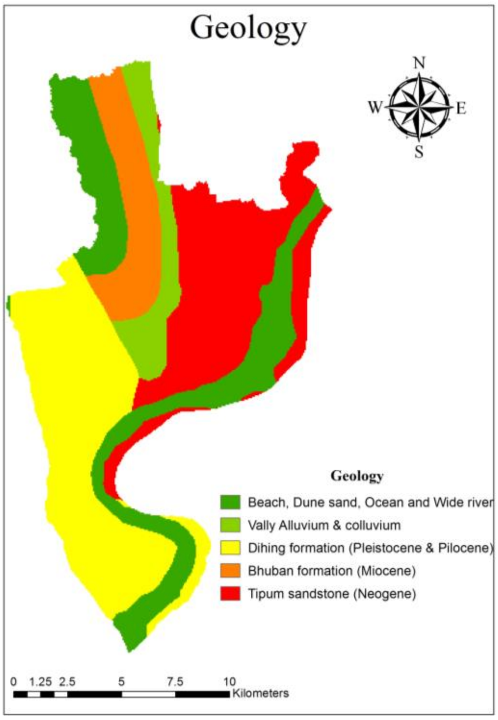
(a) (b) (c)

Figure-2(a) Slope map, (b) Plan curvature map and (c) Aspect map of the study area showing their subclasses.

Land use or land cover plays a vital role in landslide initiation. In general, the area was categorized as four classes' viz., river, urban, vegetation, and roads. Among them, vegetation areas were given highest weight value as 5, because sparsely vegetated areas exhibit faster erosion and more instabilities than forest area [20].Among the five geological units encountered in the study area Tipam / Dupi Tila formation, being comprised of, loose and less resistive sandstone layers account for maximum landslides in the study area; and thus alloted highest weight values 8 in context of landslide. Bhu-ban/Bokabill formation, on the other hand, are consist of hard and compact shale and believed to be comparatively less susceptible to landslide. Thereby, they are assigned moderate weight value as 6 in this study. Again, the Dihing Formation characterized by dominantly sand and clay lithology has given weight value 4. Rest of the units i.e. Beach, Dune Sand, Ocean and Wide River; valley alluvial and colluvial deposits, since not likely to pose any threat of landslides, are given very less weight values as 1 and 3 respectively. Relative relief is directly proportional to the probability of landslide occurrence as it controls several geologic and geomorphologic processes [19].The relative relief map of the study area has been divided into 5 classes: < 15 meter, 15 - 25 meter, 25 - 35 meter, 35 – 45 meter and > 45 meter: to show the susceptible relief of the study area. In metropolitan area, landslides occur in areas of relief above 30 meters; with this background knowledge, we put higher weight values to relief classes above 30 meter as 7 to 8.



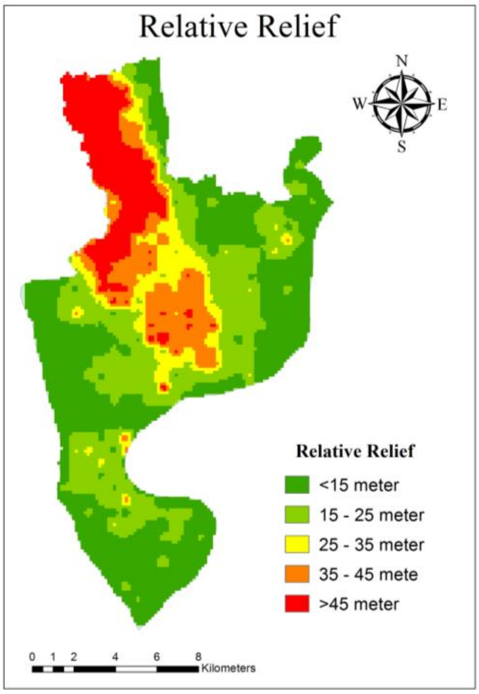
(a)



(b)

Figure-3(a) Land use map and (b) Geology map of the study area showing their subclasses.

Vegetation seems to be less risky to landslide, however, in this study, we adopted moderate weight value because of substantial occurrence of vegetation in the hilly areas of the study location. Slopes having sparse vegetation were assigned high weight value as 8 whereas moderate and high vegetation were given moderate weight values as 5 and 3 respectively [21].



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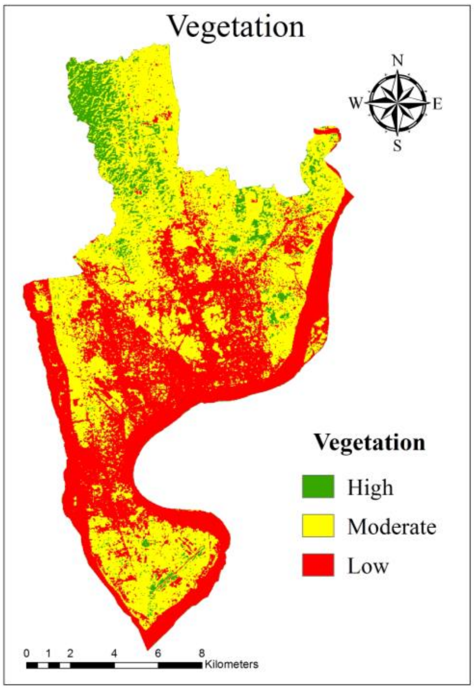


(b)

Figure-4(a) Relative relief map and (b) Vegetation map of the study area showing their subclasses.

3.3 Landslide Susceptibility Index (LSI) Mapping

The landslide susceptibility index (LSI) mapping was done with the conversion of all the spatial datasets to a common scale with weight and rank values. The reason of conversion into a common scale is that all the spatial dataset arrived from diverse source areas of the study region. Finally, integration of various thematic parameters in a single hazard index was accomplished by the procedure of weighted liner sum of the equation 1 [22].

$$LSI = \sum_{i}^{n} W_i * R_i \quad (1)$$

Where LSI is the ultimate landslide susceptibility index, W*i* is the weight of parameters subclasses, R*i* is the rank of the each and individual parameter. Once the integration was accomplished, using weighted overlay techniques in ArcGIS (version 10.2), the next step was the classification of the final outcomes.

4. RESULT AND DISCUSSION

LSI map depicts the division of land areas into zones of varying degree of stability, based on the estimated significance of the causative factors for inducing instability [23]. Using the weightage values discussed above landslide susceptibility maps were generated. The result exhibits that the values range from 79 to 258.Despite of observing the distributed pattern in histogram appearance, we applied three classification methods—natural break (79-129 as low, 129-169 as moderate and 169-258 as high risk zone), quantile (79-132 as low, 129-161 as moderate and 161-258 as high risk zone), and equal area intervals (79-138.67 as low, 138.67-198.33 as moderate and 198.33-258 as high risk zone) to attain the final hazard map. In this study, we have classified the final map into three hazard classes: Low, Moderate and High. Classification of different methods are shown in the following histograms in Figure 5(a) and 5(b)-

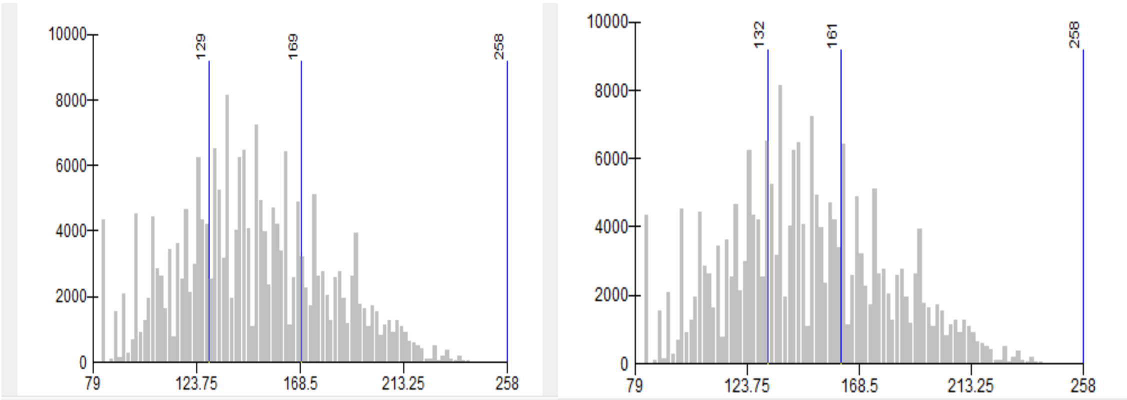


Figure 5(a). Histogram distribution for natural break (left) and quantile (right) scheme.

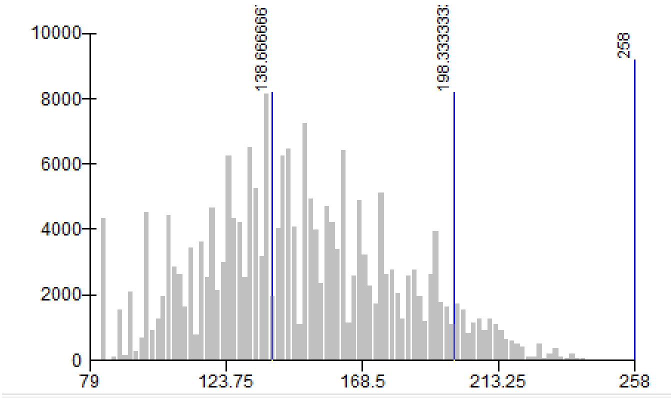


Figure 5(b). Histogram distribution for equal interval scheme.

Using these intervals following maps were generated which are showed in Figure-6(a) and,

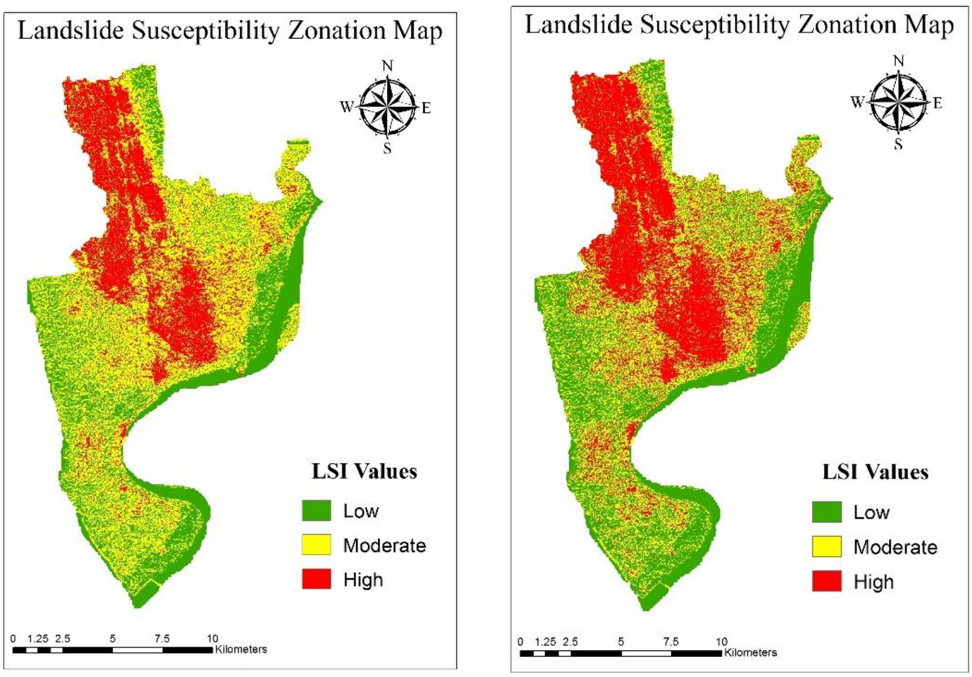


Figure 6(a). Landslide susceptibility zonation map based on natural break (left) and quantile (right) schemes.

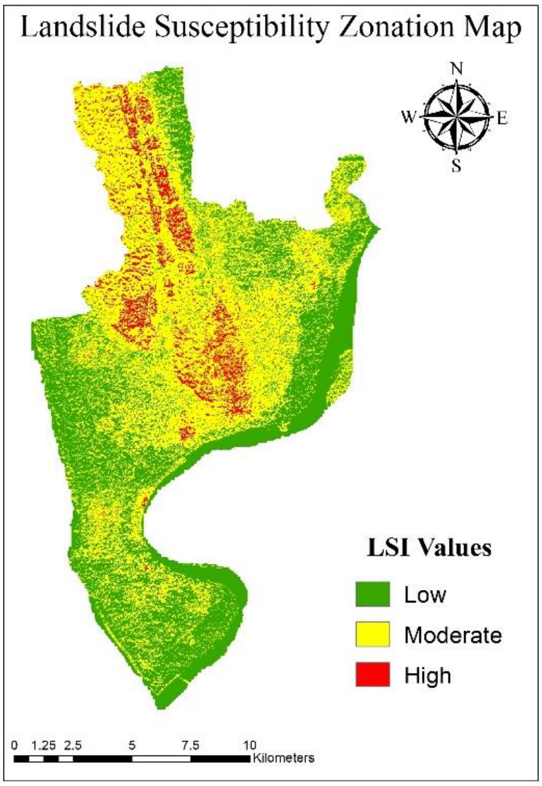
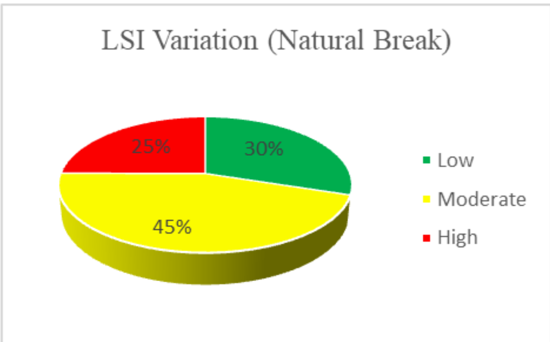


Figure 6(b). Landslide susceptibility zonation map based on equal interval scheme.

6(b). The result shows the central and northern part of the study area (Including Hathazari, Kotwali, Khulsi) is in highest risk of landslide. That means these zones are the most likely to encounter landslides. And previous major landslide events actually happened in these zones which supports the result of this analysis.

The distribution of different risk zones are shown in the following pie charts in Figure 7(a) and Figure 7(b). The result shows that about 25% of the study area (about 48 sq. km.) falls under high risk zone, about 45% of the study area (about 87 sq. km.) fall under moderate risk zone and about 30% of the study area (about 58 sq. km.) fall under low risk zone based on natural break scheme. About 33% of the study area (about 63 sq. km.) falls under high risk zone, about 33% of the study area (about 64 sq. km.) fall under moderate risk zone and about 34% of the study area (about 66 sq. km.) fall under low risk zone based on quantile scheme. About 7% of the study area (about 12 sq. km.) falls under high risk zone, about 51% of the study area (about 99 sq. km.) fall under moderate risk zone and about 42% of the study area (about 81 sq. km.) fall under low risk zone based on equal interval scheme.



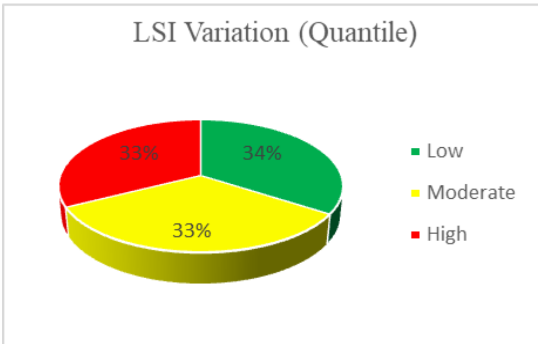


Figure 7(a). Percentage of different risk zones based on natural break (left) and quantile (right) schemes.

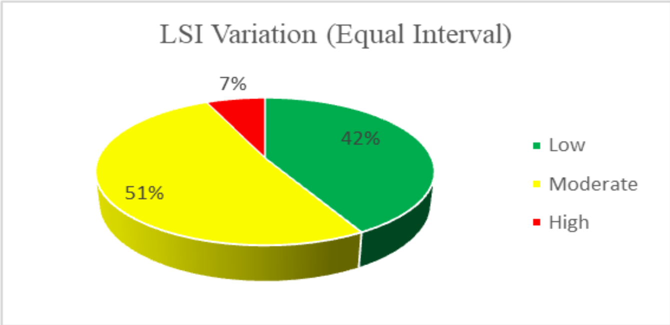


Figure 7(b). Percentage of different risk zones based on equal interval scheme.

5. CONCLUSIONS AND RECOMMANDATION

Landslide Susceptibility Index is a good measure to evaluate extend of the vulnerability prone area. The study is very important in aspect of disaster management, disaster risk mitigation, hazard mapping etc. The analysis shows that the central and Northern areas of the study area is the most vulnerable to this disaster. And the major landslides of Chittagong occurred exactly in this areas. This shows the potential applicability and importance of this sort of study. In this study seven parameters were used: Slope, Plan Curvature, Aspect, and Land use/land cover, Geology, Relative Relief, and Vegetation. For future studies, it is possible to incorporate more relevant parameters. Similar kind of studies can be carried out on other hilly areas of Bangladesh.

As this type of studies are very effective in finding out the vulnerable areas to landslide, future land development plans should incorporate this types of studies and consider for better understanding of human casualties and other damages. For this study, all the data used were open source. But many of the elements were larger in special resolution. In future, it is recommended to use more precious data sets if possible.

ACKNOWLEDGEMENTS

The Authors Express Their Gratitude Towards The Japan Aerospace Exploration Agency (Jaxa) And Usgs For Making Available Open Source Spatial Data To Carry Out The Research.

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MAPPING AND VALUATION OF BLUE ECOSYSTEM SERVICE IN AN URBAN AREA: A CASE STUDY ON WARD 30 IN KHULNA CITY, BANGLADESH

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ABSTRACT

Cities are getting increasingly dependent on the ecosystem servicers that generate both within and outside the city limit. While the city dwellers enjoys numerous benefits from ecosystem services, particularly from blue ecosystem services, they also cause degradation of these services in several ways. Therefore, the flows of a particular ecosystem services in a city is dynamic, and ofnine follow a particular trend. Knowing this dynamical nature of flows of an ecosystem service is a prerequisite to assess the benefit and the value of such benefits derived from healthy ecosystem. The paper is first, aimed to map out the blue ecosystem services available in a ward of Khulna city. Second it assesed the benefits that the local residents derive from these blue ecosystem components. Finally, some policy suggestions are given to conserve the ecosystems for ensuring sustained flow of ecosystem services in the study area of Khulna city. The study was conducted through the following steps. First all the blue ecosystem components located in the study site of the city is mapped out in GIS environment from Satellite images.The ecosystem service types, and the number of population using them and other attribute data will be collected from both field survey and secondary sources. These attribute data is linked to spatial data (ecosystem flow) in a GIS environment to assess the service areas and to quantify the value of such services. The research is underway and it is expected that the research outcome would help designing a strategy to enhance the local residents' access to sustained flow of ecosystem services.

Keywords: *Ecosystem; Blue ecosystem services; Urban ecology; Khulna city*

1. INTRODUCTION

An aquatic ecosystem is an ecosystem in a body of water. Communities of organisms that are dependent on each other and on their environment live in aquatic ecosystems. The two main types of aquatic ecosystems are marine ecosystems and freshwater ecosystems. (Alexander,1999). Ecosystem services are defined as the benefits that people obtain from ecosystems (MEA, 2005), and the direct and indirect contributions of ecosystems to human well-being (TEEB, 2010).The concept of ecosystem services is relevant for connecting people to nature. It makes visible the key role of ecosystem functioning and biodiversity to support multiple benefits to humans. Understanding the linkages between the natural and socio-economic systems can lead to improved and more sustain-able management of ecosystems (Guerry et al., 2015).

In the coming decades population growth and changes in diet will increase the global food demand and consequently the water demand for agricultural production (Devi et al., 2014). Water, food and energy are at the core of human needs and there is a boundless complex cycle among these three elements which has been recently referred to as the water–food–energy nexus (Zhang, 2002) To produce food, water and energy are needed; while to produce energy, water is required; and to access water, energy is almost always needed (i.e. to run pumps). Due to the complexity of relationships among these three elements, there is a need for them to be considered simultaneously. According to (Costanza, 2014) ecosystem services contribute at least 125–145 trillion US $ per year to the global economy and to the livelihood of more than a billion poor people in the world. Due to the value of ecosystem services to humans, governments around the world are beginning to recognize the importance of investing in safeguarding ecosystems as opposed to industrialized solutions to their problems.

The paper is first, aimed to map out the blue ecosystem services available in a ward of Khulna city. Second it will assess the benefits that the local residents derive from these blue ecosystem components. Finally, it will put some policy suggestions to conserve the ecosystems for ensuring sustained flow of ecosystem services in the study area of Khulna city. Develop a practical methodology for assessing and valuing ecosystem services relevant for water resource management, considering the links between pressures, ecological status and ecosystem services.

Major limitations of this research are the blue ecosystems (water body) having the area greater than 0.0024 square km only considered for the research, for calculating Habitat Suitability Index only 9 variables were taken and as it is a preliminary research only two blue ecosystem services were analyzed.

The paper is structured as follows. The first part describes the methodological approach adopted in the study. The second part presents the results of our analysis in the form of a practical approach for assessing and valuing ecosystem services relevant for water resource. The third part discusses the challenges in valuing ecosystem services and integrating biophysical and economic assessments.

2. THEORETICAL FRAMEWORK

An ecosystem is defined as a structural and functional unit of biosphere consisting of community of living beings and physical environment, both interacting and exchanging materials between them. Ecosystem is a self-contained, dynamic system composed of a natural community along with its physical environment. It is a community of organisms involved in a dynamic network of biological, chemical and physical interactions between themselves and with the nonliving components. An ecosystem is also defined as a functional and structural unit of Ecology (Priscila et al.) This implies that each ecosystem has a definite structure and components and that each component part of the system has a definite role to play in the functioning of the ecosystem (Devi et al., 2014). Ecosystems have two ‘parts’: The living (**Biotic**) components like plants and animals; and the nonliving (**Abiotic**) components like water, air, nutrients and solar energy. These two parts of the ecosystem do not stand in isolation, rather they continuously interact with one another. In fact, they are so closely linked to each.

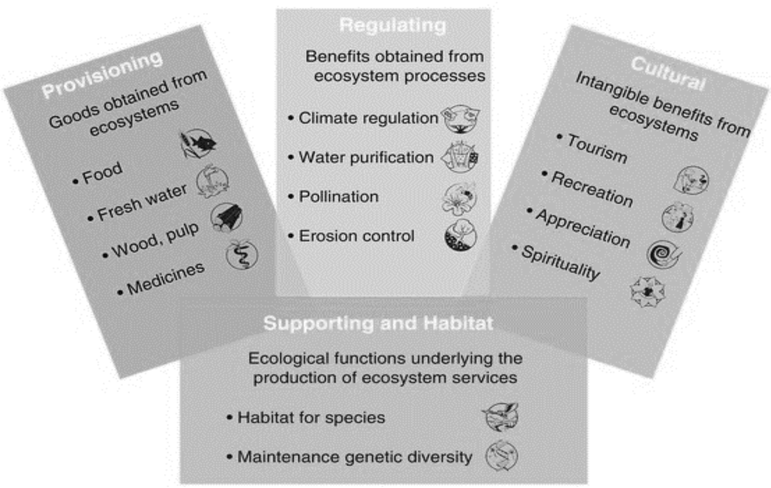

Figure 1: Classification of ecosystem services, The Economics of Ecosystem and Biodiversity (TEEB)

2.1 Ecosystem Service Values:

Valuation of ecosystem services involves dealing with multiple, and ofnine conflicting value dimensions (Oldham, 2000). In this section, we broaden the traditional focus of the ecosystem services literature on biophysical measurement and monetary values to explore a range of value domains, including biophysical, monetary, socio-cultural, health, and insurance values, and discuss concepts and methods through which they may be measured and captured.

2.2 Habitat Suitability Index (HSI) for fishes:

HSI scoring systems were originally developed by the US Fish and Wildlife Service as a means of evaluating habitat quality and quantity. An HSI is a numerical index, between 0 and 1. 0 indicates unsuitable habitat, 1 represents optimal habitat.HSI evaluates (pond) habitat quality. (Oldham, 2000).

How to collect data and calculate HIS

The HSI is a geometric mean of nine suitability indices:

HSI = (SI1 x SI2 x SI3 x SI4 x SI5 x SI6 x SI7 x SI8 x SI9 x SI10) ^1/9

- The nine Suitability Indices are scored for a pond, in the field and from map work.
- The nine field scores are then converted to SI scores, on a scale from 0.01 to 1 (0.01 is used as the bottom end of the range instead of 0, because multiplying by 0 reduces all other SI scores to 0).
- The nine SI scores are then multiplied together.
- The ninth root of this number is then calculated (X)˜1/9 the calculated HSI for a pond should score between 0 and 1.

HSI	Pond suitability
<0.5	Poor
0.5- 0.59	Below average
0.6- 0.69	Average
0.7- 0.79	Good
>0.8	Excellent

Suitable Criteria:

a)Geographic Location (SI-1)
b) Pond Area (SI-2)
c)Pond Drying (SI-3)

Field score	SI	Criteria
Never	0.9	Never dries
Rarely	1	Dries no more than two years in nine or only in drought
Sometimes	0.5	Dries between three years in nine to most years
Annually	0.1	Dries annually

d) Water Quality (SI-4)

Category	SI	Criteria
Good	1.0	Abundant & diverse communities Netting = diverse inverts including may fly larvae & water shrimps
Moderate	0.67	Moderate invert diversity
Poor	0.33	Low invert diversity (e.g. Species such as midge and mosquito larvae), few submerged plants
Bad	0.01	Clearly polluted, only pollution tolerant species (rat-tailed maggots), no submerged plants

e)Water Depth (SI-5)

Category	SI	Criteria
Good	1.0	More depth (more than 3 m)
Moderate	0.67	Moderate depth (2-3 m)
Poor	0.33	Low depth (about 1 m)

f) Phytoplankton (SI 6)

Category	SI
Adequate	1
Possible	0.67
Minor	0.33

g) Waste dumping (SI 7)

Category	SI
Absent	1
Possible	0.67
Minor	0.33
Major	0.01

h) Adjacent ground cover (SI 8)

Category	SI
Adequate	1
Minor	0.50
Absent	0.01

i) Presence of water hyacinths (SI 9)

Category	SI
Adequate	0.01
Minor	0.33
Absent	1

3. STUDY AREA AND METHODOLOGY

3.1 Study Area

The geographic area of Khulna city is bounded by Jessore, Narail districts to the north, The Bay of Bengal to the south, Bagerhat district to the east, Satkhira district to the west. Total area is 4394.45 Sq Km. There are 31 wards in Khulna city corporation. The selected study area is ward 30 (Figure 2) that it has a population of 18719 male and 17108 female where the literacy rate is 74.2% . It is in 24.47'N and 89.35'E. There is a salient feature of the study area that Rupsha river flows beside the ward and a huge number of water body also available there.

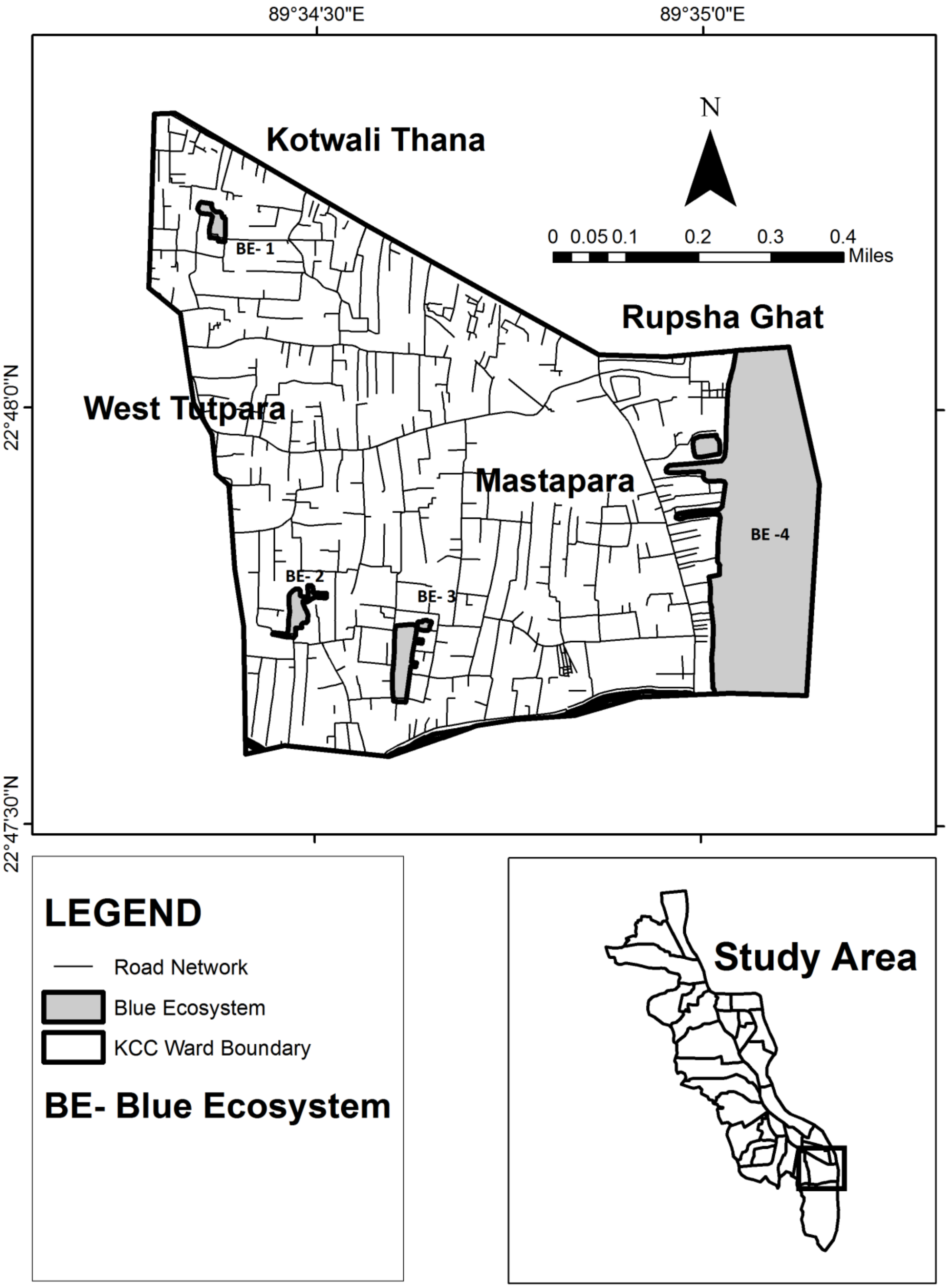

Figure 2: Ward 30 (Study Area), Author 2017

3.2 Methods

After the fixation of the study area, preliminary data was collected through the desktop research and reconnaissance survey were done. Then conceptualization of the problem completed by reviewing a huge number of literature about the blue ecosystem and the valuation. Questionnaire survey was done for finding the user's perception and the relationship between the variables. Collected data was inputted in SPSS, Excel and GIS specially used here to analyze the problem. Statistical analysis, satisfactory level analysis and Habitat Suitability index were the focused issue in this research. Habitat suitability index was analyzed for assessing the habitability condition of fishes in the ponds of Ward 30. Satisfaction level also identified through these analyses. The results of the analysis were interpreted and at last some findings were mentioned on the basis of the overall analysis. Index is analyzed for certain service such pond which is given below: Evaluates (pond) habitat quality. Factors are scored for the pond convert to SI scores ranging from 0.01- 1. The calculated habitat suitability index should be between 1 and close to 0.

Table 1: Habitat Suitability Index

HSI	**Pond Suitability**
<0.5	Poor
0.5- 0.59	Below average
0.6- 0.69	Average
0.7- 0.79	Good
>0.8	Excellent

On the basis of the findings and the present condition of the low-income people and the impacts of the various issues of ecosystem services and disservices of the study area, some recommendations were provided. The recommendations were provided in such a way that they may help to improve the ecosystem services and reduce the ecosystem disservices.

4. PRELIMINARY FINDINGS

4.1 Basic information

There are different types of people for maintain the ecological balance. Among them maximum people have only Secondary education and their family member also large. The demographic table also shows the composition of the population structure.

Table 2: Demographic information

		Family member			**Total**
		2	**3-5**	**>5**	
Education	Illiterate	0	2	0	2
	Primary	0	2	0	2
	Secondary	3	8	2	13
	Higher Secondary	0	4	0	4
	Degree and Above	0	2	0	2
	Technical Education	0	2	0	2

(Field Survey, 2017)

Table 3 shows the dependency relationship among the different ecosystem services in the locality. Blue ecosystem services mainly served as supporting and provisioning services which is shown in the table that the Sig. value between them is quite satisfactory than others.

Table 3: Sig. value of different types of services

	Cultural	**Provisioning**	**Supporting**	**Regulating**
Cultural	1	.220	.728	.599
Provisioning	.220	1	.019	.226
Supporting	.728	.019	1	.381
Regulating	.599	.226	.381	1

(Field Survey, 2017)

4.2 Social Value

In the locality people satisfaction level was judged by the survey and the result shown in figure 2 that about 39% food is generated from the blue ecosystem services. People really relied on this part of service facility and the willingness to pay for protecting this service is very high than other services. The social value of the service is measure from the checklist which shows that the value of the blue ecosystem is higher than the other parts.

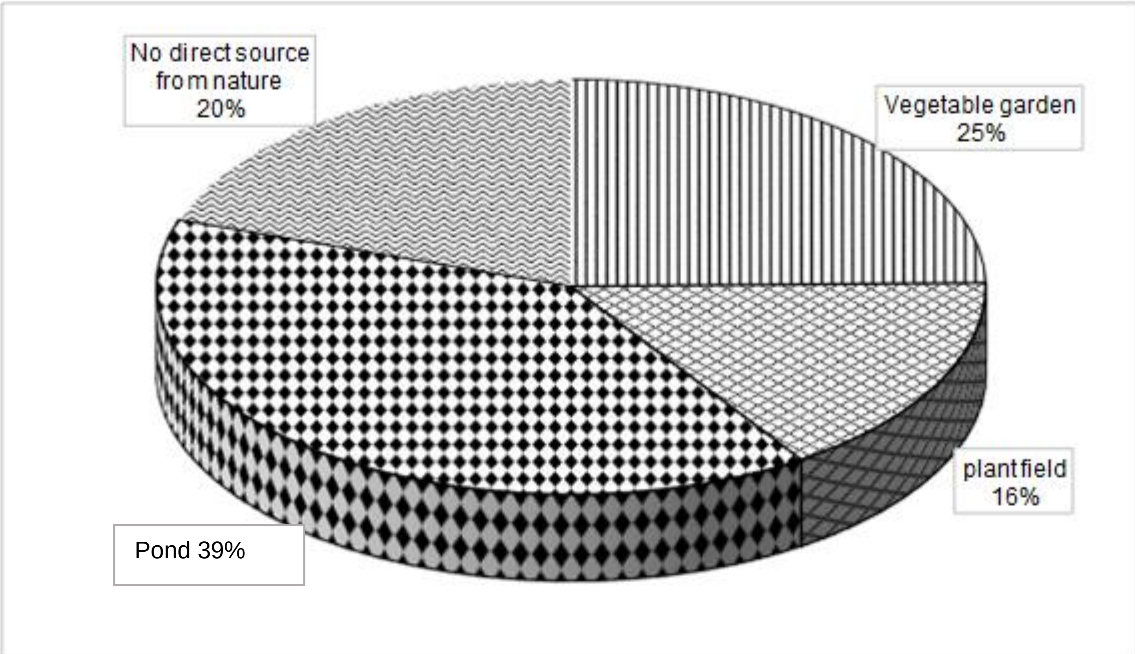

Figure 3: Direct source of food from nature (Field Survey, 2017)

From the survey data it was observed (Figure 3) that there exists 8 ponds in Ward 30 and the linear regression equation about the different ecosystem services is **$y = -1.2x + 6$ and $R^2 = 0.3495$**. The result indicates that there is no well-balanced combination among the ecosystem services. The model is moderately acceptable.

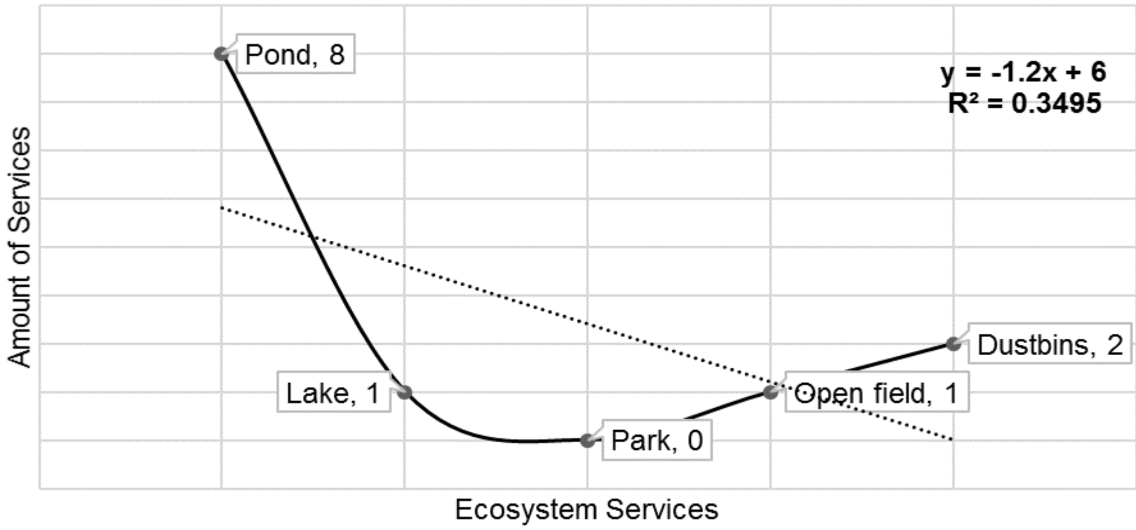

Figure 4: Different Ecosystem services of study area (Field Survey, 2017)

4.3 Habitat Suitability Index

Blue Ecosystem - 1

Location:
Latitude:22°48'15.1"N
Longitude: 89°33'40.5"E

Criteria	SI
a) Geographic Location (SI-1)	0.8
b) Pond Area (SI-2)	0.8
c) Pond Drying (SI-3)	0.5
d) Water Quality (SI-4)	0.33
e) Water Depth (SI-5)	0.33
f) Phytoplankton (SI- 6)	0.67
g) Waste dumping (SI- 7)	0.01
h) Adjacent ground cover (SI- 8)	0.50
i) Presence of water hyacinths (SI- 9)	0.01

(Author, 2017)

HSI = [1.167*10^ (-6)] ^ (1/19)
=**0.22**

As, Habitat Suitability Indices (HSI) value is less than 0.5, this pond is unsuitable for fishes and it has poor condition.

Blue Ecosystem - 2

Location:
Latitude:22°47'04.1"N
Longitude: 89°34'00.3"E

Criteria	SI
a) Geographic Location (SI-1)	0.9
b) Pond Area (SI-2)	0.9
c) Pond Drying (SI-3)	0.9
d) Water Quality (SI-4)	0.67
e) Water Depth (SI-5)	0.67
f) Phytoplankton (SI 6)	1

g) Waste dumping (SI 7)	1
h) Adjacent ground cover (SI 8)	0.50
i) Presence of water hyacinths (SI 9)	0.33

(Author, 2017)

HSI = 0.054^ (1/9) = **0.72** As, Habitat Suitability Indices (HSI) value ranges from (0.70-0.79), this pond is suitable for fishes.

5. CONCLUSIONS

Blue Ecosystems and the services they deliver underpin and enable our exisninece. For producing food, regulating water supplies and climate, and breaking down waste products ecosystem is very essential. We also value them in less obvious ways: contact with nature gives pleasure, provides recreation, has aesthetic appeal and is known to have a positive impact on long term health and happiness.

From the study, it has been found that 39% food is generated from the blue ecosystem services in ward 30 so that people are greatly depends on it. Here the value of R^2 is 0.3495. The result indicates that there is no well-balanced combination among the ecosystem services as the value of R^2 is very higher than .005 at 5% sig. level. From the suitability index it can be said that the living condition of fishes may certainly depends on 9 criterias. The value of the first BE shows that it is 0.22 and it stands for unsuitable situation where it puts negative impact on environment. Second observation may describe it is good for the fishes. So, this procedure may apply for further research to know the scenerio of blue ecosystem services and the consequences.

Now it is important to think about why they are important in terms of governance and policy making. European and international state governments and organizations have recognized that economic value can be gained by including ecosystem service assessment in policies and decision making. By understanding these considerations from the start, it is possible to avoid significant costs and risks to policy objectives, and help to increase long–term resilience of policies. Also, to reduce risks to our policy objectives from failing natural systems and to reduce public costs from degraded natural services.

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PRESENT SCENARIO OF MUNICIPAL SOLID WASTE MANAGEMENT IN SATKHIRA MUNICIPALITY

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ABSTRACT

The increasing quantity of solid waste is a burning issue and is faced by all developing countries specially in urban areas due to increasing population rate, rapid economic growth, rise in community living standard and unawareness of common people. This study aimed at investigating present scenario of solid waste management in Satkhira municipality located in the south west corner of Bangladesh. This paper has been planned to collect primary and secondary data, field observation, questionnaire survey, total operating cost and give some proposal for the improvement of proper solid waste management through various schemes to ensure sustainable development. Questionnaire Survey 2017 reveals that in Satkhira Municipality (SM) many people have no proper idea on Municipal Solid Waste Management (MSWM). In spite of containing 110 dustbins, a large number of people drop their waste beside the road, due to distance and miserable dirty condition. The municipality collects the solid waste from dustbins and secondary disposal sites. It has 3 trucks, 8 rick-vans and 2 alom-sadhu and a total number of 92 waste collectors. The current coverage of this facility is about 50% of the municipal area and the collected waste is about 10 tons/day which is only 25% of the total production. Moreover, clinical and industrial wastes are not managed by SM. The Municipality has installed a dumping station (9.84 acres) in Binerpota. Recently, a Bio gas plant (80m3) has been installed in Rosulpur to generate energy from waste. Some public-private partnership initiatives have been taken to facilitate resource recovery and sustainable environmental development.

Keywords: *Solid waste generation, solid waste management, questionnaire survey, uncontrolled dumping, sustainable development*

1. INTRODUCTION

Waste refers to materials, produced from all levels of human and animal work which are designated as useless or unwanted. According to Global Waste Management Market Assessment (2007) around 2.02 billion tons of waste are producing annually around the world with an annual increasing rate of 8%. Safe and sustainable waste management is now one of the imminent challenges in the urban dominated modern world. Increasing population, and development of community living standards, rapid urbanization and industrialization are working as a catalyst in solid waste generation rate in developing countries particularly in urban areas. Bangladesh is currently experiencing a period of rapid growth and urbanization concurrently with which proper management of generated solid waste is becoming a major issue otherwise it will cause health effect, aesthetic problem, drainage congestion, and odor, even might contribute to climate change issue (Rashid et al, 2011). The problem of waste is not only the due to the increase in number but also the lack of management system (Tinmaz & Demir, 2006). The municipalities are failing to provide proper waste management service to its dwellers due to severe financial constraints, lack of motivation and the absence of effective legislation to protect the environment and to handle the waste, the whole system is becoming a threat for city dwellers, planners and other concerned stakeholders (Alamgir & McDoland, 2005). Like all the other municipalities in Bangladesh Satkhira municipality is also facing a huge challenge finding a way to manage its solid waste in a proper manner. It has a daily waste generation rate of 48.2 tons in which only around 12 to 15 tons are collected and managed by the municipality. Which shows that a huge amount of wastes remains unmanaged which is very alarming for its inhabitants. To ensure a clean, hygienic, and beautiful Satkhira the municipality is in search for a proper waste management system. All the tires of MSW management at Bangladesh are in the primitive stage and needs modernization through innovative and appropriate approach in association of local conditions for its proper management (Alamgir & Ahsan, 2007). To make a plan for the sustainable development of the SWM system the analysis of the present waste management system is necessary. This study aims to provide a clear and quantitative concept of the present scenario of solid waste management system in Satkhira municipality through physical investigation as well as social survey to seek out the motivations, problems and opinions of its dwellers. The final objective is to create a platform for planning of a Sustainable Waste Management System for Satkhira Municipality.

2. STUDY AREA

The study was conducted in Satkhira municipality located between latitude of 22°43'41''N and longitude of 89°05'54''E. The study area was comprised of 9 wards covering an area of 31.10 sq. Km. Figure 1 shows the location & map of satkhira municipality. Satkhira, the land of Sundarbans, gained a huge reputation as a business town for Bhomra port, the largest land port of Bangladesh. It is also famous for the production and export of Shrimp and mango. Satkhira municipality was introduced first as a "C" grade municipality in 1869 with an area of 31.1 sq. Km. It was reconstituted as Satkhira Town Committee in accordance with the provisions of Basic Democracies Order, 1959. Satkhira Town Committee was replaced by Satkhira Shahar Committee according to the Bangladesh Local Councils and Municipal Committees (amendment) in 1972. And then in 1977, it was replaced by Satkhira Pourashava in accordance with the Pourashava Ordinance and was declared an "A" class municipality with 7 mouzas namely Katia, Satkhira, Polaspole, Ramdebpur, Dohakhula and Rasulpur under its administrative jurisdiction with 9 wards. Satkhira municipality has a total population of 153,969 nos. Satkhira municipality is very sincere in providing good municipal facilities to its dwellers. In this regard, proper management of generated solid waste has become a huge challenge for the municipality as it is a prerequisite to maintain a healthy and safe environment. So, they are trying to improve the present solid waste management system by undertaking various policies. Yet a huge amount of solid waste is remaining unmanaged. To improve this situation the existing solid waste management system should be analysed and its weaknesses should be pointed out. In that context, this study will help a lot.

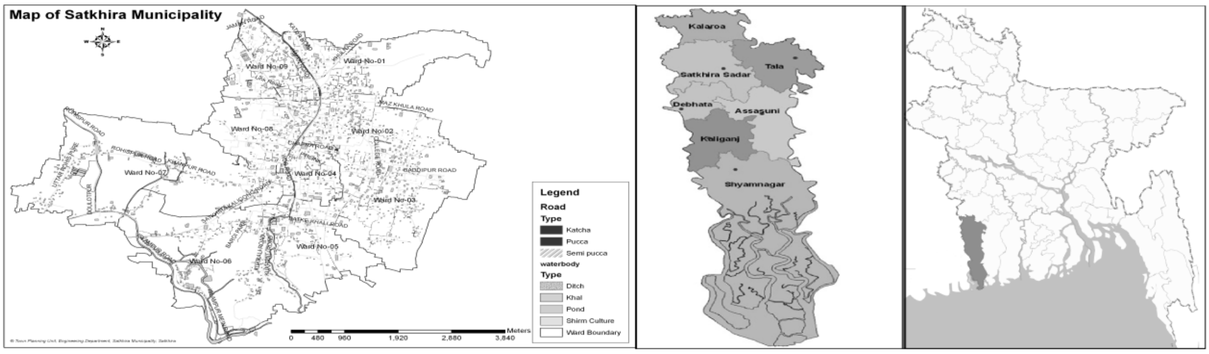

Figure 1: Location & Map of Satkhira Municipality

3. METHODOLOGY

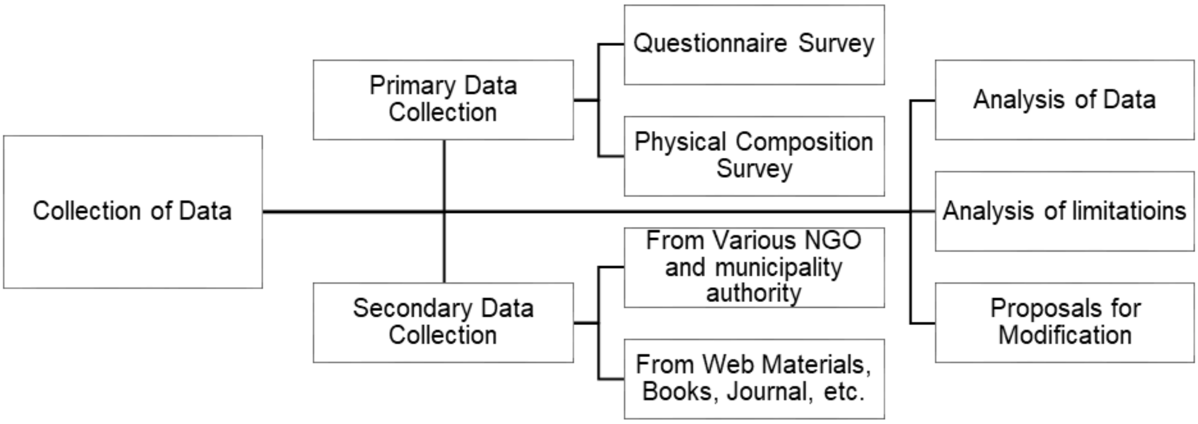

Figure 2: Flow Diagram

3.1 Collection of Data

3.1.1 Collection of Primary Data

The primary data was collected by means of two types of field survey. One is physical composition survey in the various points of the study area and the other is questionnaire survey.

The physical composition survey was conducted for the determination of the composition of the generated solid waste. Samples were collected from secondary disposal sites (SDS) and door to door collection vans. 10 kg samples were taken from each SDS and vans. The composition of the solid waste in percentage is computed by taking weight of the different components.

Figure 3: Satkhira Pourasava

A questionnaire was prepared for the survey. The study area has the population of 144245 nos. The sample size of the survey was determined by using Solvin's formula. Considering maximum degree of variability and a confidence level of 93%, the sample size is 204 nos. In every ward 24 surveys are made and total 216 nos surveys are conducted. The sample was taken randomly by using random table for getting unbiased result. After the collection of primary data, the raw data were processed by using Statistical Package Software Spreadsheets (SPSS) to meet up the objective of the study.

3.1.2 Collection of Secondary Data

In addition to the primary data, secondary data were collected from different sources. The information on area, household, population were gathered from Satkhira Municipality authority. Data about the present system of solid waste management, no of dustbin, workers, vehicle etc. were collected from the conservancy sector of Satkhira Municipality. The information about ongoing initiatives on SWM were collected from the town planner of Satkhira municipality.

4. RESULTS AND DISCUSSIONS

For the correct assessment of overall SWM situation in Satkhira municipality it is important to know about the waste generation, waste collection, transportation and disposal, waste recycling including composting. The data on existing management practices in the study area were collected in various possible ways. A questionnaire was prepared for the survey. The study area have the population of 144245 nos. The sample size of the survey was determined by using Solvin's formula. Considering maximum degree of variability and a confidence level of 92%, the sample size is 209 nos. in total. Here we took the number of perticipants in the survey was 214 nos. The characteristics of the respondents were as follows. (a) Sex: The nos. of male and female were 81 and 133 respectively, (b) Education: The education level was found as postgraduate 23, graduate 35, HSC 30, SSC 55, Secondary 27, Primary 22 and illiterate 17 nos., (c) Age: The respondents with respect to age group were 1.4% teens, 6.9% adults, 48.6% middle aged, 43.1% senior citizen, (d) Profession: The profession was found as housewife 95, day-labourer 10, shopkeeper 3, service holder 59, business 32, student 9, retired 7 nos., (e) Family Income: The family income of the respondents were 34.3% low income, 49.5% medium income and 16.2% high income. A physical composition survey also conducted to find out the composition of the generated waste.

4.1 Waste Generation

Solid waste is heterogeneous composition of wastes, organic and inorganic, rapidly and slowly biodegradable, fresh and putrescible, hazardous and non-hazardous, generated in urban areas due to human activities (Alamgir & McDonald, 2005). It is, however, difficult to obtain retainable data for quantity and composition of solid wastes generated at different places. This is primarily because most data are based on measurements of waste at the disposal sites (Ahmed and Rahman, 2003). According to Satkhira municipal authority approximately 40 tons of solid waste generates every day. The composition of solid waste depends upon a number of factors such as food habits, cultural tradition, socio-economic and climatic condition. From the physical composition survey composition of generated solid waste was derived (Fig. 5). It is found that among different components the amount of food and vegetables was found to be comparatively higher (68.47%). As it is biodegradable, it can be used to make compost and only 26% being non-compostable. As the large quantity of organic content is present for this it need regular collection and removal.

In a study by JICA (2004) it has been found during wet season the waste generation rate increases by 46%. In another study by Ahmed (1991) this variation was found to be within 15% to 50%. Composition of solid waste varies not only from city to city but even within the same city itself and also seasonally (Enayetullah, Sinha, & Khan, 2005). Satkhira district is traditionally famous for the production, manufacturing and exporting of mangoes in the huge extent. So, it is easily prominent that the composition of solid waste varies in mango and non-mango season. Here, the period from April to August is denoted as the 'Mango Season' and remaining mouths are 'Non-Mango Season' (Sharholy, Ahmad, Mahmood & Trivedi, 2008). In Bangladesh, the summer starts from April. But the marketing of the mangoes starts with green mango from the midway of March. In March, only 15% of total waste composites with mango waste. The tidal season of the mango production is from May to July because of further warm and interim precipitation. In figure 4 we showed the quantity and variation of Solid Waste generation during both mango and non-mango season.

The mango waste contribution is expressed as the tidal near about one-fourth of total waste generation. Therefore, additional management should be introduced to control the huge amount of mango and mango waste. According to collected data, the annual production of the mango is about 20 million tons in Satkhira town. According to their estimation, 5% of total collected mangoes get rotten and disposed as solid waste. Besides, the post-consumption wastes of mango are mainly seeds called as pit containing kernel and thick peels. The seed represents from 20% to 60% of the whole fruit weight, depending on the variety. The kernel inside the seed represents from 45% to 75% of the whole seed (Maisuthisakul et al, 2009). The peel represents 7% to 24% of the whole weight of mango (Bedardini et al, 2005). According to the available varieties of the mango in Satkhira, the seed contains 50% and the peel contains 10% of total weight of the mango. In mango season, the average daily mango waste generation is about 8.1 tons which are about 19.3% of daily waste generation. On the contrary, this waste generation tends to become zero as the mango is a seasonal fruit. But the quantity of other waste remains more or less same.

4.2 Waste Collection

A main portion of municipal solid waste is generated from households. After generation of waste householders store waste in different system. From questionnaire survey it is found that 53.7 % household store generated waste in dustbin/basket, 6.9% store in polythene bag, 35.9% in open space and 3.7% do not store at all (Figure 10). From field observation it is found that the storage system is related to the income and socio-economic status. Majority portion of medium and high-income family uses dustbin to store their waste. On the other hand, majority portion (55.4%) of low income family store waste in open place. Most of the people use same storage for both organic and inorganic components. Some inorganic wastes are reusable such as plastic bottles, paper, textile etc. There is an informal sector which contributes a lot to waste management.

4.2.1 Primary Collection & Accumulation

4.2.1.1 Collection of SW from door to door and dustbin

The disposal and collection system in Satkhira Municipality are the conventional process of the dustbin. There is total 110 number of dustbin available in this town of which around 60 dustbins are being used.9-part time waste collectors cover specific number of household. 13 waste collector work part time to collect restaurant waste specially. They also work in Municipality in master roll. Municipality have more than 70 waste collectors to collect waste from public places and drains. The part time waste collector uses different types of waste collection vans including mechanized and non-mechanized ones, capacity varying from 250-350kgs generally covered or open. Another group of waste collector collect recyclable waste in different modality. They collect directly from households; the maids generally collect them and sell them. About 70 dustbin collectors collect waste from all of the 11 wards every day in the morning. Primary collection time is from 6.30 AM to 10.30 AM. The mango waste is also disposed at the dustbin by both the public and companies. The van unloads the waste to the secondary transport station.

4.2.1.2 Collection of drain sludge and SW by cleansing of drain

The total length of drain of Satkhira municipality is 260 km. Of these 115.24 km of katcha drain, 10.89 km of RCC drain and 58.90 km of brick drain. Satkhira municipality on the supervision of the conservancy department cleans the drain at regular intervals by its sweepers. Sometimes on request or on complain the emergency team of the sweepers clean the drain. The sweepers remove the dug-up materials which mostly compose of grit, sand and decomposed organic substances on the roadsides or the drain sides for drying. After drying within several days, it is transported to the final disposal site by the garbage trucks.

4.2.2 Secondary collection & disposal

After the collection of the SW by the garbage vans the waste are disposed or stored in the SDS or ramps by the garbage vans. There are 5 secondary disposal sites in Satkhira. They are Powerhouse more, Itagacha, Katia, Kukhrali and Terminal more. The municipality has 89 skilled workers, 1 heavy truck having capacity of 4 ton, 2medium truck with 2.5-ton capacity. Besides it has 8 vans and one alom-sadhu to carry the waste from secondary disposal site to the final dumping station. In Figure 4 some of the vehicles used by Satkhira Municipality are shown. This project costs the municipality around 390000 taka including al the salary and other expenses.

4.3 Final Disposal Site

Previously there were no final dumping or disposal site in Satkhira Municipality. The municipality often dumped their waste in different places like Labsha, Abader-hat, Bakal etc, and places far from the town. But this was not a very good solution because the waste there remained untreated and hazardous for both man and animal life. So Satkhira municipality has recently taken steps to eradicate this problem. They recently acquired a place having an area of 9.84 acre and declared it as dumping ground of municipal solid waste. Now they have started to dump the waste there.

4.4 Waste Management & Practical Action

"Practical Action" is a non-government organization, working to develop the socio environmental condition of the poor people. Recently they have started a good humanitarian programme in Satkhira municipality. They have combined with another NGO named "Practical Action" and trying to develop the waste management system by helping the conservancy section of the municipality in collecting and disposing the generated solid waste. Previously there was no household or door to door waste collection system in Satkhira municipality. But recently the conservancy section started a joint venture program with "Practical Action" to collect waste from door to door collects SW by door to door garbage vans. It has 10 garbage vans, 10 workers (drivers) work on the garbage vans. Each van collects SW from about 70-80 households. Figure 8 denotes some of the works that Practical Action has performed in Satkhira the workers start collecting waste early in the morning from the households and work till afternoon. Householders collect and store their waste in a basket or bin. The garbage van-drivers come and blow their whistle. The householders drop their collected waste into the garbage vans. The garbage vans carried these waste to the Secondary Disposal Site (SDS) or ramps. But this process is still at its primary stage. They only manage to collect waste from about 700 households. But they have a plan to expand this in other part of the municipality also. The collection workers are not paid by the Satkhira municipal authority. They collect money directly from the household owners. About 50 taka per month is paid by the users. The amount varies from ward to ward, even in the same ward house to house. Not all household uses this service. There is a mix opinion in low income dwellers about the opinion on the payment of the door to door service. But majority portion of medium and high-income community do agree to pay for the service. Practical Action has also set up a Biogas plant to treat the collected household bio degradable waste. In figure 12 some pictures of the bio gas plant taken while we visited the plant are shown. Primarily they have set up a plant having capacity of $50m^3$ and gave gas connection to 5 houses. The householders are using this biogas for their daily use. The Managing Director of Practical Action has said that he has a plan of expanding the whole program in a broader level.

4.5 Problems & Limitations

Municipalities are unable to achieve its goal of SWM because of lack of technical infrastructure and human resources, relevant data, statistical records, proper planning, insufficient budget, less private participation and unnecessary political interventions (Singh, & Gupta, 2011). Satkhira municipality is trying to develop the condition yet a portion of generated waste remain unmanaged. From the survey it is found that 45% resident are not satisfied with the present SWM system of Satkhira municipality. From the respondents of survey about 14% found the present system satisfied, 38% good and only 3% found it very good (Figure 11). One of the main objective of this study was to analysis the present situation of SWM in Satkhira municipality and find out its lapses and constrains. Residential waste is the main source of MSW in Satkhira municipality. Although municipal solid waste includes both residential and commercial waste, but this study mainly focuses on the residential waste and exclude other waste such as commercial waste, institutional waste etc. Informal sector plays a vital role in recycling of solid waste. Waste pickers locally known as "Tokai" collect recyclables from the crude dumping sites and sell it to market. Hawkers' collects reusable and recyclable material such as plastic bottle, paper, textile and metal from the household and sell it to the recyclable market. The SDS of the municipality are located roadside, causing the reduction of effective width. Again, for in sufficient space and lack of awareness in garbage van drivers usually waste overflow or deposited at the surroundings. This creates an unhygienic condition and reduce the economic value of the area. There is also lack of awareness in municipality residents. They dispose their waste directly to the drain and cause blockage. There is no local dustbin in Satkhira municipality. It has been observed that people throw waste in the surroundings of the dustbin or in an open place (Figure 9) and many people don't want dustbin near to their resident. So, who do not use door to door system, have no option than dumping in an open area or in drains. Most of the low-income resident do not want to use door to door service as they have to pay a certain amount per month. So, they dump in open place. As the van puller and helpers engaged in door to door collection system get tinny salary, uncertainty of salary. From the Municipal authority we came to know that they have a long-term plan for upgrading the management system, but lack of proper budget is a great restraint in this path although the annual budget in this sector is at upward direction in the last few years (Figure 13). There is a lack of encouragement to perform the duty properly. The Bio-gas plant of Practical Action is a good opportunity to convert waste into resource. But it is not running to its full potential as yet the municipality do not get the license to sell compost in the market. They are selling compost locally. As the expenditure of the compost plant is derived from the selling of compost, it is becoming difficult to run the plant to its full potential.

4.5.1 Alarming Situation

In Satkhira Municipality there is more or less a good collection and disposal system of both household and market waste, but one of the most alarming news is there is no management system for the waste generated from hospitals and nursing homes. A large portion of the generated Solid Waste remain unmanaged (Figure 14). Medical waste is one of the most problematic types of wastes for a municipality or a solid waste authority. In Satkhira there is 1 general hospital, 1 medical college. 1 veterinary hospital and other about 22 private hospitals which produce a large number of waste. From the physical composition survey, it was found that about 2.5 tons of medical waste generate each day but there is no management system for that. The hospital authority dumps their waste in various places sometimes open places. When such wastes enter the municipality solid waste stream, pathogens in the wastes pose a great hazard to the environment and to those who come in contact with the wastes. Which is a becoming a prominent threat to the city dwellers. The Municipal authority has assured that they are also very concerned about it and are trying to take necessary steps to eradicate this problem.

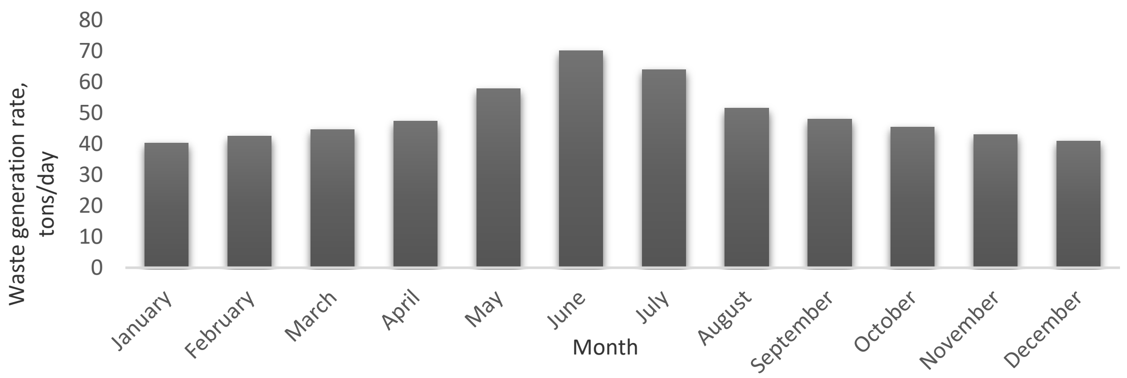

Figure 4: Month wise variation of Solid Waste generation

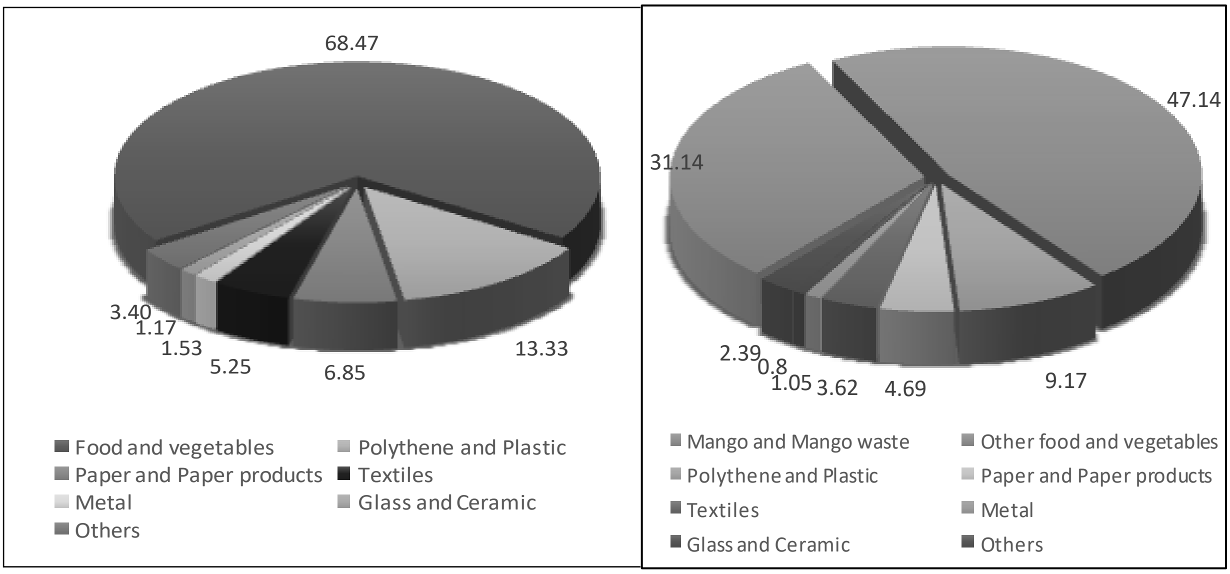

Figure 5 **:** Composition of SW in non-mango season (left) and Mango season (right)

Figure 6: Different vehicles used by Satkhira Municipality in SWM purpose

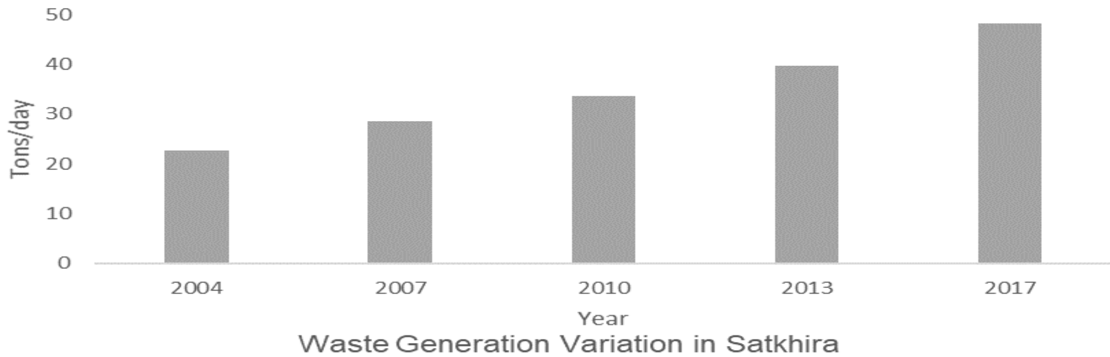

Figure 7: Variation of SW generation during recent years

Figure 8: Some of the contribution of Practical Action in SWM of Satkhira

Figure 9: Thrown away waste in different places in Satkhira

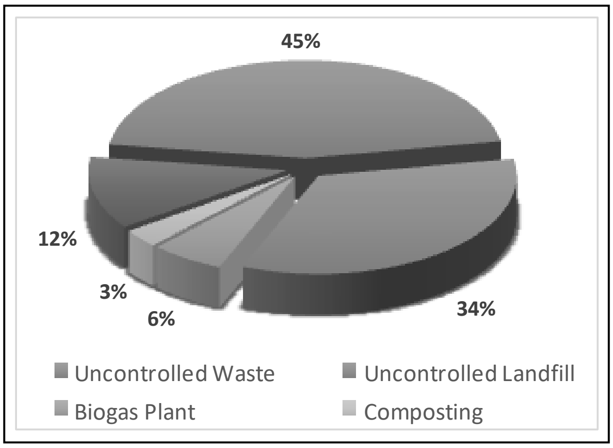

Figure 10: Disposal of produced Solid Waste (percentage) in Satkhira Municipality

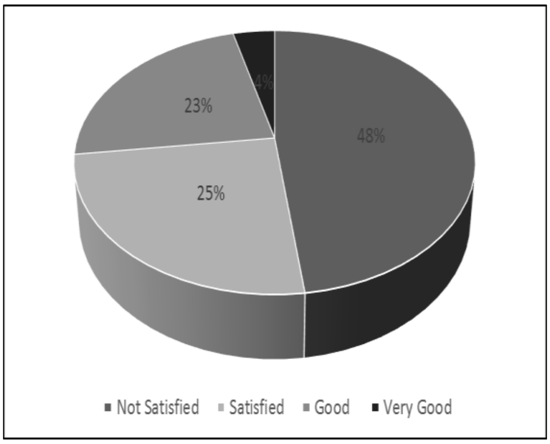

Figure 11: Opinion of the inhabitants about the SWM of SM

Figure 12: Bio gas plant of Practical Action

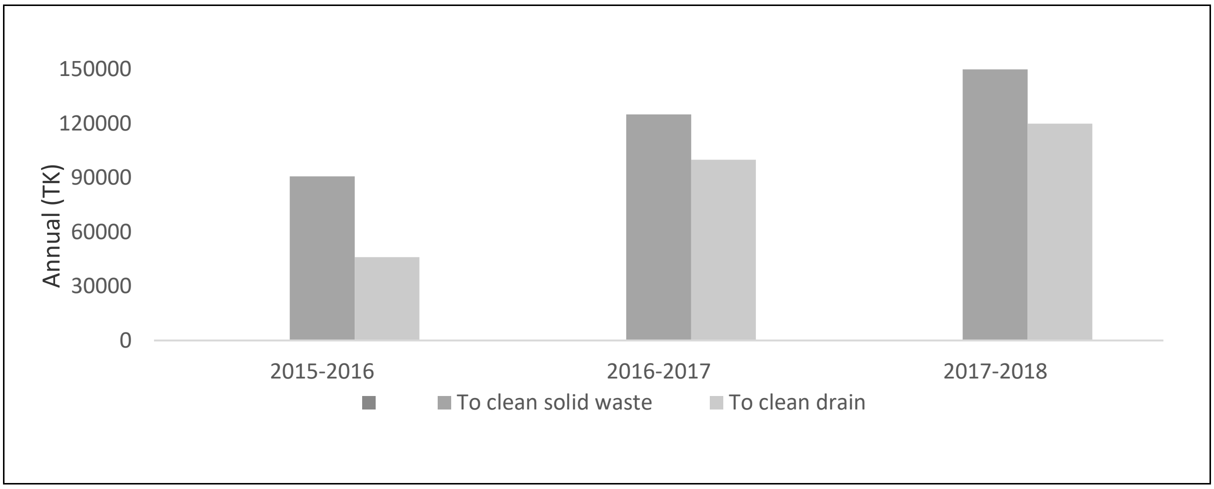

Figure 13: Comparison of annual budget if SP in recent years

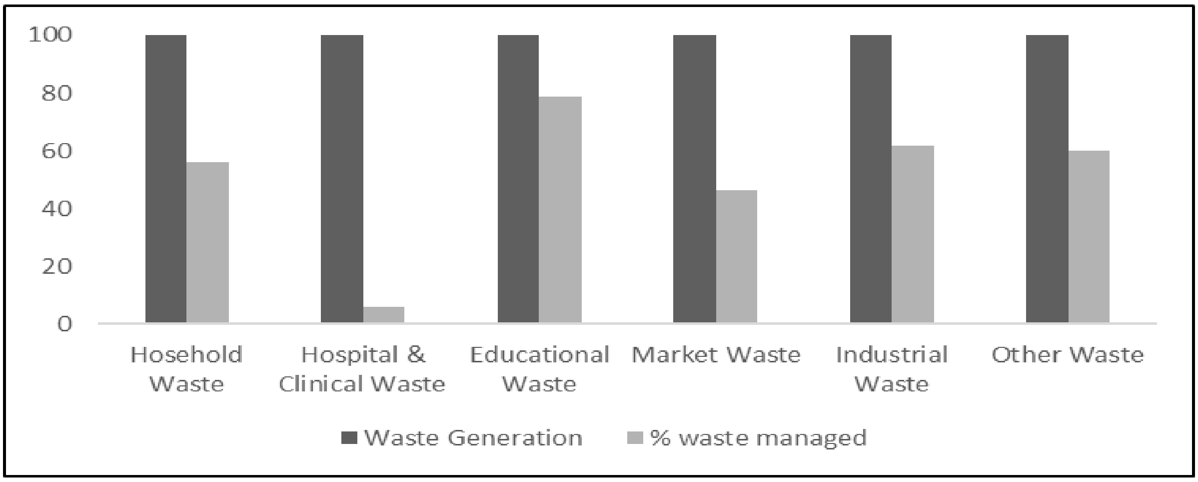

Figure 14: Different types of waste generation vs % managed

5. CONCLUSIONS AND RECOMMENDATIONS

Municipal solid waste management is a complex process because it involves many disciplines and stakeholders. Satkhira municipality is trying to improve its SWM system by adopting new policies such as door to door collection, compost plant etc. After the analysis of the prevailing situation it is found that the present waste collection system of the Satkhira municipality is not fully capable of managing total generated waste. About 10 tons/day waste remain managed. Only 14.6% use the door to door service but the majority portion yet dump waste in open place. The practice of open dumping is high in low income community (about 71.6%). It is also found that majority (62%) of the low-income community wants dustbin as waste disposal system but the scenario is opposite for the high-income community. It is found from the survey that 45% are not satisfied with the present SWM situation of the municipality. A flow path is generated from the study. It is from the flow path that most of the people sell plastic bottles and other recyclables. Informal sector plays a vital role in managing these recyclables. To improve the present SWM situation the municipality may conduct awareness campaign about door to door collection, waste storage, source separation, reduce, reuse, recycle and refuse of waste. From the field survey it is found that there is different opinion about the waste disposal system. Municipality can adopt a mixed waste disposal system considering socio-economic status of the area. A separate department on SWM with more man power can overcome this situation. A vigilant group can be formed in every ward to monitor and improve the SWM of the ward. Particularly, the outcome of this study would provide data for future research and development of SWM in Satkhira municipality.

- To recover this problem, the following things could be done.
- Increase the facility to door to door collection in all areas of Satkhira municipality.
- Sweeping the streets, when the waste is carried on the final disposal.
- The plastic cylindrical dustbin in a street may be covered by a door system to reduce odour.
- NGO participation in SWM practices.
- Public awareness strategy.
- Financial strengthening of local bodies.
- Hazardous waste should be collected and transported separately and disposed of carefully.
- Increase awareness for reduction of solid waste generation.
- Increase awareness to the people about the resource recovery from the solid waste.

ACKNOWLEDGEMENTS

The project was carried out under the supervision of Professor. Dr. Md. Saiful Islam, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh. The author wishes to express his profound gratitude and indebtedness to him for his valuable guidance, advice, help constructive criticisms during the investigation and preparation of the project. The author also would like to thank to all the officers of Satkhira Municipality and Palli Chetona who helped a lot.

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MANAGEMENT OF FAECAL SLUDGE BY RAJSHAHI CITY CORPORATION

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ABSTRACT

One important component of sanitation management is Faecal Sludge Management (FSM) which is the second generation challenge of sanitation. It includes the management of entire Faecal Sludge (FS) systems, on-site sanitation and services, as well as costing, economics, FS collection and haulage, FS treatment and Reuse or disposal of FS. As many of developing cities like Rajshahi, FSM offers a thriving challenge, producing significant adverse human health and environmental hazards. In the present study, a survey was made in Rajshahi City to know the situation of FSM and the data of last six years was collected from Rajshahi City Corporation authority. This paper represents the scenario of FSM arrangements in Rajshahi City by City Corporation in Rajshahi such as existing facilities of FSM, types of collection process and collection cost, treatment process, disposal methods and present and historical data for revenue earning by service providing authority per year, charge for collection per septic tank and how many septic tanks have been cleaned per year. It is found from the survey that the conservancy department of City Corporation has only one vacutug of 2000 L capacity and provides the service for only emptying the septic tank on a rent basis. The authority does not have any treatment facilities and disposed of in crude manner to the nature. Therefore, it could be concluded that in the upcoming years the management of FS by Rajshahi City Corporation should improve to save the nature.

Keywords: *Faecal sludge; scenario; collection; treatment; disposal*

1. INTRODUCTION

Bangladesh, a country of 160 million people, has achieved commendable sanitation success during the 15-year Millennium Development Goals (MDG) period. The laudable achievement was possible through a remarkable growth in on-site sanitation (OSS) facilities of which about 98% of the people in the country depend upon. However, the management of OSS remains neglected with a large quantity of faecal sludge generated in these facilities inaptly managed leading to significant environmental, health and economic challenges. Bangladesh has recognized the importance of an ‘Institutional and Regulatory Framework’ (IRF) for Faecal Sludge Management in order to ensure that the achieved sanitation successes are sustained. On-site sanitation (OSS) is a system that generally stores, treats and disposes faecal wastes within the premises of a household or a small community. In the urban context, septic tanks (with or without soakage pits) and different types of pit or pour-flush latrines are common OSS systems. The sludge generated within these OSS systems needs to be emptied at certain intervals and must be treated off-site (Rahman, et al., 2015). Onsite technologies include pit latrines, unsewered public ablution blocks, septic tanks, aqua privies, and dry toilets (Bari, 2017). Sludge is a hazardous material that harms human health and the environment including soil, air and aquatic systems (DoE, 2015). Globally a huge number of people rely for their sanitation on non-sewered systems which generate a mix of solid and liquid wastes generally termed ‘faecal sludge’. Faecal sludge (FS) is the general term given to undigested and partially digested slurry or solids resulting from storage or treatment of blackwater or excreta (Peal, et al., 2014).

Faecal Sludge Management (FSM) is the second-generation challenge of sanitation. Faecal Sludge Management (FSM) refers to a systems approach that includes technologies and mechanisms for the management of entire Faecal Sludge (FS) systems, on-site sanitation and services, as well as costing, economics, FS collection and haulage, FS treatment, disposal and reuse of FS and conventional sewerage is not included in a FSM system (Agyei, et al., 2011). OSS facilities have become major sources of groundwater and surface water pollution. People living in high-density urban slums and low-income communities depend entirely on OSS facilities shared by multiple families. Most of OSS facilities including septic tanks are built without following any engineering design principle and therefore perform poorly. Therefore, in the absence of effective faecal sludge management (FSM) services, a huge quantity of FS generated in septic tanks and pits or pour-flush latrines are being discharged in low-lying areas, storm water drains, in lakes, canals and rivers leading to serious environmental degradation, particularly in urban areas, endangering public health. Recently FSM has been initiated as an urban sanitation option in some areas of Bangladesh. Some 16 Paurashavas (Municipal) towns have initiated FSM services, on a limited scale, with treatment plants built with assistance from the Department of Public Health Engineering (DPHE) and NGOs, and employing 'vacutug' for emptying, collection and transportation of faecal sludge to treatment plants. In large cities including the mega-city Dhaka, limited emptying and collection services are available through NGOs/private organizations, but the subsequent disposal of faecal sludge into sewers/low lands without treatment needs addressing. In all urban areas, unhygienic manual emptying systems predominate over the mechanical emptying system using 'vacuum' because of its limited availability and lack of public awareness. However, there are very little researches, regarding the sanitation services and Faecal Sludge Management situation of Rajshahi City Corporation. There are few projects run by private NGO's who analysis the sanitary situations (Rahman, et al., 2015).

Rajshahi is an important Metropolitan city, covers an area of approximately 97.18 sqkm. Its population is 4,49,756 (including male population is 2,32,975 and female is 2,16,782), total Holding No is 60,000 and consisting of 30 wards (RCC, 2017). It is the 4th largest city on the basis of population. The sanitation facilities of this city are not sufficient. Although every fiscal year a huge amount of money is collected for the improvement of sanitation system, for want of proper planning, the sanitation system failed to meet its demand. The environment of the city and the living standard of people are deteriorating due to lack of proper sanitation system (Moshiur et al., 2017). At present Rajshahi city is rapidly expanding and depending only on on-site sanitation system, the scenario of faecal sludge management is becoming critical day by day. The main purpose of the study was to assess the management practice for faecal sludge in Rajshahi by City Corporation.

2. METHODOLOGY

2.1 Study Area

Rajshahi City Corporation (RCC), which was formed in 1988, is one of the major divisional city corporations of Bangladesh and covers an area of approximately 48 sq. km being bounded on the east, north and west by Paba Thana. Before its establishment as City Corporation, it was a municipal corporation. Rajshahi city Corporation has 30 wards in which there are 30 selected ward councillors. Basically, Rajshahi City Corporation is a formation under the local government administration of Bangladesh to regulate the city area of Rajshahi, which is under the Ministry of Local Government & Rural Development (LGRD).

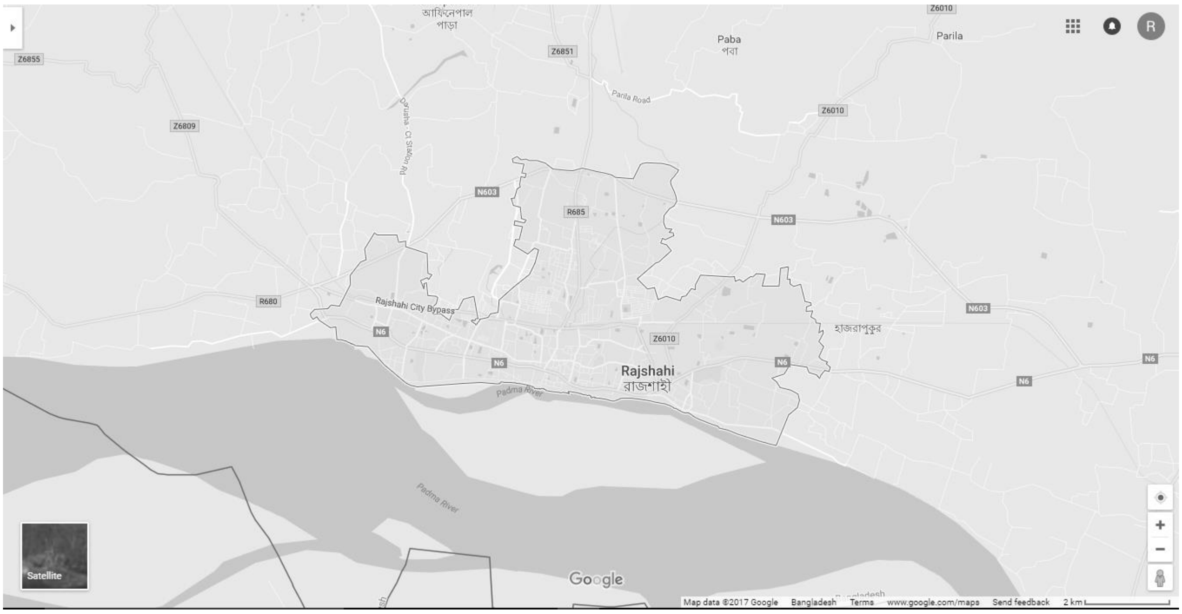

Figure 1: Rajshahi City Corporation map (google Earth Maps)

2.2 Field Observations

The information presented in this report is the outcome of experience, observations and field research data gathered from the RCC authority. To collect the information, specific questions about the existing facilities of FSM, collection, transportation, treatment, disposal process and costing of faecal sludge management were prepared to collect information from the RCC authority. The number of service for emptying the septic tank in each year was collected from the city corporation garage authority. Accordingly, RCC authority provided the information only on such important issues as the costing, economics and management of entire FSM systems, which would include all relevant infrastructure components and services, such as

- existing facilities of FSM
- types of collection process and collection cost
- treatment process
- disposal methods
- present and historical data for revenue earning by service providing authority per year
- charge for collection per septic tank and how many septic tanks have been cleaned per year.

These are described below-

Existing facilities of FSM:

Existing facilities of FSM includes technologies and mechanisms for the management of entire Faecal Sludge (FS) systems, on-site sanitation and services, as well as costing, economics, FS collection and haulage, FS treatment, disposal and reuse of FS.

Types of collection process and collection cost:

The action of collecting something is known as collection. There is only one way to collect the FS and that is by using the deslugding vacuum tanker. The collection cost in the year between 2002-2013 is BDT 2000 (25 US$).

Treatment process:

Treatment refers to the manner in which someone behaves towards or deals with the collected faecal sludge. There is no facilities for the treatment of the sludge which are collected by RCC authority.

Disposal method:

Disposal refers to the process of getting rid of something. At present there is only one disposal site to dispose the FS and that is at City Hut.

Others:

The present and historical data for revenue earning by service providing authority per year, charge for collection per septic tank and how many septic tanks have been cleaned per year is briefly described in the FSM scenario below.

3. FSM SCENARIO

All information collected from Rajshahi City Corporation authority were analysed and represented here. Total sanitation coverage of the city is 96%. The faecal sludge management by RCC authority has started from 2002. Before that the septic tanks were emptied manually or directly connected to open drain or soak pit.

3.1 Collection

Collection of FS from septic tanks by RCC authority is call for service basis. When someone chooses to use the service provided by RCC authority, has to go to the city corporation office to collect form of that specific service and deposit fees to the specific bank.
Desludging vacuum tanker has been being used for collecting FS since 2011. Before the arrival of desludging vacuum tanker, City Corporation collected the FS manually by refilling the faecal sludge in big drums from septic tanks. This was very poor process because there was possibility of dissipating the FS which creates nuisance to the environment.
There is only one desludging vacuum tanker having capacity of 2000 liters with 100 ft hose pipe. Other equipment provided by RCC authority are tractor and pump machine. Figure 2 shows the vacutug used for collection and transportation of faecal sludge by City Corporation.

Figure 2: Desludging Vacuum Tanker with Tractor

The number of service for emptying the septic tank from 2011 to 2017 is presented in Table 1. In the year of 2011 only one septic tank was emptied because the service was started near the end of that year. There are 30 septic tanks that have been emptied up to June of 2017. From the data table it is seen that the demand and service are increasing every year. Because of the publicity and feasibility of the service the rate of emptying septic tank in Rajshahi city is increasing day by day. Public awareness and cost of emptying is another reason of this increasing rate of emptying septic tank every year.

Table 1: Number of emptied septic tank

Year	Number of emptied septic tanks
2011	1
2012	17
2013	26
2014	29
2015	69
2016	54
2017	30+

3.2 Transportation

The desludging vacuum tanker is connected with a tractor to provide the collection and transportation service from household to the disposal point. The tractor connected with the desludging vacuum tanker travels from the city corporation garage to the house owner's place who chooses to take the service. Labourers connect the pipe of desludging vacuum tanker to the septic tank. After collecting the FS from the septic tank according to the capacity of the desludging vacuum tanker the tractor travels to the disposal site. Basically, the traffic condition of the city is mixed traffic condition. Distance of the disposal site at City Hut from the important point of the city was measured from google earth map and the required travel time based on 30 km/hr average vehicle speed were calculated and are given in Table 2. The route distance was measured from google earth map. There are eight probable routes from important locations to the disposal site are shown in Figure 3.

Table 2: Important points of Rajshahi City and their distance

Route	**Location**	**Distance From City Cow Hut (km)**	**Estimated Time at 30 (km/hr)**
1	Court	8	16 min
2	Court Station	6.8	15 min
3	Binodpur Bazar	11.9	24 min
4	CNB more(N6)	6.6	14 min
5	Horogram Bazar	8.1	17 min
6	Laxmipur more	6.2	13 min
7	Zero point	8.4	17 min
8	Alu pottir mor	9.2	19 min

Figure 3 (a): Travel routes to sludge disposal site from Court

Figure 3 (b): Travel routes to sludge disposal site from Court Station Road

Figure 3 (c): Travel routes to sludge disposal site from Binodpur Bazar

Figure 3 (d): Travel routes to sludge disposal site from CNB More (N6)

Figure 3 (e): Travel routes to sludge disposal site from Zero Point

Figure 3 (f): Travel routes to sludge disposal site from Horogram Bazar

Figure 3 (g): Travel routes to sludge disposal site from Alu Pottir Mor

Figure 3 (h): Travel routes to sludge disposal site from Laxmipur More

Figure 3: Travel routes to sludge disposal site from important points of Rajshahi City (google Earth Maps)

3.3 Treatment

The collected sludge is disposed directly to the disposal site at municipal waste dumping site without any treatment which is very harmful to the environment, public health and underground resources.

3.4 Disposal

FS collected from septic tank are disposed to the disposal site. There is only one disposal site at Rajshahi city which is near City Hut (Figure 4) where FS are disposed along with solid wastes. This site covers approximately an area of 4 acres. Wastes have been disposed at this site since 2004. The capacity of this site has almost filled. It is reported by Bari (2017) that sometimes the faecal sludge is discharged in the municipal large open drain at remote place which is harmful to the environment. FS collected in drums were also disposed at the City Hut and sometimes to open drains near the house or on the way to the disposal site which was a very harmful activity. Previously at first, FS was disposed at new market, then stadium and at last Zia Shishu Park. And presently the disposal site is at City Hut. A scheme has taken by RCC authority to construct a disposal site along with treatment plant over an area of 300-400 acres at City Hut.

Figure 4: City Hut Disposal Site

3.5 Costs

In between 2002-2013 a house owner had to pay BDT 2000 (25 US$) to the RCC to empty a septic tank. The amount of money was deposited to RCC fund. From November, 2013, the cost has decreased and the money has to be deposited to the Agrani Bank, a schedule bank of Bangladesh, with additional vat of 15% of the total amount to Bangladesh Bank. Data of cost of emptying per septic tank is given in Table 3.

Table 3: Cost of Emptying

Duration	Cost (BDT)	Cost (US$)
2011-2013	2000.00	25.00
2013-2014	1400.00	17.25
2014 to present	1200.00	15.00

From the table it is seen that the cost for emptying septic tank is decreasing. This is another reason for the increasing rate of emptying septic tank per year. Along with this cost there are some additional costs such as fuel cost, labourer and driver fee, chemical cost etc. which have to be paid by the house owner. According to the distance from septic tank to the disposal site the amount of fuel cost has to be paid by the house owner. The desludging vacuum tanker needs one liter diesel for each 3 Km up and down distance. Each liter diesel costs 0.875 US$ or BDT 70.00. At least two labourers are required for this operation and each labourer demands 6.25 US$ or BDT 500. The driver's fee is same as labourer. The additional costs varies according to the size of the septic tank.

4. CONCLUSIONS

From the above information and discussion it could be concluded that Rajshahi City Corporation authority provides faecal sludge collection, transportation and disposal service as call for service basis with payment. They collect FS from septic tanks by desludging vacuum tanker called vacutug and dispose them directly to the disposal site without any kind of treatment which is very dangerous to the environment and the major cause of environmental pollution. Dumping site at City Hut has already reached to its capacity. The authority does not have any faecal sludge treatment plant and proper management system rather they are only providing septic tank emptying and sludge disposal service. Therefore, to save the environment as well as the Divisional City, Rajshahi City Corporation should immediately take necessary steps for proper faecal sludge management system including collection, transportation, treatment and reuse or disposal.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the valuable support and information provided by Eng. SK. Md. Mamun (Chief Conservation Officer), Md. Reazat Hossaain (Executive Engineer, Mechanical Engineering) and Md. Sohel Rana (Office assistant).

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TREATMENT OF MUNICIPAL WASTEWATER BY USING LOCALLY AVAILABLE MATERIALS AS COAGULANTS

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ABSTRACT

Water quality remains one of the most significant environmental issues. Especially surface water contains both dissolved, suspended and colloidal particles. In wastewater treatment, coagulation has been practiced since earliest times to remove colloidal impurities and turbidity. Nowadays, there has been great attention in the improvement and implementation of natural coagulants in wastewater treatment for their least cost. In the present study, wastewater collected from different locations of municipal primary drain in Rajshahi City were tested for various physical and chemical parameters to characterize. An attempt has been taken to check how natural coagulants such as Acacia nilotica, Moringa oleifera, banana stem, banana peels and Ficus carcia can remove the TDS, TSS and turbidity from wastewater through coagulation process at its optimum conditions so that this treated water becomes suitable to safely discharge into river or directly use for irrigation. Based on the experimental results, it is found that the maximum removal of TSS, TDS and turbidity are obtained 75.65% by banana stem, 65.27% by Ficus carcia and 96.42% by banana stem respectively. Therefore, it could be concluded that further study might improve the impurities removal efficiency.

Keywords: *natural coagulants, turbidity, impurities, dissolved and suspended particles*

1. INTRODUCTION

Everyday huge quantity of wastewater is producing in municipal area and discharge without treatment of this wastewater in the natural receiving bodies creates environmental hazard. Municipal wastewater is a combination of different types of wastewaters originating from the sanitary system of commercial housing, industrial facilities and institutions, in addition to any groundwater, surface water and storm water that may be present (Al-Sarawy, et al., 2001.). The municipal wastewater usually contains numerous pathogenic microorganisms, heavy metals, toxic compounds, suspended solids, nutrients and some other organic materials (Devi, et al., 2008). It kills fish, blooms algal and increases the eutrophication and bacterial contamination (Clescerl, et al., 2001). To control the environmental and health hazards, municipal wastewater must immediately be treated appropriately before final disposal. The ultimate goal of wastewater management is the protection of the environment with public health and socio-economic concerns (Clescerl, et al., 2001). Different wastewater treatment technologies are used worldwide. Each one has its advantages and disadvantages in terms of construction costs, operational costs, energy consumption, operational complexity, effluent quality, reliability, land requirements, and environmental impact. Recently some modern technologies were reported for waste water treatment like up flow anaerobic sludge blanket (USAB) (Tawfik, et al., 2006; Axberg, et al., 1980; Camp, 1973), multi stage bubble column reactor (El-Hallwany, 2005), sequential batch reactor (SBR) (EPA, 2004), fixed film anaerobic filter (AF) (Renault, 2009), expanded granular sludge bed (EGSB), which is a modification to UASB (Heber, 1985), up flow septic tank/baffled reactor (USBR) (Yu, et al., 2010), submerged membrane hybrid system (Sahu, et al., 2009), anaerobic-anoxic-aerobic bioreactor (Kemira, 1990).

Coagulation-flocculation is one of the chemical treatment processes commonly used for water and wastewater. It has a wide range of application in water and wastewater facilities because it is efficient and simple to operate (Wang, et al., 2007; Zheng et al., 2011). The mechanism of Brownian movement in wastewater where there is a repulsion of negatively charged surfaces to form a stable dispersed suspension was reported (Bache, et al., 1999). Coagulant is a chemical used that is added to the water or wastewater to withdraw the forces that stabilizes the colloidal particles and causing the particles to suspend in the water. Once the coagulant is introduced in the water, the individual colloids must aggregate and grow bigger so that the impurities can be settled down at the bottom of the beaker and separated from the water suspension. Hence nowadays, there has been great attention in the improvement and implementation of natural coagulants in wastewater treatment (Saharudin and Nithyanandam, 2014).

Natural coagulants are mostly carbohydrates (polysaccharides) and proteins Rodiño-Arguello, et al., 2015). These natural coagulants can be formed or extracted from animal, microorganisms and also plant. Natural coagulants usage is profitable in wastewater treatment since the treatment cost is low, the steady pH levels in the treated water and because they are highly biodegradable. The application of natural coagulants is based on their traditional use in tropical, rural areas (Prodanović, et al., 2013). A prime concern of the environmental engineer today is how to lower the coagulants cost (Abdelaal, 2004). Therefore, the aim of this study is to find out the suitable natural coagulant for the treatment of wastewater.

2. METHODOLOGY

2.1 Materials Collection and Preparation

The plant based natural coagulants such as *Acacia nilotica*, Moringa oleifera, banana stem, banana peels and *Ficus carcia* were used as coagulant to avoid the drawbacks of chemical coagulation. The five coagulants used are shown in Figure 1.

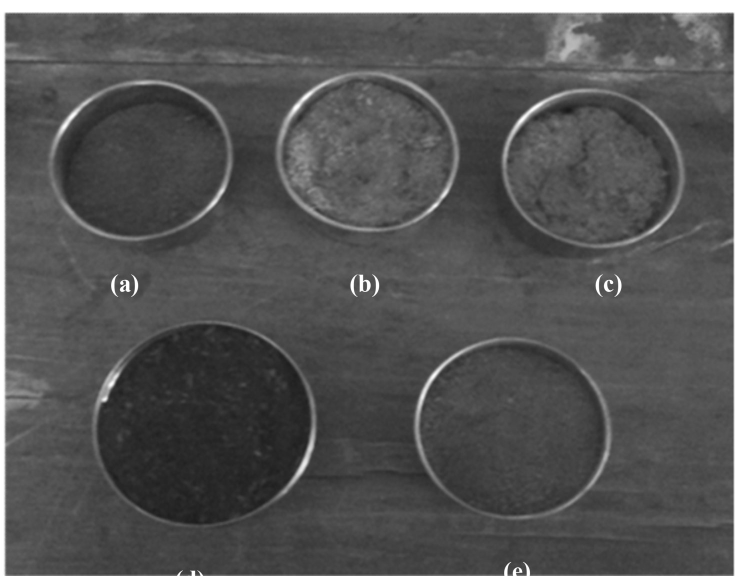


Figure 1: Natural coagulants: (a) Banana peels, (b) Banana stem, c) *Moringa oleifera*, d) *Acacia nilotica* and (e) *Ficus carcia*

2.2 Wastewater Sample Collection and Characterization

Wastewater samples were collected from five different primary drains located near Padma garden, Suvo filling station, Dorgapara, Barnali and Talaimari within Rajshahi City Corporation area. Representative wastewater samples were collected in PET bottle in sufficient quantity by following standard procedure. All the samples were brought as early as possible to the laboratory and kept in chiller below 4°C temperature to protect from the physical, chemical and biological changes. The laboratory analysis was conducted on a regular basis. The collected Wastewater samples were characterized before going for treatment. The characteristics of all samples were determined based on TDS, TSS, turbidity, pH, alkalinity and conductivity.

2.3 Experimental Instruments

The turbidity values of the wastewater sample were measured by using a turbidity meter (Turbidimeter-TN-100) from Eutech Instrument. The pH values of the wastewater samples were measured by using DZB-718 Multi-Parameter Analyzer. The conductivity values of the samples were measured by HACH conductivity meter. The bench top Jar-Tester (Model: SF6 and power 220V, 50Hz) was used for coagulation experiment (Figure 2).

Figure 2: Jar-Tester (Flooculators)

2.4 Treatment

Based on the characterization results, the worst wastewater samples were selected for treatment using different natural coagulations separately. The treatment process was divided into two parts and these are variation in coagulant doses and variation in contact time.

2.4.1 Dose Variation

Different 5 coagulants (*Ficus carcia*, banana stem, banana peels, *Acacia nilotica*, *Moringa oleifera*) were used with the same variations of doses separately as batch wise. Treatments were carried out in triplicate for each condition. Wastewater samples of 100 ml were taken in 500 ml flask. The coagulant doses were varied as 25 mg/l, 50 mg/l, 75mg/l, 100 mg/l and 125 mg/l while contact time and stirring speed were maintained of 30 minutes and 70 rpm, respectively. The flask was placed in the Jar-Tester flocculator (Model: SF6) for coagulation and flocculation. After 30 minutes, the flasks were removed from the machine and kept for sedimentation. The supernatant was tested for TDS, TSS and turbidity and percentage removal was determined.

2.4.2 Contact Time Variation

Similar to dose variation one-factor-at-a-time method was used in case of contact time variation. The contact time was varies as 10 minutes, 20 minutes, 30 minutes, 40 minutes and 50 minutes while coagulant dose was kept fixed at 75m g/l and stirring speed at 70 rpm.

3. RESULTS AND DISCUSSION

Characterization experiments were carried out for raw wastewater to determine the strength of pollutants. The highly polluted sample was selected for treatment to remove the total suspended solids, total dissolved solids and turbidity through coagulation process with locally available natural materials. The results are presented and discussed in the following sections.

3.1 Characteristics of Raw Wastewater

The collected wastewater was characterized on the based on TDS, TSS, turbidity, pH, alkalinity and conductivity. The results are presented in Table 1.

Table 1: Characteristics of raw wastewater collected from different municipal drains

Sampling location	TDS (mg/l)	TSS (mg/l)	Turbidity (NTU)	pH	Alkalinity (mg/l)	Conductivity (micro-mohoes/cm)
Padma garden	1100	100	31.00	6.08	240	2025
Suvo filling station	912	88	27.10	6.85	215	1800
Dorgapara	633	77	16.48	7.11	230	1900
Bornali	829	71	25.71	7.14	220	1950
Talaimari	740	60	22.90	7.45	225	2025

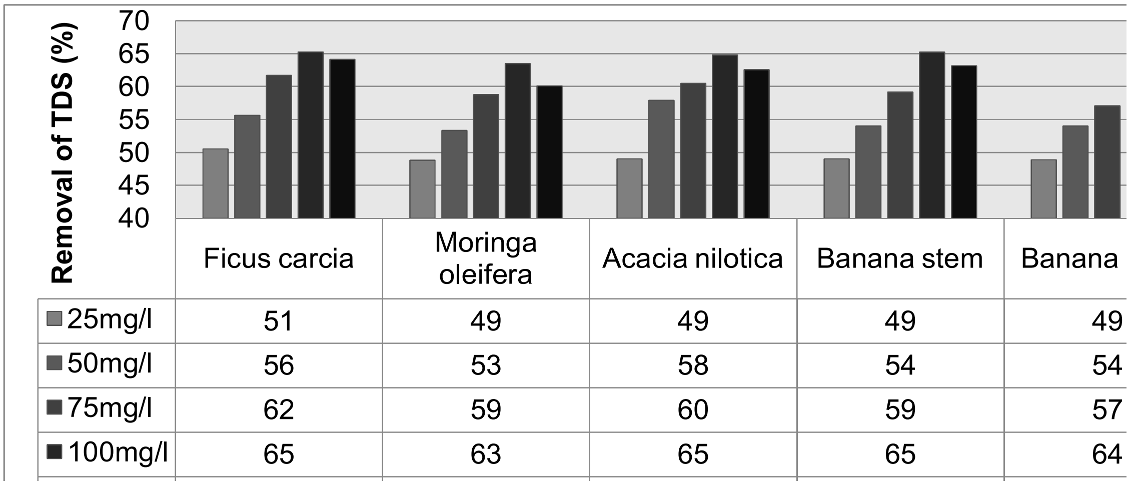
The dissolved solids, suspended solids, turbidity, pH, alkalinity and conductivity vary from 633 to 1100 mg/l, 60 to 100 mg/l, 16.48 to 31.00 NTU, 6.08 to 7.45, 215 to 240 mg/l and 1800 to 2015 micro-mohoes/cm, respectively. From the results it is revealed that the pollutants levels are varying in wide ranges from drain to drain. It might be due the source of wastewater, velocity of flow, interval of cleaning of drain, sampling location and surroundings. During the sampling it was observed that most of the cases the flow is almost laminar and solid were deposited at the bottom of the drains. Considering the all parameters, it is found that sample collected from the primary drain near the Padma garden is more polluted compared to others.

3.2 Treatment of Wastewater

The treatment was carried out to reduce the concentration of pollutants. The treatment efficiency was determined based on removal of TDS, TSS and turbidity. The effects of coagulant doses and contact time on the removal of these pollutants were examined. The performance of each natural material was also evaluated. The results are discussed in the following sections.

3.1.1 Effect of doses of coagulants

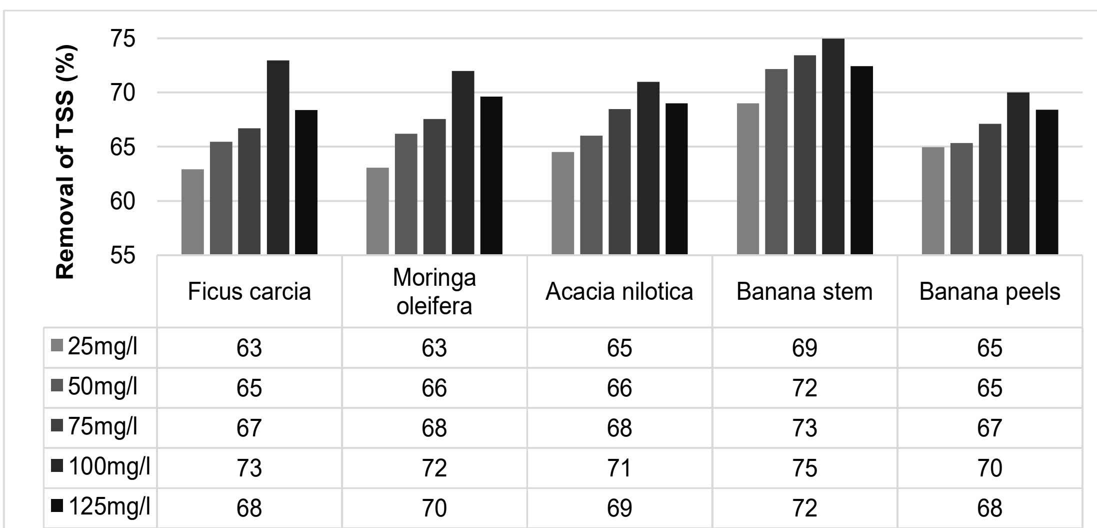
Effects of varying doses of different coagulants on TDS, TSS and turbidity are shown in Figure 3 to 5. The other parameters, contact time and stirring speed were maintained at 30 minutes and 70 rpm, respectively.



	Ficus carcia	Moringa oleifera	Acacia nilotica	Banana stem	Banana
25mg/l	51	49	49	49	49
50mg/l	56	53	58	54	54
75mg/l	62	59	60	59	57
100mg/l	65	63	65	65	64

Figure 3: Removal of TDS with variation of different coagulant doses

From Figure 3 it is observed that all the coagulants are capable to remove dissolved solids and removal capacity of coagulants is also almost same in every dose level. The highest removal was obtained with 100 mg/l of coagulant dose for every coagulant. The highest removal of 65% (717.97 mg/l) was achieved with *Ficus carcia*, *Acacia nilotica* and Banana stem. It can be clearly understand from the trend of dissolved solid removals that the removal is increasing with increase of coagulant doses and reached the highest at 100 mg/l of coagulant dose. However, further addition of coagulant decreased the removal which means that 100 mg/l could be the optimum dose for removal of dissolved solids from municipal wastewater.



	Ficus carcia	Moringa oleifera	Acacia nilotica	Banana stem	Banana peels
25mg/l	63	63	65	69	65
50mg/l	65	66	66	72	65
75mg/l	67	68	68	73	67
100mg/l	73	72	71	75	70
125mg/l	68	70	69	72	68

Figure 4: Removal of TSS with variation of different coagulant doses

Figure 4 shows the removal capacity of suspended solids from wastewater by different coagulants. Similar trend of removal is also observed for suspended solids in all coagulants. Total Suspended solid of the sample is reduced considerably. Here also the highest removal was achieved with 100 mg/l of coagulant dose for all cases. The highest removal of 75% (74.96 mg/l) of suspended solids was obtained with banana stem followed by 73% by *Ficus carcia*, 72% by *Moringa oleifera*, 71% *Acacia nilotica* and 70% by banana peels.

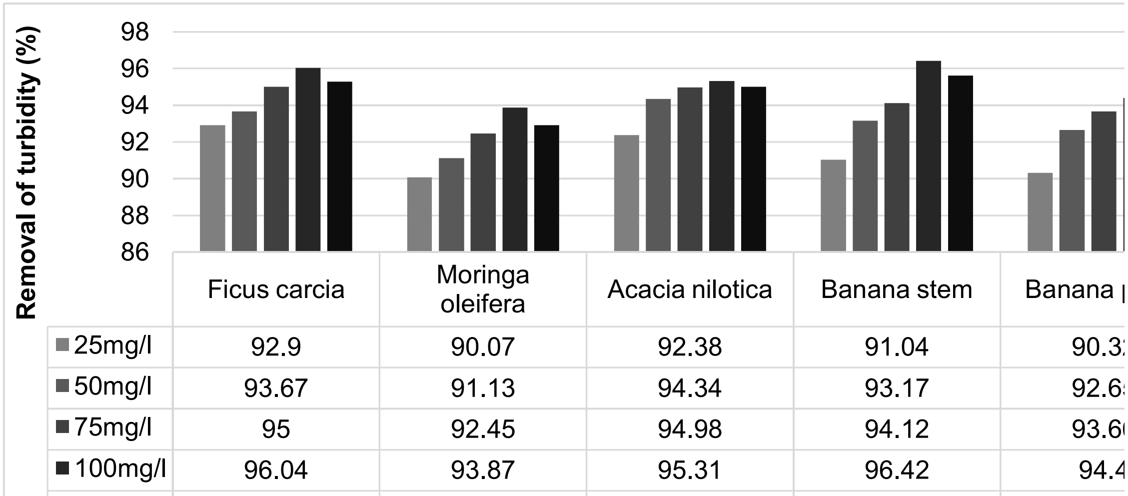


Figure 5: Removal of turbidity with variation of different coagulant doses

Turbidity of the sample is reduced considerably, being highest 1.10 NTU (96.42 %) at 100 mg/l dose for banana stem coagulant and it is within maximum permissible limit. Optimum dose found is 100 mg/l following the same removal trend with variation of doses.

3.1.2 Effect of contact time

Contact time is an important parameter for coagulation process. Contact was varied from 10 minute to 50 minutes at an interval of 10 minutes. The removal of TDS, TSS and turbidity with respect to contact time with different coagulants are presented in Figure 6 to 8 where coagulant dose and stirring speed were maintained at 75 mg/l and 70 rpm, respectively as fixed parameters.

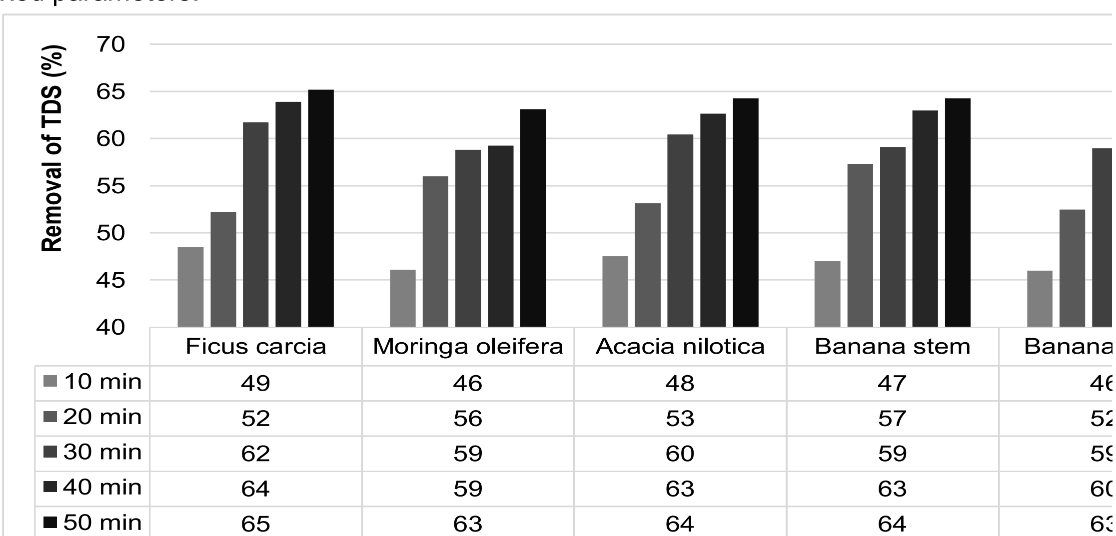
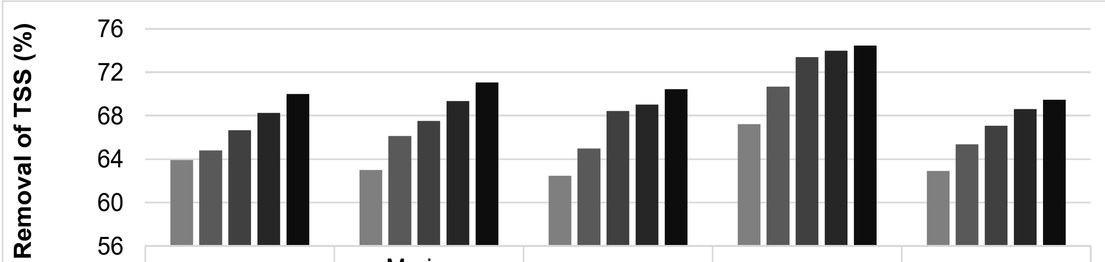


Figure 6: Removal of TDS with variation of contact time for different coagulants

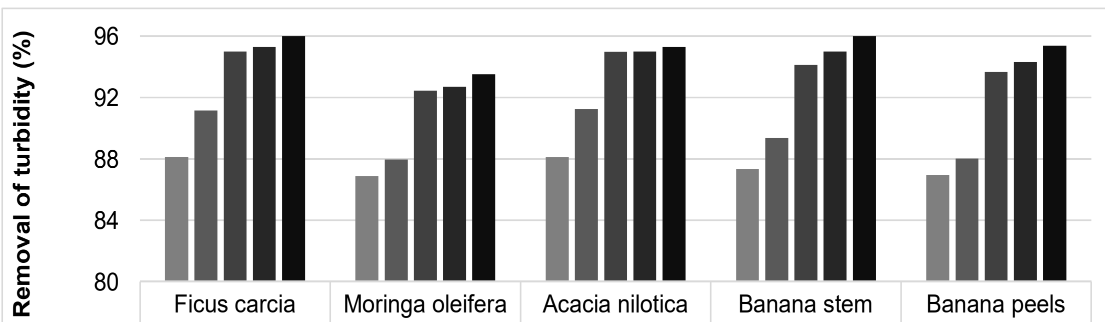
Total dissolved solid of the sample is reduced considerably, being highest 709.5 mg/l (65%) for 50 minutes for *Ficus Carcia* coagulant which is within maximum permissible limit. However, it is remarkable that the incremental rate of removal is very insignificant after 30 minutes of contact time. Therefore, it would better to consider the other parameters and interactive effect in removing dissolved solids to find out the optimum contact time.



	Ficus carcia	Moringa oleifera	Acacia nilotica	Banana stem	Banana peels
10 min	64	63	62	67	63
20 min	65	66	65	71	65
30 min	67	68	68	73	67
40 min	68	69	69	74	69
50 min	70	71	70	74	69

Figure 7: Removal of TSS with variation of contact time for different coagulants

Total Suspended solid of the sample is reduced considerably, being highest 75.68 mg/l (74%) for 50 minutes of contact time with Banana stem coagulant and it is within maximum permissible limit. Similar to dissolved solids removal suspended solids removal is also increasing with increase of time but not significant.



	Ficus carcia	Moringa oleifera	Acacia nilotica	Banana stem	Banana peels
10 min	88	87	88	87	87
20 min	91	88	91	89	88
30 min	95	92	95	94	94
40 min	95	93	95	95	94
50 min	96	94	95	96	95

Figure 8: Removal of turbidity with variation of contact time for different coagulants

From Figure 8 it can be said that effect of contact time on removal of turbidity is insignificant after 30 minutes. Turbidity from wastewater sample is reduced considerably being highest 1.24 NTU (96%) for 50 minutes for *Ficus carcia* and Banana stem coagulants. From this treatment, turbidity can be possible to reduce within maximum permissible limit and can be used for irrigation or discharging to the natural receiving bodies.

4. CONCLUSIONS

It could be concluded from the obtained results that municipal wastewater of Rajshahi City Corporation area is highly turbid (16.5 to 31 NTU) due to the presence of large amount of suspended and dissolved solids. In this study, about 65% removal of TDS, 75% removal of TSS and 96% removal of turbidity was achieved. Therefore, all five selected materials *Moringa oleifera*, *Acacia nilotica*, *Ficus Carcia*, banana stem and banana peels are found to be potential coagulants for the treatment of municipal wastewater of Rajshahi city. The optimum dose and time is obtained to be of 100 mg/l and 50 minutes for all types of materials used as coagulants for the maximum removal of TSS, TDS and turbidity.

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SPATIO-TEMPORAL ASSESSMENT OF THE IMPACT OF LAND COVER CHANGE IN THE NORTH-WEST REGION OF BANGLADESH

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ABSTRACT

Temperature is one of the most important climatic parameters and it is highly influenced by vegetation coverage of any region. Bangladesh is located at the lowermost reaches of the three mighty rivers, the Ganges, the Brahmaputra and the Meghna. The physiology and geography of the north-west region of Bangladesh is much more critical compare to others. This region mainly consists of Barind tract, Diara, agricultural lands and chars etc. During summer this region experiences scorching heat and people suffer from extreme events due to water scarcity. On the other hand, this region experiences very cold winter. In Bangladesh, the weather data is absolutely localized and based on recorded data of particular weather stations of particular time period, which very often prove to be insufficient in the case of analyzing several natural events. Hence, the requirement of an integrated system or approach is eminent that will enable the analyzing and assessment of monitoring land cover along with temperature both spatially and temporally. In this study surface temperature and land cover have been observed using remote sensing technology. Landsat 5 TM data of different years namely 2008, 2010 and 2011 have been utilized. After various pre-processing e.g. band compositing, radiometric corrections etc. Normalized Difference of Vegetation Index (NDVI) and land surface temperature (LST) has been calculated and the respective maps are created. It has been found that the temperature is comparatively low in vegetation area and high in non-vegetation area. Finally relation between LST and NDVI has been established by monitoring several random points and in this study they are found to be negatively correlated.

Keywords: *Remote sensing, Landsat, Normalized Difference of Vegetation Index (NDVI), Land surface temperature (LST), Geographical Information System*

1. INTRODUCTION

Bangladesh, a low-lying deltaic country with an area of 147,470 square kilometres, has been remarked as one of the most vulnerable countries of the world in phrases of natural and anthropogenic hazards. The physical geography of Bangladesh can be categorised by two distinctive features: a broad deltaic plain subject to frequent flooding, and a small hilly region crossed by swiftly flowing rivers (Geography of Bangladesh, 2017), which has made the country vulnerable to different geo and hydro-metrological hazards. In addition, increased temperature and variations in rainfall are the governing elements of climate change that is affecting the lives and livelihoods of Bangladeshi people.

Land coverage pattern and its associated change have a great significance on the surface temperature. Living in a threatening era of global warming, it has become increasingly important to understand the relationship between land cover patterns of a region with the corresponding spatial and temporal temperature distribution. This knowledge is important not only to learn its impacts on environmental issues but also on human health (Stone & Rodgers, 2001). Energy consumption, increment in land coverage with high heat radiated artifical materials, fall in vegetation and water pervious surface which helps to reduce surface temperature through evapotranspiration etc are some examples of anthropogenic heat emission (Kumar et al., 2012) and are the major reasons behind the increment in surface temperature.

Although there are 34 weather stations in Bangladesh, sometimes adequate data with required interval is not available. Due to lack of adequate data and integrated approaches in Bangladesh, monitoring and evaluating climatic events which includes their origin, pattern, characteristics and corresponding impacts, often become difficult. Hence more studies and new integrated approaches are needed to be introduced in this sector.

In 1979, Normalized Difference Vegetation Index (NDVI) is first proposed by Tucker as an index of vegetation health and density. Weng et al. (2004) observed that the vegetation cover has a slightly stronger negative correlation with land surface temperature (LST). Joshi and Bhatt (2012) stated that the built-up areas have higher temperature as compared to the areas with vegetation and water body. On the other hand, Gorgani et al. (2013) tried to correlate NDVI and LST by utilizing Landsat 5 TM and Landsat 7 ETM+ satellites image and found that they have strong negative correlation.

In this research, with the help of geospatial technologies, Normalized Difference Vegetation Index (NDVI) has been monitored with respect to land surface temperature (LST). The specific objectives of this study are to:

a) Generation of NDVI and LST maps.
b) Assess relation between LST with NDVI
c) Monitor land cover change with respect to spatio-temporal land surface temperature distribution.

2. STUDY AREA

In this research a total area of 16,446 square kilometres is covered by the study area. It has fallen under Rajshahi division and its geographic location is 24º 33' North latitudes and 89º 10' East longitudes. Seven north-western districts namely; Bogra, Joypurhat, Naogaon, Natore, Pabna, Rajshahi and Sirajgan is covered by the study area. The climate of this region is generally marked with high temperature, considerable humidity and moderate rainfall. The hot season commences early in March and continues till the middle of July. The average annual temperature is 25.8°C and annual rainfall is 1419 mm of this region (Climate-data.org, n.d.). Common natural events are drought, flash flood, tornado etc (C. Change & Perspectives, 2016) and people of this region mostly suffer due to insufficiency of water in summer.

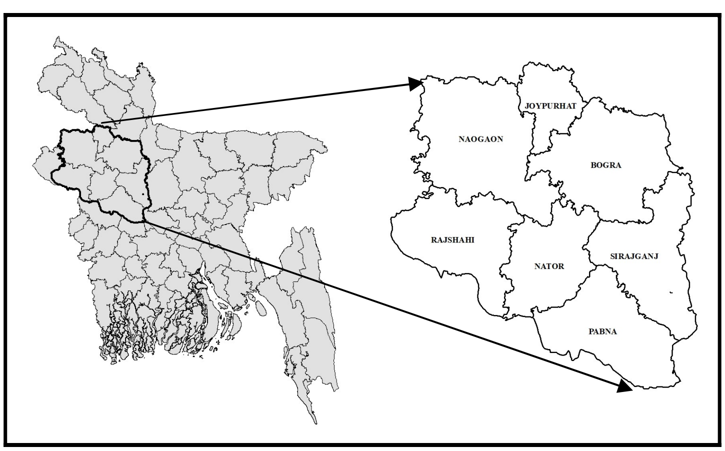

Figure 1: Study Area

3. METHODOLOGY

3.1 Data Collection and Pre-processing

Three years' time series data namely 2008, 2010 and 2011 of Landsat TM with path/row of 138/43 has been downloaded from the US Geological Survey (USGS) Global Visualization Viewer. These data are Level 1 Terrain Corrected (L1T) product. Table 1 represents some of the most useful technical specifications of the downloaded images.

In the part of image pre-processing, each band (except band 6) of every image, has gone through two steps of the radiometric correction using the following equations (I. Change & Maine, 2012). Values of different parameters of the equations can be found from the metadata files (MTL files), which is available for each band for each Landsat scene.

(a) Conversion of digital number to radiance:

$$L_\lambda = ((LMAX_\lambda – LMIN_\lambda)/ (QCALMAX\text{-}QCALMIN))*((Band\ Layer\text{-}(QCALMIN))+LMIN_\lambda)$$

where, L_λ = Spectral radiance, $L_{\lambda max}$ and $L_{\lambda min}$ = highest and lowest possible values of radiance, $QCAL_{max}$ and $QCAL_{min}$ = calibrated maximum and minimum cell values.

(b) Conversion of radiance to reflectance:

$$\rho_\lambda = (\pi * L_\lambda * d^2) / (ESUN_\lambda * \cos \theta_s)$$

where, ρ_λ= Top of atmosphere (TOA) reflectance of each pixel, L_λ = spectral radiance at the sensor aperture, d = distance from the earth to the sun in astronomical unit, $ESUN_\lambda$= mean solar exoatmospheric irradiance, ɵ = angle between the sun and the satellite.

Table 1: Specification of Landsat TM Images

`	Satellite	Path/Row	Julian Day of Acquired Image	Wavelength (micrometer)
2008	Landsat-5 TM	138/43	336	Band 1: 0.45-0.52 Band 2: 0.52-0.60
2010			309	Band 3: 0.63-0.69 Band 4: 0.76-0.90 Band 5: 1.55-1.75
2011			312	Band 6: 10.4-12.5 Band 7: 2.08-2.35

After radiometric corrections, the study area is clipped (Graham, 2010) using the corresponding shapefile. For each year, band-wise clipping is done in this step.

3.2 Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is called a measure of greenness or vegetation. When sunlight falls on a plant, most of the red wavelengths in the visible portion of the spectrum (400-700 nm) are absorbed by chlorophyll in the leaves, whereas the cell structure of leaves reflects the majority of NIR radiation (700-1100 nm) (Babu et al., 2016). NDVI is a satellite data driven index that measures chlorophyll absorption in the red portion of the spectrum relative to reflectance or radiance in the near infrared. So, NDVI is based on Landsat (TM) band 2 (Red) and band 4 (Near-Infrared) and it is calculated by using the following equation.

$$NDVI = (NIR−RED)/(NIR+RED)$$

NDVI varies from +1 to -1. The negative values of NDVI generally represent free standing water and values of 0.1 and below stand for barren areas of rock, sand or snow. Moderate values of (0.2-0.3) correspond to shrub and grass lands. High values between (0.6 – 0.8) indicate temperate and tropical rainforests (Seminar, n.d.). In this study, after calculating NDVI, it has been reclassified into five classes according to table 2.

Table 2: Reclassification Schemes for NDVI

Class	Pixel Value
Water	<0
Barren Area	(0 - .1)
Soil	(.1 - .2)
Shrub & Grassland	(.2 - .3)
Dense Vegetation Canopy	(.3 - .8)

3.3 Land Surface Temperature (LST)

Land surface temperature is associated with thermal band of any Landsat image. To analyse the surface temperature variations, band 6 (thermal band) of Landsat TM image, has been processed using the following stepwise formulas:

Step 1. Conversion of the Digital Number to Spectral Radiance (L_λ):

$$L_\lambda = ((LMAX_\lambda - LMIN_\lambda)/ (QCALMAX\text{-}QCALMIN) *((Thermal\ Band\text{-}(QCALMIN))+LMIN_\lambda)$$

where, L_λ = Spectral radiance, $L_{\lambda max}$ and $L_{\lambda min}$ = highest and lowest possible values of radiance, QCALmax and QCALmin = calibrated maximum and minimum cell values.

Step 2. Conversion of Spectral Radiance to Temperature in Kelvin:

$$Tb = K_2 / \ln ((K_1/L_\lambda) + 1)$$

where, K_1, K_2 = Calibration Constant 1 and Constant 2 and their values are 607.76 and 1260.56 respectively for Landsat 5 TM, Tb = Surface Temperature.

Step 3. Conversion of Kelvin to Celsius:

$$Tb = Tb - 273$$

After calculating LST respective maps with suitable colour combination have been produced for observation purpose.

3.4 Correlation between NDVI and LST

In order to find the relation between NDVI and LST, 100 random points (Roni, 2013) have been generated using the study area shapefile. After that, from both NDVI and LST, values of each point have been extracted. Finally, these values are plotted against each other and the correlation coefficient has been calculated.

4. RESULTS AND DISCUSSION

As discussed earlier after calculating NDVI, it has been reclassified into five classes. All output maps both of NDVI and LST have been shown in above figure 2. If we compare the maps, it can be seen that the temperature is comparatively low in water and vegetation areas where temperature is comparatively higher in soil and barren i.e. built-up areas. In this study, it has been found that from 2008 to 2011, surface temperature is increased by 6.55°C.

The correlation factors for LST-NDVI that have been calculated using 100 random points for each year, were found -0.221, -0.201 and -0.218 for the year 2008, 2010 and 2011 respectively. From all three factors it can be seen that LST and NDVI are negatively correlated. The scatter plot shows the correlation between LST-NDVI in figure 3.

In this study, it has been found that NDVI is negatively correlated with surface temperature which means areas with least vegetation are going through higher land surface temperature. Hence, surface temperature increases with increased built-up intensity and decreases with increased greenness and moisture intensity. Again, surface temperature is increasing day by day and it is highly influenced by land coverage and its corresponding change.

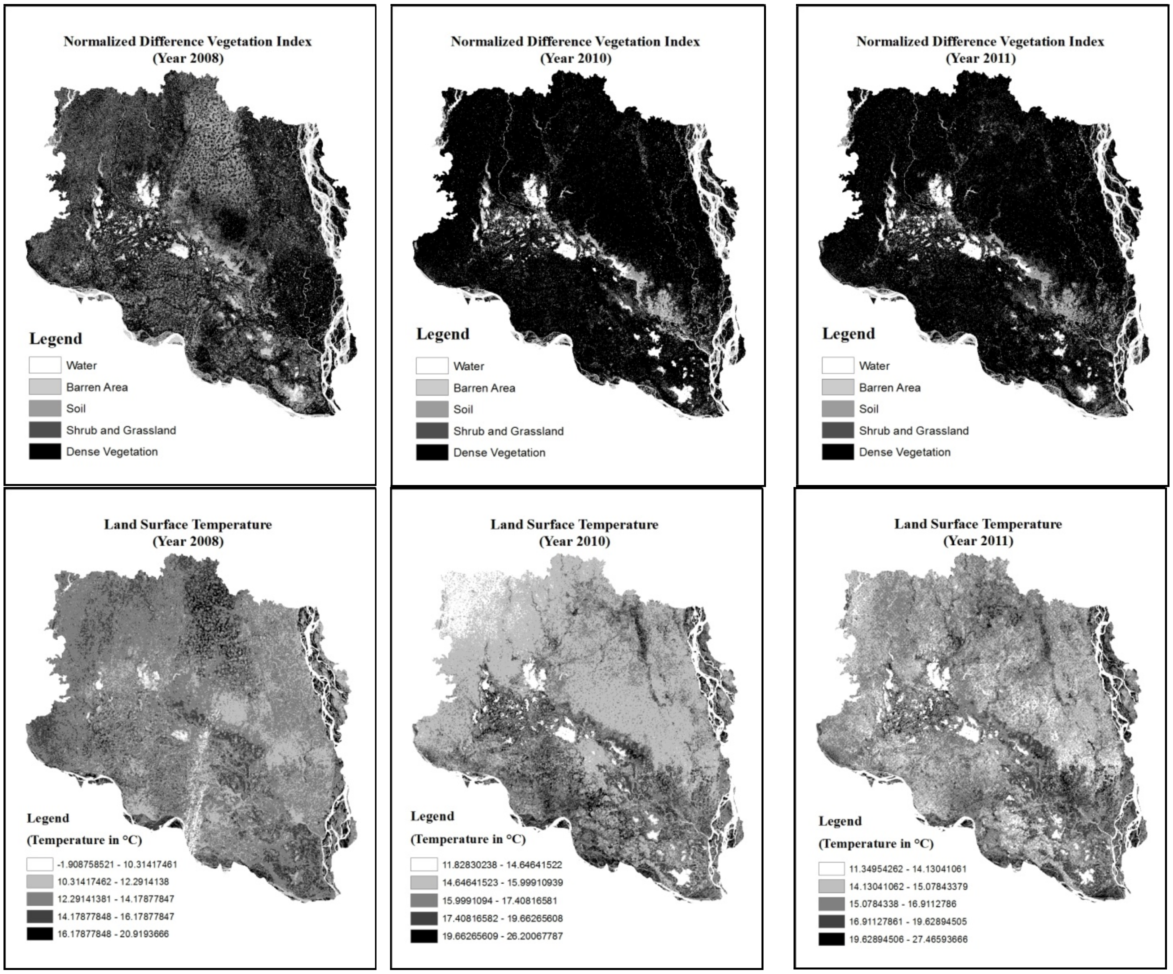

Figure 2: Output maps of both NDVI and LST

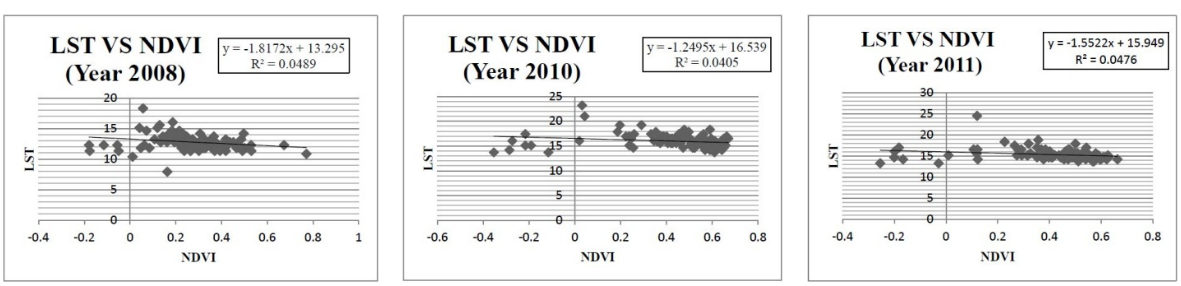

Figure 3: Scatter Plots

In this research, due to unavailability of the summer season's cloud free image, winter season's images were used. It can be a reason of lower valued correlation factors that have been found in this study. Again, due to budget limitation, ground truthing and collection of high resolution satellite images was not possible. That's why; all analyses are done using low resolution of freely available Landsat image.

5. CONCLUSIONS

This research was an attempt of mapping and monitoring land cover change with respect to spatio-temporal land surface temperature for the north-western region of Bangladesh. In spite of having some deficiencies as discussed earlier, the methodology of this study can be considered as an effective one in the sector of observing climatic issues.

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ASSESSMENT OF AIR POLLUTANTS EMISSION FROM MOSQUITO COIL

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ABSTRACT

Burning mosquito coils can generate smoke in the indoor environment containing pollutants of health concern. This study was performed to determine the concentration and emission rate of air pollutants from mosquito coil. Chamber experiment was performed to measure the concentration and emission rate of air pollutants. VOC of burning mosquito coil was measured from 71% to 83%. The atmospheric emission rate for all mosquito coil was ranged from 90 to 105 mg/h. The concentration of CO, SO_2, NOx were measured respectively from 279 to 373 µg/m3, from 1.1 to 2.6 µg/m3 and from 1.6 to 8.9 µg/m3. Average emission rates of CO, SO_2, and NOx were found as 320.2mg/h, 1.7 mg/h and 3.7 mg/h, respectively. The average concentration of $PM_{2.5}$ and PM_{10} was exceeded the indoor guideline limit. Formaldehyde and acrolein were the major carbonyl compounds identified in the coil smoke which was also exceeded the indoor guideline limit.

Keywords: *Indoor air pollution; Mosquito coil; Chamber experiment; Emission rate*

1. INTRODUCTION

Mosquito coil is generally used for mosquito repellent and insecticide in the tropical and subtropical areas (Li et al., 1993). The combustion of mosquito coils could generate carbon monoxide (CO), sulfur di-oxide (SO_2), nitrogen oxides (NOx), particulate matter ($PM_{2.5}$, PM_{10}), carbonyl compounds, volatile organic compounds etc. Liu et al. (2003) also indicated that burning one mosquito coil mosquito coil would release the same amount of $PM_{2.5}$ mass as burning 75–137 cigarettes. The major active ingredients of the mosquito coil are pyrethrins, accounting for about 0.3–0.4% of coil mass (Lukwa and Chandiwana 1998). Pyrethrins are major active ingredients. Pyrethrum is a natural extract from the chrysanthemum flower. When a mosquito coil is burned, the insecticides evaporate with the smoke, which prevents the mosquito from entering the room. Pyrethrins are of low chronic toxicity to humans and low reproductive toxicity in animals, although headache, nausea, and dizziness were observed in male sprayers exposed to 0.01–1.98 µg/m3 pyrethrins for 0.5–5 hr. (Zhang et al. 1991).

Despite the fact that mosquito coil smoke may have many potential adverse health effects, large populations in developing countries still use mosquito coils in their daily lives. In previous studies of various aspects of mosquito coil smoke, emissions of irritating and carcinogenic compounds and other pollutants have not been quantified, which precludes the use of emission rate data to predict pollutant concentrations in households and to quantify health risks. Data are also lacking for comparing emissions from different types of mosquito coils. To make informative recommendations to consumers as to which types of mosquito coil have lower emissions of health-damaging pollutants, it is necessary to perform tests of coil emissions in a systemic manner. The objectives of this study were to determine the physical properties of mosquito coil, concentration and emission rate of air pollutants.

2. MATERIALS AND METHODS

Five types of mosquito coils were tested in this study. The material selection was based on production quantity of the materials and extent of use in a home. The appearances (shape, diameter and color) of these mosquito coils are quite similar.

2.1 Proximate Analysis

Five brands of mosquito coils were taken. Then smashed the mosquito coil with the help of hammer. Then collect the weight of powdered mosquito coil of each sample was taken and kept it in an oven at a temperature of 100˚C for 24 hours. The samples were then cooled and reweighted. Then moisture content was determined. The previous samples were taken which were used for moisture determination. Then the samples were placed into a furnace at a temperature 550˚C. After half an hour the samples were taken out and reweighted. Then the volatile organic compound was calculated.

2.2 Atmospheric Emission Rate

The weight of the sample was taken before burning. Then the mosquito coil was ignited until the coil was extinguished. The weight of ash was determined after burning of the mosquito coil. Then the atmospheric emission rate was calculated by following equation:

$$Emission\ Rate = \frac{A - B}{A \times T}$$

Where,
A= Weight of Coil before burning
B= Weight of Coil after burning
T= Time of Burning

2.3 Chamber Experiment

A chamber using plastic box with two small openings was taken to conduct chamber experiment. The ignited mosquito coil is placed into the chamber for 5 minutes. Then air quality analyzer was placed in the chamber. Three boxes are used in this experiment. Then using that data the concentration and emission rate were determined for a typical room (4.3m×6.1m×3m with 79.31m^3 effective volume). 30% air exchange rate is considered here.

2.4 Emission Estimation

By using the value of emission factor of $PM_{2.5}$ and PM_{10} from Lee et al. (2006) the concentration and the emission rate was estimated for $PM_{2.5}$ and PM_{10} for the same room. By using the maximum concentration of formaldehyde, acetaldehyde, acetone, acrolein and propionaldehyde from Lee et al. (2006) the concentration of carbonyl compounds were estimated for the same room of volume 79.31 m^3.

3. ILLUSTRATIONS

3.1 Proximate Analysis

The proximate analysis comprises of moisture content, volatile organic content and ash percentage of mosquito coil. Experimental result on proximate analysis is shown below Table 1. Here, MC (%) ranged from 12(%) to 14%. For MC3, MC4 and MC5 the percentage of moisture contents were same. For MC1 and MC2 the MC (%) are close enough. The VOC of burning mosquito coil was measured from 71% to 83%. Percentage of ash is high for MC1. The overall proximate results are same for MC4 and MC5.

Table 1: Experimental result on proximate analysis

Sample ID	MC (%)	VOC (%)	Ash (%)
MC1	12	71	17
MC2	14	80.5	5
MC3	13	77	9.5
MC4	13	83	4
MC5	13	83	4

3.2 Atmospheric Emission Rate Estimation

Atmospheric emission rate of mosquito coil for five different brands were shown in Table 2. Here, the atmospheric emission rate for MC2 to MC4 are close enough and ranged from 90.3 to 105 mg/g-hr. But for the sample MC1 the rate of emission is 78.38 mg/g-hr. MC1 is the product of china.

Table 2: Atmospheric emission rate calculation

Sample ID	Amount of Emission (%)	Emission Rate (mg/g-hr)
MC1	58	78.38
MC2	62	100.5
MC3	67	90.3
MC4	81	105
MC5	87	103.8

3.3 Concentration and Emission Rate of Air Pollutants

Chamber experiment is shown in the following figures (1, 2, 3, and 4)

Figure 1: Plastic boxes with two small Openings

Figure 2: Ignited mosquito coil placed into chamber

Figure 3: Air quality analyzer

Figure 4: Placing of air quality analyzer

3.3.1 Concentration of criteria gas pollutants (CO, SO_2, NO_x, NO)

From chamber experiment the data of carbon monoxide (CO), Sulfur dioxide (SO_2), nitrogen oxides (NOx) was collected in mg/m^3 by air quality analyzer. The concentration of tested mosquito coils for 4 criteria gas pollutants (CO, SO_2, NOx, NO) are summarized in Table 3.

The CO concentration was ranged from 279 to 373 µg/m^3. The highest concentration of CO was measured for MC4 and the value is 373 µg/m^3. The permissible limit of CO is 10000 µg/m^3. So the average concentration of CO measured from the chamber experiment is under the permissible limit. The concentration of CO for five samples. Average, minimum, maximum and standard deviation of concentration of CO are respectively 336 µg/m^3, 279 µg/m^3, 373 µg/m^3 and 36.4 µg/m^3.

Table 3: Concentration of Air Pollutants for typical indoor environment

SAMPLE ID	CO (µg/m^3)	SO_2 (µg/m^3)	NO_x (µg/m^3)	NO (µg/m^3)
MC1	361	1.1	1.6	1.2
MC2	279	1.7	8.9	5.4
MC3	338	2.6	5	3.1
MC4	373	1.6	2	1.6
MC5	329	1.6	1.7	1.2
AVERAGE	336	1.7	3.8	2.5
SD	36.4	0.5	3.2	1.8

The SO_2 concentration were so close for tested mosquito coils. It ranged from 1.1 to 2.6 µg/m^3. For MC3 sample the concentration of SO_2 was the highest and the value was 2.6 µg/m^3. The standard deviation was found 0.5. The permissible limit for SO_2 given by WHO is 125 µg/m^3 for 24 hours.

MC2 had the highest concentration of NO and NOx and which were respectively 8.9 µg/m^3 and 5.5 µg/m^3. The NO_x concentration was ranged from 1.6 to 8.9 µg/m^3.The average concentration of NO_x was found 3.8 µg/m^3. The permissible limit of NO_x is 0–1000 ppb. So the concentration of NO_x is under limit.

3.3.2 Emission rate of criteria gas pollutants (CO, SO_2, NOx, NO)

The maximum, average, standard deviation and minimum emission rate of the air pollutants emitted from five mosquito coils are shown in Table 4. Here, average rate of emission is 320.2 mg/h. MC1 emit the maximum rate of CO. The CO emission rate ranged from 266 20 355 mg/h.

The SO_2 emission rates were so close for tested mosquito coils. The average SO_2 emission rate is 1.7 mg/h and ranged from 1.06 to 2.47 mg/h. The NOx and NO emission rates varied among tested mosquito coils. The highest emission rate occurred on MC2 (respectively 8.46 mg/h and 5.17 mg/h), which was nearly six times of that of MC1 (1.53 mg/h).

Table 4: Emission rate of air pollutants for typical indoor environment

SAMPLE ID	CO mg/h	SO_2 mg/h	NOx mg/h	NO mg/h
MC1	344	1.06	1.53	1.18
MC2	266	1.65	8.46	5.17
MC3	322	2.47	4.76	3
MC4	355	1.59	1.94	1.59
MC5	314	1.59	1.59	1.23
AVERAGE	320.2	1.7	3.7	2.4
SD	34.5	0.5	3	1.7

3.3.3 Concentration and emission rate of particulate matter ($PM_{2.5}$, PM_{10})

By using the emission factor the concentration and emission rate of particulate matter were estimated. Table 5 shows the concentration and emission rate of particulate matter ($PM_{2.5}$, PM_{10}).

Table 5: Concentration and emission rate of particulate matter ($PM_{2.5}$, PM_{10})

SAMPLE ID	Emission rate of $PM_{2.5}$ mg/h	Emission rate of PM_{10} mg/h	Concentration of $PM_{2.5}$ µg/m^3	Concentration of PM_{10} µg/m^3
MC1	62	57	40.5	180
MC2	91	84	50	220
MC3	98	91	60	250
MC4	118	110	80	270
MC5	104	96	77	190
AVERAGE	95	88	62	222

Here, the emission rate ranged from 62 to 118 mg/h for $PM_{2.5}$ and from 57 to 110 mg/h PM_{10}. MC4 had both the highest emission rate for $PM_{2.5}$ and PM_{10}. Liu et al. (2003) found that the ultrafine and fine particles dominated the counts of particles emitted by coil combustion, and the emission factor of $PM_{2.5}$ were from 32.7 to 70.1 mg/h, which was close to the findings in this study. In table 5 the concentration ranged from 40.5 to 80 mg/h for $PM_{2.5}$ and from 180 to 270 mg/h for PM_{10}. MC4 had both the highest concentration for $PM_{2.5}$ and PM_{10}. The permissible concentration of $PM_{2.5}$ and PM_{10} are respectively 40 µg/m^3 and 150 µg/m^3. From Table 3.5 the average concentration of $PM_{2.5}$ and PM_{10} were 62 and 222 µg/m^3 which crossed the permissible limit.

3.3.4 Concentration of Carbonyl Compounds

Table 6 illustrates the concentrations of 5 carbonyl compounds identified for five tested mosquito coils. From this table the average concentrations of formaldehyde, acetaldehyde, propinaldehyde and acrolein were respectively 299 µg/m^3, 275 µg/m^3, 77 µg/m^3, 96 µg/m^3 and 120 µg/m^3. The minimum permissible limit of concentration for formaldehyde, acetaldehyde and acrolein were respectively 120 µg/m^3, 9000 µg/m^3 and 50 µg/m^3. So the average concentrations of formaldehyde and acrolein exceeded the permissible limit. So it is called that formaldehyde and acrolein were the major carbonyl compounds.

Table 6: Concentration of carbonyl compounds

Sample ID	Formaldehyde (µg/m^3)	Acetaldehyde (µg/m^3)	Acetone (µg/m^3)	Propinaldehyde (µg/m^3)	Acrolein (µg/m^3)
MC1	298	274	76	95	119
MC2	250	230	64	80	100
MC3	298	274	76	95	119
MC4	310	285	79	99	124
MC5	338.5	311	87	108	135
Average	299	275	77	96	120

4. CONCLUSIONS

The study revealed that VOC of burning mosquito coil was measured from 71% to 83%. The atmospheric emission rate for all mosquito coil was ranged from 90 to 105 mg/h. The concentration of CO (279 to 373 µg/m3), SO2 (1.1 to 2.6 µg/m3), NOx (1.1 to 2.6 µg/m3) were measured using chamber experiment. Average emission rates of CO, SO2, and NOx were found 320.2mg/h, 1.7 mg/h and 3.7 mg/h, respectively. The average concentration of PM2.5 (62 µg/m3) and PM10 (222 µg/m3) were exceeded the indoor permissible limit. The concentration of formaldehyde (299 µg/m3) and acrolein (120 µg/m3) were estimated which also exceed the indoor guideline value. The research can be continued by analyzing the health risk using the air pollutants data.

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ASSESSING THE EXISTING CONTAINMENT MANAGEMENT PRACTICES OF FAECAL SLUDGE IN A WARD OF KHULNA CITY

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ABSTRACT

Faecal sludge (FS) is the human excreta both in liquid and semi-liquid contents which stored in pits and septic tanks accumulating in on-site sanitation and Faecal Sludge Management (FSM) refers to the containment, emptying, transport, treatment, and safe disposal of human waste. In this study, the aim is to identify the on-site containment management practices at three different types of settlements in Ward No. 9 of Khulna City Corporation (KCC). The three types of settlements has been selected as a residential area, a mixed-use area and a slum area. The study has been conducted by a series of questionnaire survey and analysed by Standard Package for Social Science (SPSS) and Microsoft Excel software. The study finds that only 7% of septic tanks having soak well and rest of the septic tank is connected to a nearby drain or water body in the residential area. Again, 81% of the containment is suitable and accessible for mechanical emptying as 77% in the residential where about 41% containment is accessible and 59% are not in the mixed-use area. In the residential area, 58% of containment has not emptied yet where this percentage is 41% and 5% respectively for mixed-use and slum. The study also reveals that about 31% of the septic tank has been emptied by manually where only 13% is mechanically in the residential area. However, for the mixed-use area, manual emptying is about 50% and mechanical emptying is about 7% where all emptying operations have been done either manually or self. In all three areas, the emptied sludge is disposed of off to nearby drains if emptied by manually and disposed to Khulna Faecal Sludge Treatment Plant (FSTP) if emptying is done by mechanically.

Keywords: *Faecal Sludge, Faecal Sludge Management, Containment, Emptying.*

1. INTRODUCTION

Sanitation has been a matter of concern to the human race for a very long time. According to WHO (2008), the importance of sanitation is indisputable. It is a crucial stepping stone to better health that sanitation offers us the opportunity to save the lives of 1.5 million (Agyei, 2009) children a year who would otherwise succumb to diarrheal diseases, and to protect the health of much more. It is also key to economic development such as education and health, and bring measurable economic returns (Nkansah, 2009). Bangladesh has reached to her goal of improved sanitation and mostly completed the Millennium Development Goal (MDG)-7 by 2015 (Islam, 2016). According to JMP (2015), Open defection has reduced from 19% in 2000 to 3% in 2012, though 53% of households still do not use improved sanitation. Bangladesh has shown remarkable progress in sanitation sector, so it’s urgent need for Faecal Sludge Management (FSM) in Bangladesh (Islam, 2016) mainly in urban areas, where most human waste is dumped untreated into waterways or onto marginal land, harming the health of the country poorest (Opel, 2011). Most of the cities in Bangladesh, including the third largest city Khulna (Islam, 2012) and one of the most climate vulnerable cities in the world (Haque, 2013) having a population around 1.5 Million (KCC, 2017) has no sewer network. In Bangladesh, sanitation coverage is unhappily inadequate with about 15% in urban and about 6% in rural areas as of 2006 (WHO, 2008). There are also instances where faecal sludge are disposed of into the environment untreated (Murungi and Peter, 2014). Urban populations are growing very rapidly due to economic migration. As a result, most city residents connect their septic tanks directly to drains and local water bodies which is risky for the environment and have been unable to regulate pollution effectively despite the detrimental effects on the environment or the public health threat (Opel, 2006).

Faecal sludge comprises all liquid and semi-liquid contents of pits and vaults accumulating in on-site sanitation system, namely un-sewered public and private latrines or toilets, aqua privies and septic tanks (Strande et al., 2014). The solid part that has been the partially digested and settled at bottom of the onsite sanitation systems is known as fecal sludge (Koottatep, 2014). Faecal Sludge Management (FSM) includes the storage, collection, transport, treatment and safe enduse or disposal of FS that means all five component of the sanitation value chain (Singh et al., 2017). FSM is important because although over a billion people in urban and peri-urban areas of Africa, Asia, and Latin-America are served by on-site sanitation technologies, FS is not well managed in many cities (Murungi and Peter, 2014).

Khulna, the third largest metropolitan city in Bangladesh where the inadequate emptying option is found for FS (Kabir and Salauddin, 2015). In this city, about 628,070 m3 (Islam, 2016) of FS is produced every year. Unfortunately, in Khulna City Corporation (KCC) the entire FSM process is unsystematic and mainly maintained by informal private service providers (Islam, 2016). Hence the households are connecting the toilet to a drain. In Khulna city, about 84% of the total have a septic tank (Kabir and Salauddin, 2015) are connected to a drain or surface water. The practice of safe septic tank emptying is almost absent in Khulna city. More than half of the total households, irrespective of wealth situation, either use unsafe emptying or do not at all practice fecal sludge emptying. Safe disposal and treatment of fecal sludge are mostly absent in Khulna (Kabir and Salauddin, 2015).

The specific objective of this study is to identify the existing management practices of on-site containment at three different types of settlements in Ward No. 9 of Khulna City Corporation (KCC).

2. METHODOLOGY

In this section, the methodology to conduct the study has been described and also represents the steps of the research work process. The methodology also includes study area selection, sampling, extensive data collection and analysis procedure.

2.1 Study Area Selection and Description

Khulna is the third largest metropolitan city and situated in the south-western part of Bangladesh. The area of the total city corporation is 45.65 km^2. The population in this city is about 1.5 million with a density 67994 per km2. KCC has in total 31 wards with 66,257 holdings (KCC, 2017).

This study mainly focuses on the emptying of three types of settlements for the assessment. The first type of settlement is a planned residential area, the second one is a mixed-use area and the last one is a slum area. This three types of settlements have been found in Ward No. 09 in Khulna City Corporation. For this reason, Ward No. 09 is selected as the study area.

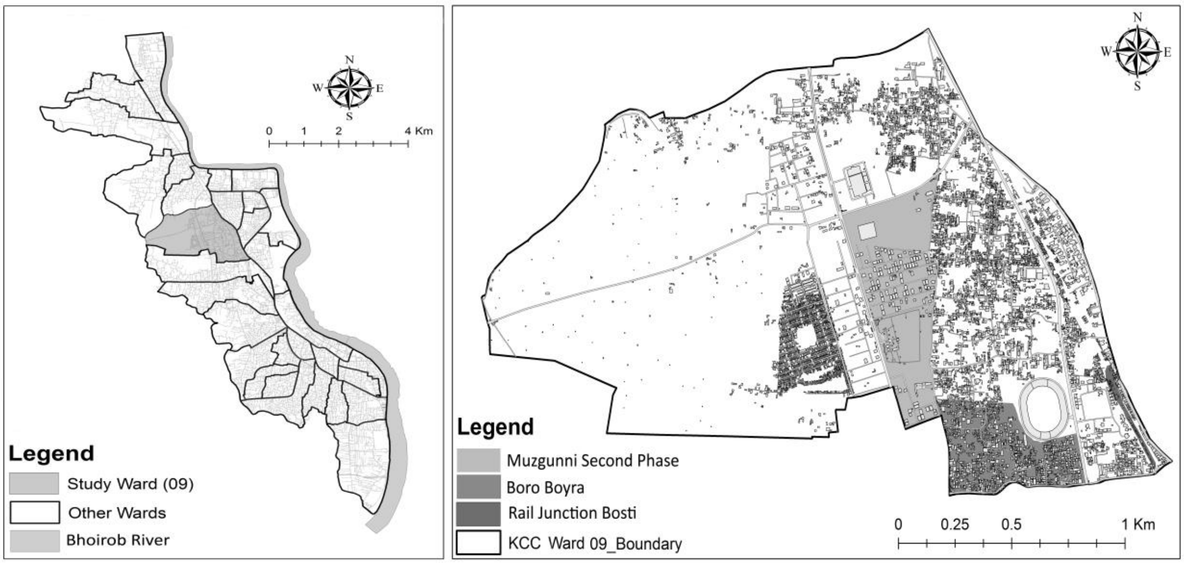

Figure 1: Study area location of Ward No. 09

2.2 Selection of Indicators

The research focus is mainly on the assessment of emptying quality determination. But emptying of FS has been linked with containment management practices and knowledge and perception of the users. In baseline survey by SNV (2014), Kabir and Salauddin, 2015 divided the emptying provision into five criteria. Applying some modification here the emptying quality has been divided into three categories namely unsafe emptying, safe emptying and moderate emptying that means partially safe emptying.Table 1: Indicators of containment management.

Table 2: Indicators for existing containment management

Criteria	Indicators
Containment	Containment size
	Containment condition
	Containment location & accessibility
	Containment outlet connection
Emptying	Emptying type
	Emptying service providers
	Emptying frequency
	Safety issues
	Emptying cost
	Vacutug efficiency
	Disposal of FS
Users Knowledge & Perception	Containment infrastructure
	Policy and regulations
	Mechanical emptying provision

2.3 Sample Size Determination and Questionnaire Administration

The questionnaire has been prepared in such way that there are three portions i, e; unsafe emptying, partially safe emptying and safe emptying for each parameter under each indicator. That's why the questionnaire has been prepared into three sections for each question. The first portion of the question is for totally unsafe emptying and will get score 0, then the middle part of the answer is moderate which means partially safe emptying and will get score 0.5. And the last one is for safe emptying which gets score 1. Actually, the households have asked questions with respect to these parameters. The questionnaire target is the house owner who can give the extensive information about the containment. The questions have repeated sometimes to check the consistency of the answers.

The sample size has been calculated based on the total number of containment of the study area. A stratified random sampling method has been adopted for this study and sample size has determined to assume 95% confidence level and 5% confidence interval. The sample size calculation formula for the whole study area has been shown in equation 1.

$$\text{Sample Size, } n = \frac{Z^2 pqN}{e^2(N-1)+Z^2 pq} \tag{1}$$

Where,
N= Number of household
Z= The nominal variants and which has 1.96 for 95% confidence level
p=0.5, q=0.5, e= 0.05

The sample size is adjusted for three types of settlements using that formula and distributed according to the total number of containment each.

Table 2: Distributed sample size for specific study area

Ward No.	Area Name	Number of Containment	Calculated Sample Size	Distributed Sample Size
09	Muzgunni Second Phase	156	234	62
	Boro Boyra	330		131
	Rail Junction Bosti	105		41

The questionnaire has been prepared in such way that there are three portions i, e; unsafe emptying, partially safe emptying and safe emptying for each parameter under each indicator. That's why the questionnaire has been prepared into three sections for each question. The first portion of the question is for totally unsafe emptying and will get score 0, then the middle part of the answer is moderate which means partially safe emptying and will get score 0.5. And the last one is for safe emptying which gets score 1. Actually, the households are asked questions with respect to these parameters. The questionnaire target is the house owner who can give the extensive information about the containment. The questions are repeated sometimes to check the consistency of the answers.

2.4 Data Entry and Analysis

After collection of total 234 household information, the data has firstly entered and processed in Standard Package for Social Science (SPSS) software. The variables have selected and identified for the preparation of data input. After completing data input, the data have converted to a Microsoft Excel spreadsheet for further analysis.

Averaging the responses of unsafe, partially safe and safe emptying for each parameter has been obtained from the SPSS software and necessary illustrations have made for the results from this data.

3. RESULTS AND ILLUSTRATIONS

This sections describes the output of the study and reveals elaborately the existing containment management practices. Also, the comparison has been shown for each component of FSM indicator taken among the three study areas.

3.1 Existing Containment Management Practices at the Study Area

To evaluate the existing containment management practices in the three types of study areas, extensive data collection and analysis has been conducted. Different management types issues i.e. containment types, containment suitability, containment outlet connection, ever emptied or not, emptying types, emptying service providers, emptying frequency, and disposal facilities etc. component of the research have been revealed and compared among the three study areas in this section.

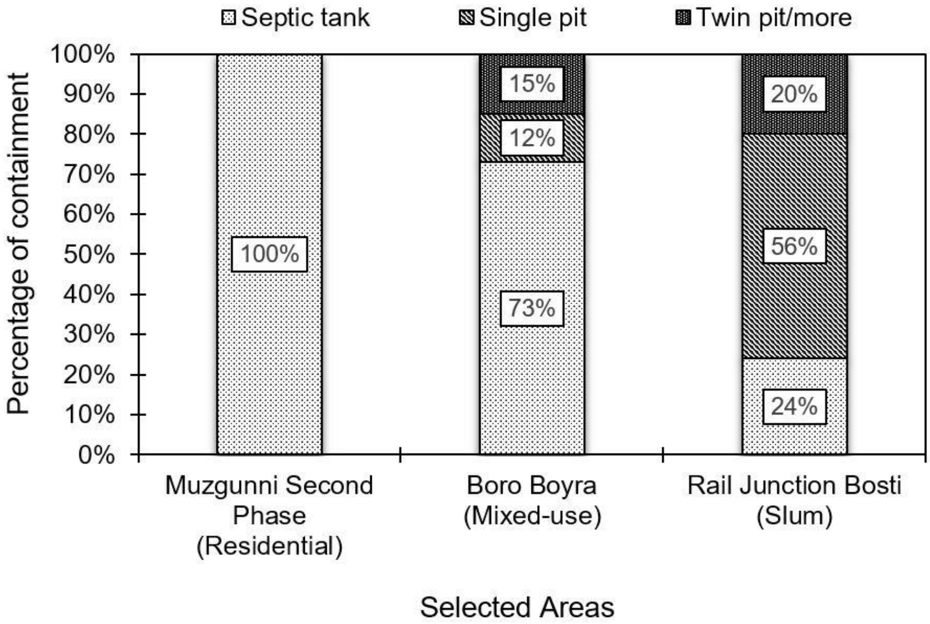

Figure 2: Containment types of the study areas

At first, the containment types have been described in the following and shown in figure 2. Muzgunni Second Phase as a residential area, 62 No. household has been surveyed and found all the containment is the septic tank. However, both the septic tank and the ordinary pit has been found in mixed-use and slum. About 73% of containment is septic tanks and remaining 27% is pit latrine in this area where the single pit is 12% and the twin pit latrine or more is 15%. In Rail Junction Bosti as the slum area, 41 households have been surveyed where pit latrine is dominant than septic tank. About 76% of containment is found as pit and only 24% is septic tank. In pit latrine, the single pit is 56% and twin pit is 20%. In slum area, the low-income community is living here and most of the people here are a worker, day labour.

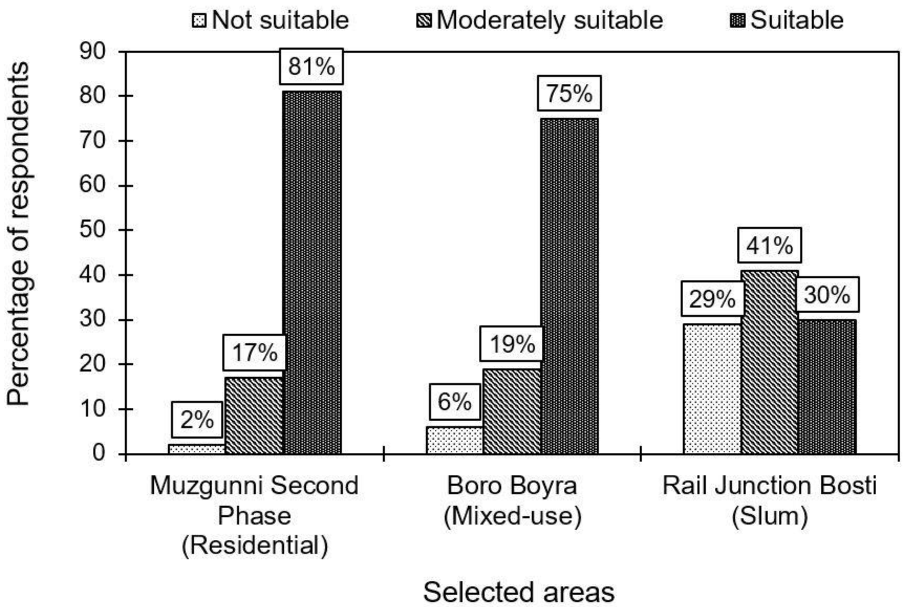

Figure 3: Containment size suitability of the study areas

Figure 3 describes the containment suitability of the study area and it is classified into three categories namely suitable, moderately suitable and not suitable. When the containment size is less than the size needed according to the number of users is termed as not suitable containment. But when the size of containment is optimum, termed as moderately suitable and if the containment has enough according to users said to be suitable. Containment size is determined by the field observations practically. Where theoretically the size is found by the number of users multiplying by the per capita accumulation rate and then matching with the previous one. However, containment size suitability is linked with the combined scoring of no. of the user, permission is taken from the authority, proper design.

From this figure4, a total 62 household are surveyed for the residential area and the majority of the containment is suitable where only 2% of containment is not suitable with respect to size. Almost same criteria have been found in the mixed-use area where about 75% of containment is suitable, 19% is in moderate and 6% is not suitable. Similarly, 49% of containment is suitable, 41% is in moderate and rest 10% is not suitable in the slum. In the slum, the percentage of containment unsuitability and moderate is more than other two area.

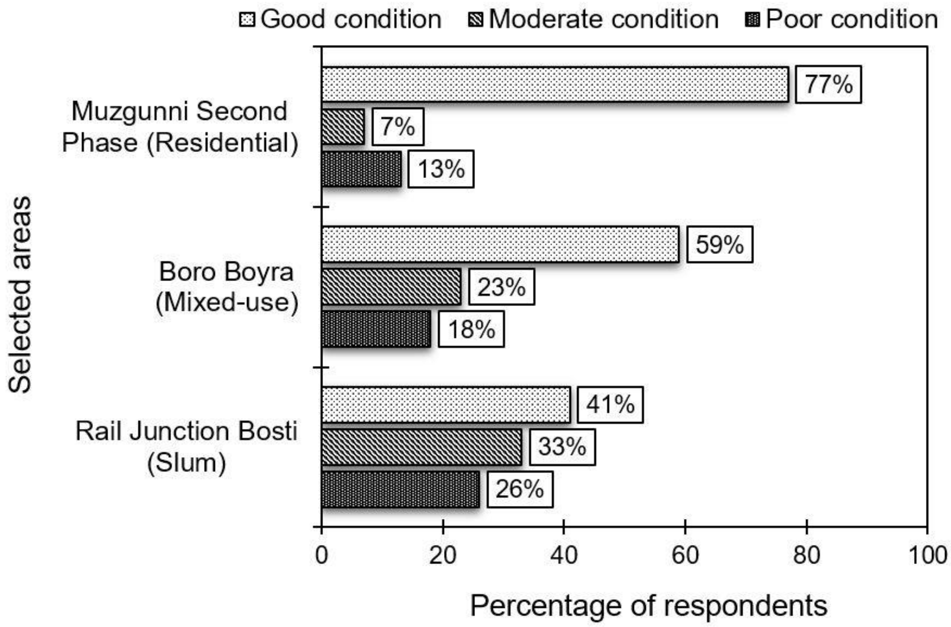

Figure 4: Containment condition at the study areas

Figure 4 describes the containment condition of the selected study area. It is found by the combined scoring of leakage, overflow, the frequency of facing a problem, types of the problem, the condition of the cover slab and checking the frequency of containment. To describe the containment condition, it has been classified into three categories e.g. good, moderate and poor. Containment is in good condition means the containment is structurally safe, have not any leakage, doesn't overflow during any season, no problem faced, etc. which can be considered as safe. Containment is in poor condition means the containment is structurally unsafe, the cover slab is open and broken, having leakage, overflowing in all season, frequently problem faced, etc. which can be considered as unsafe. And finally, containment is in moderate condition means the containment is between in good and poor condition.

From the Figure 4, it is also seen that containment condition is found good in most of the household in almost all three types of area. About 77% of containment are in good condition, 10% are in moderate and 13% are in poor condition in the residential area. Similarly, it shows that 59% of containment are in good condition, 23% are in moderate and 18% are in poor condition at the mixed-use area. And in the slum area, it has been shown that 41% of containment are in good condition, 33% are in moderate and 26% are in poor condition. It is obvious that the condition of containment is better in Muzgunni Second Phase and worst in Rail Junction Bosti.

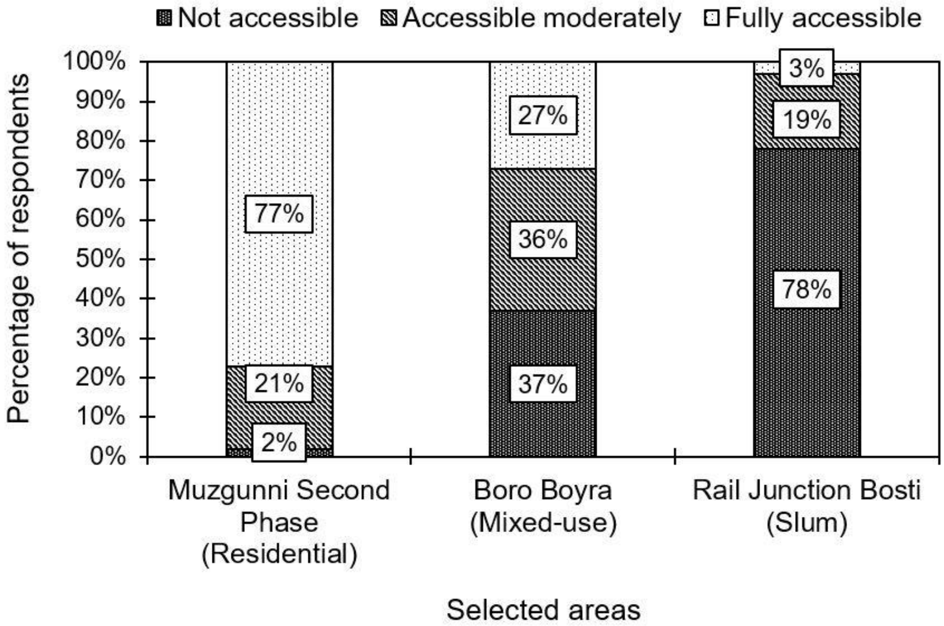

Figure 5: Containment accessibility for mechanical emptying at the study areas

Figure 5 describes the containment is accessible or not for the mechanical emptying operation of the study area. It is determined by the combined scoring five variables i.e. types of road, road width, the distance of containment from the road, the location of containment of the building and any obstruction to get the containment during emptying.

From this figure 5, it has been found that most of the containment are accessible for emptying operation by both manually and mechanically at the residential area where 77% of containment are easily accessible, 21% of containment are moderately accessible or partially accessible that means containment is accessible by removing some removable obstacles and around 2% of containment are not totally accessible for emptying operation. The main cause for not accessible is narrow road width or the long distance from the roadside or the non-removable obstacles to get the containment.

Similarly, for the mixed-use area, it is seen that 37% of containment is not totally accessible for emptying where 36% and 27% of containment are accessible moderately and easily accessible respectively. The AB Siddique road and Jhurivita road in this area are not fully accessible for vacutug entry due to its narrow road width and some of the containment is situated long distance from the roadside. For this reason, the percentage of accessibility has been decreased. In the slum, 81% of containment is not totally accessible because this slum is situated beside a rail line and the people use rail line as their road. A small portion of the slum beside a road in which a vacutug can get an entry. So for this reason, most of the containment to are inaccessible for mechanical emptying. About 19% of containment are moderately accessible and 3 % are fully accessible.

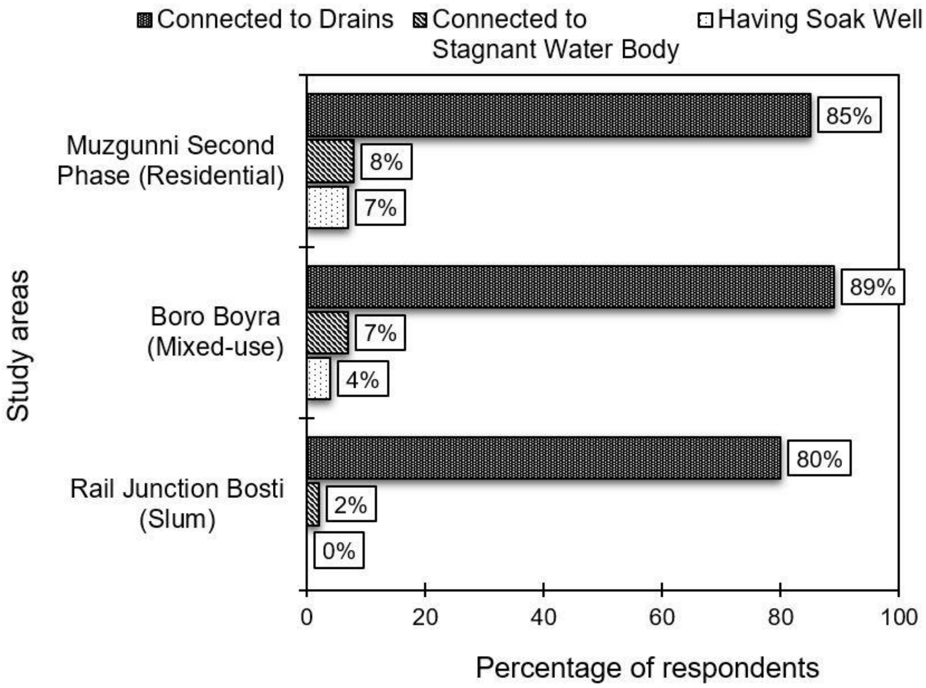

Figure 6: Septic tank outlet connection at the study areas

One of the main issues of containment management indicators is outlet connection of septic tank and figure 6 describes it for the study area. There is no sewerage facility in Khulna City. For this reason, most of the containment is connected to nearby drains or stagnant water body and it is 85% to drain and 8% to ponds or stagnant water body in the residential area. A small number of the septic tank has to soak well and its quantity is 7%. On contrary, a total 131 respondents are surveyed and found that most of the septic tank (89%) are connected to roadside drains and about 7% of the septic tank is connected to stagnant water body as shown in Figure 4.5. Like as the residential area, a small number of the septic tank has to soak well and it is only 4%. For Rail Junction Bosti area, it has been found that no septic tank have to soak well except the community-based toilets septic tank. Like that as the residential and the mixed-use area, most of the septic tank is connected to nearby drains and it is about 80%.

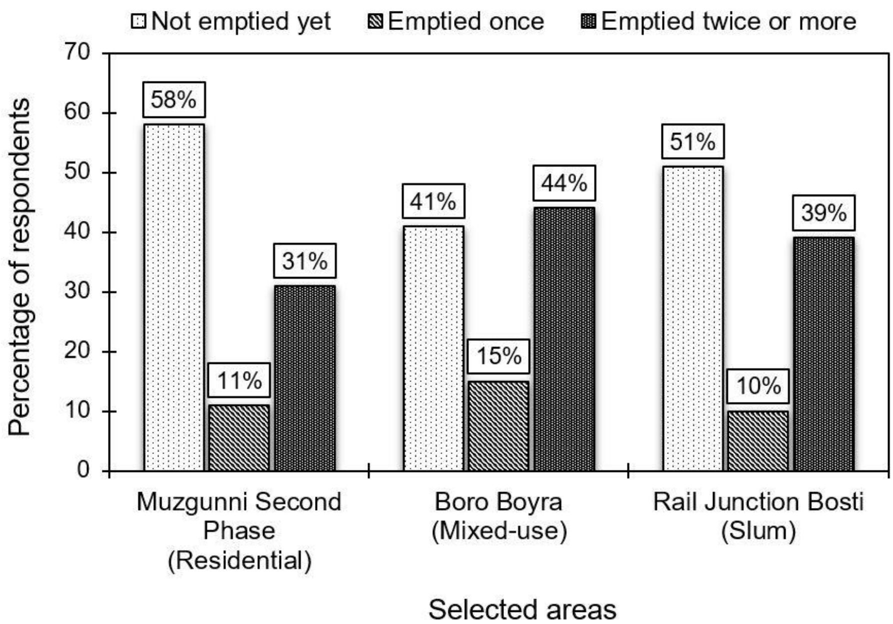

Figure 7: Containment emptied ever or not in the study areas

Figure 7 describes the containment emptied ever or not for the study area. About 58% of respondent have emptied their containment yet where 11% are emptied once and 31% are emptied twice or more times at the residential area. In this area, most of the septic tank is big and suitable according to the number of users. For this reason, it takes a long time to fill up and the respondent do want to empty until it completely fills. Again, some user linked their septic tank to nearby drain in such way that they do not need to empty ever because all the sludge goes to drain through the outlet connected pipe. But in the mixed-use area, emptying percentage has slightly increased and it is 44%. Similarly, in the slum area, 51% of respondent have not taken emptying service ever, 10% are emptied once and 39% are emptied twice or more times.

Emptying types of containment have been shown in figure 8 and it is seen that most of the containment have emptied by manual emptying process in all three types of the study area. It also shows that a big portion of people are not emptied their septic tank in the residential area and its quantity is 58%%. This cause is most of the respondents building is new and age of these building is about 6-8 years. On contrary, 42% of the septic tank is emptied. Emptying is done by the manual process is 29% and the mechanical process is 13%.

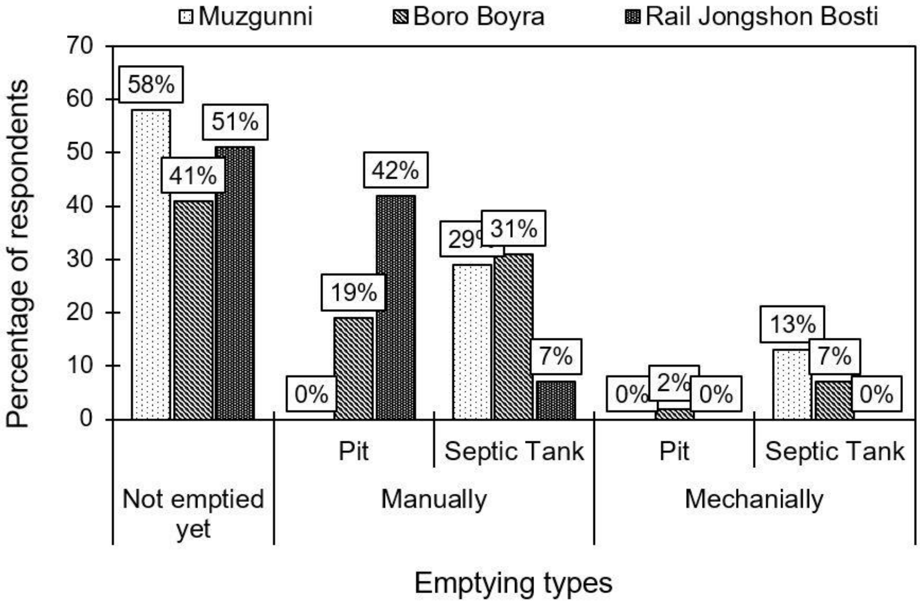

Figure 8: Emptying types of containment in the study areas

In the residential area, about 47% of people know about the mechanical service of emptying but the respondent is not willing to empty their septic tank by a mechanical process. It has been also identified that the average cost for manual emptying process and mechanical emptying process is found approximately 1500 BDT and 3000 BDT respectively. Again, from the figure 8, at the mixed-use area, 41% containment have not emptied ever where 19% of pit and 31% of septic tank have emptied manually.

Again the percentage of mechanical emptying is very low in this area and 2% of pit and 7% of septic tank emptied mechanically. The average cost for manual emptying process and mechanical emptying process is found approximately 1200 BDT and 2500 BDT respectively. In a similar way, at the slum area, 51% containment have not emptied ever where 42% of pit and 7% of septic tank emptied manually. No mechanical emptying is occurred in this area due to vacutug inaccessibility. It has been mentioned that this slum is situated beside a rail line. There is no road by which a vacutug can get an entry for mechanical emptying is not possible. In this slum, 5 community septic tank is built in 2015 and the size of the septic tank is large, so it has not required emptying till now. The average cost for manual emptying process and mechanical emptying process is found approximately 700 BDT. Safety issues during the emptying operation are almost neglected. During manual emptying, sweepers do not wear the safety protective gear i.e.; dress, gloves, gumboot, mask etc.

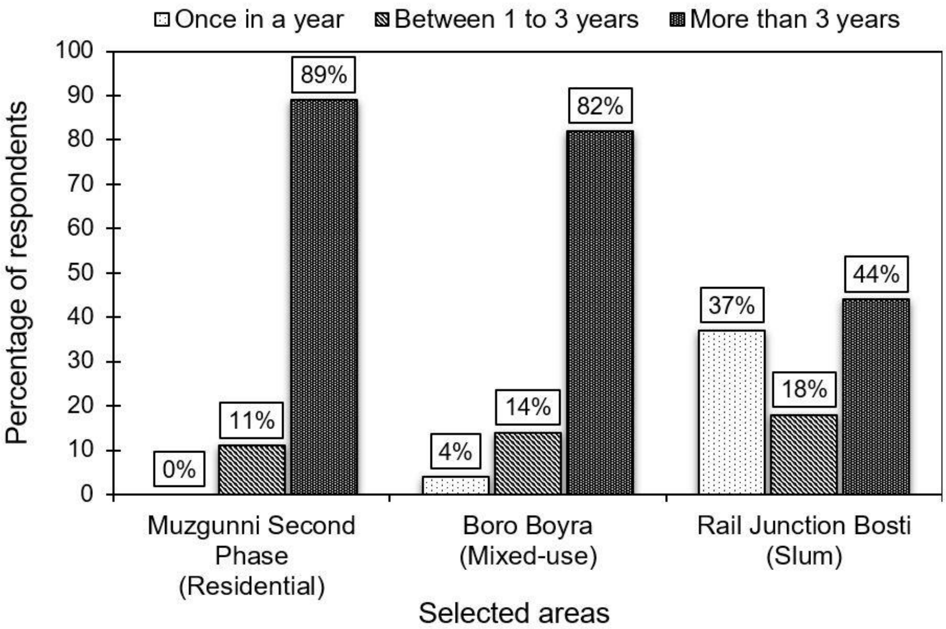

Figure 9: Emptying frequency of containment at the study areas

Figure 9 describes the containment emptying frequency of the study area. Emptying frequency of containment has been categorized into three types i.e. more than 3 years, equal or less than 3 years and at least once in a year. At residential area, total 26 respondents have emptied their septic tank and 19 respondents have emptied twice or more times and only 7 respondents have emptied once. In this 19 respondents, 17 of them that means 89% respondents have emptied their septic tank by 3 years or more and rest of them have emptied their septic tank by less than 3 years as shown in figure 9. But no septic tank is emptied once in a year which has been stated in Bangladesh National Building Code (BNBC) in the residential area.

Again, at the mixed-use area, about 82% of respondents have emptied their containment by 3 years or more and 14% of respondents have emptied their containment by less than 3 years. But only 4% of respondents have emptied the containment once in a year. Similarly, at the slum area, 44% of respondents emptied their containment by 3 years or more and 18% emptied their containment by less than 3 years. But 37% of respondents have emptied the containment once in a year. The respondents who emptied their containment once in a year is pit latrine and the number of the user against this pit is more, for that reason, emptying frequency decreased.

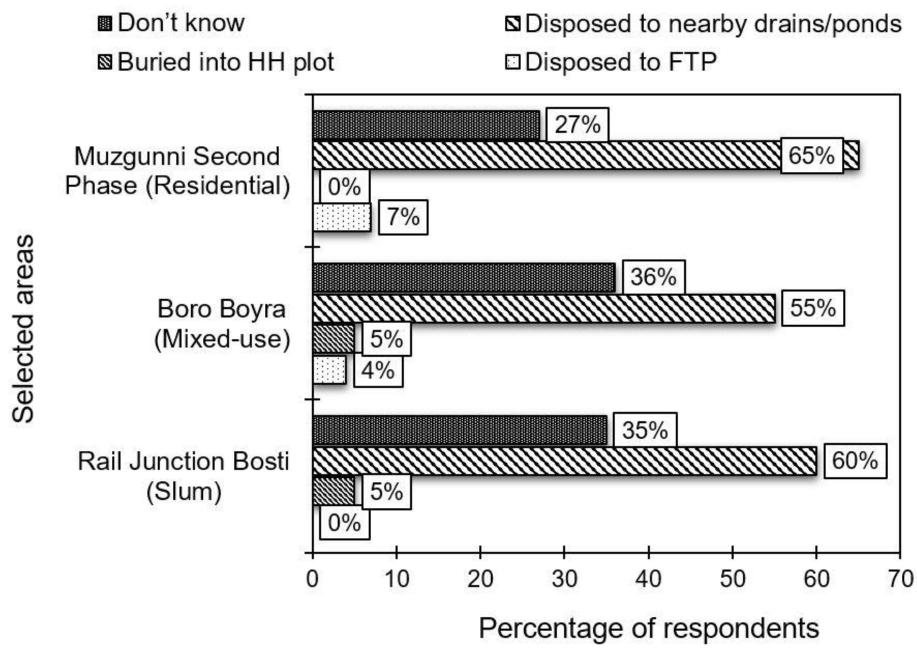

Figure 10: Sludge disposal at the study areas

Figure 10 describes the sludge disposal facilities of the study area. At residential area, it is seen that about 65% of emptied sludge is disposed to nearby drains or stagnant water body or rivers which is harmful for the surrounding environment where only 7% of emptied sludge is disposed to faecal sludge treatment plant (FTP). A big portion of respondents nearly 27% do not know where the emptied sludge finally being disposed. On the other side, at mixed-use area, about 55% of emptied sludge is disposed to nearby drains where only 4% of emptied sludge disposed to FTP. Similarly, at slum, 35% of respondents have not any idea about the sludge disposal, 60% of respondents septic tank connected to drains or ponds or other water body. 5% of sludge buried into the household plot at both the Boro Boyra and Rail Junction Bosti area. By KCC, previously the emptied sludge had being disposed to the KCC solid waste dumping trench ground at Rajbondh 2 if emptying operation is done by the KCC or CDC emptiers .But presently a new FTP has been constructed beside the solid waste dumping site and sludge is being dumping there currently.

4. CONCLUSIONS

Faecal sludge management has now a trending and valuable options to protect the environment.

- Septic tanks are dominant as containment in both at the residential area and the mixed-use area where pit latrines are dominant in the slum. In containment size suitability, 81% of containment are suitable at the residential area where this value was 75% and 30% respectively for the mixed-use and slum area. Most of the containment are suitable in all three areas except slum area where 29% of containment are not suitable. Most of the septic tank at all three area is connected to the nearby the roadside drains or ponds or stagnant water body where only 7% and 4% of containment had soak well for purification.
- Most of the containment overall current condition is in good condition except only the slum. Highest 77% of containments condition is good in the residential area where 26% containment at the slum is in poor condition. In containment accessibility, two contrary things are available where 77% of containment are accessible at residential area, on the other side 78% of containment is not totally accessible for emptying operation at the slum.

- About 31% of the septic tank has been emptied by manually where only 13% is mechanically in the residential area. However, for the mixed-use area, manual emptying is about 50% and mechanical emptying is about 7% where all emptying operations have been done either manually or self.
- In all three areas, most of the containment is not emptied yet and a small number of containment have been emptied once. There is lack of knowledge among the people about the mechanical emptying. For this reason, private sweepers are dominantly doing the emptying job by the rudimental way. All the emptiers both manual and mechanical, ignore the safety issues during emptying operations.
- In the sludge disposal section, most of the sludge disposed to nearby sewerage drains, ponds, stagnant water body or river and the value is 65%, 55% and 60% times of emptied sludge disposed to that place which is harmful to the surrounding environment. Presently a new faecal sludge treatment plant (FTP) is constructed beside the solid waste dumping site and sludge is being dumped there.

ACKNOWLEDGEMENT

The authors would like to thank KCC FSM Scholarship Programme, SNV Netherlands Development Organization, for providing financial support for the entire study period of M. Sc Engineering Program.

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TEMPORAL DYNAMICS AND RELATIONSHIP OF LAND USE LAND COVER AND LAND SURFACE TEMPERATURE IN DHAKA, BANGLADESH

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ABSTRACT

Analysis of change in LULC and LST helps to understand the UHI effect, as rapid urbanization and industrialization often take place without any coherent planning and control policies in cities of developing countries. This study aims to detect the pattern of LULC change in Dhaka City, the capital of Bangladesh, from the Landsat images of the year 1988, 2002 and 2016, considering four major LULC types named Built Up Area, Bare Lands, Vegetation and Wetlands/Lowlands. Along with the LULC, LST of those years have also been computed from the thermal band of the satellite images using the calibration of spectral radiance and emissivity correction of remote sensing, to investigate the changing nature of the climate. The change detection study has revealed that Dhaka can be characterized by increased Built Up Area and decreased Vegetation and Wetlands within these 28 years. Due to excess population pressure and rapid urbanization, Built Up Area has increased and encroached the Bare Lands and the Wetlands/Lowlands. Regression analysis has been used to characterize the relationship between LULC types and LST, which has revealed a very strong positive correlation (r^2=0.9281) between Built Up Area and LST and a very strong negative correlation (r^2=0.9556) between Wetlands/Lowlands and LST. This study will facilitate the land use managers and policy makers to monitor how the land is used and understand the development and directions of various kinds of land use, in particular, urban land use in the past, present, and future and to promote substantial and sustainable development accordingly.

Keywords: *Landsat; LST; LULC; correlation*

1. INTRODUCTION

Analysis of Land Use Land Cover (LULC) change is important to evaluate the global changes at various spatial-temporal scales and it has become one of the key issues in sustainable development and global environmental changes (Guan et al., 2011; Halmy et al., 2015; Zheng et al., 2015). For understanding the urban heat island (UHI) effect, exploration of the change in LULC is very essential. In developing countries, urbanization and industrialization often take place rapidly without any sustainable planning and guiding policies. Study of LULC to understand UHI effect has been proved to be very valuable for these countries (Tran et al., 2017). Change of LULC should be monitored regularly as it causes irreversible impacts on the environment, especially causing urban micro-climate warming (Ahmed et al., 2013; Dewan, 2015; Hahs et al., 2009; Heinl et al., 2015; Nagendra et al., 2012; Niyogi et al., 2010). These environmental impacts are most prominent and severe in rapidly growing developing nations of Asia, which have agricultural based economies (Chaudhuri & Mishra, 2016).

Like other developing countries, Bangladesh experienced a fast increase of urban population in the recent decades. This rapid urban growth results in encroachment of other land use types by Built Up Area to accommodate the huge population pressure (Dewan & Yamaguchi, 2008). This land use transformation results in more impervious surface and increases the heat storage capacity which is the main cause of UHI. UHI is considered as one of the main causes of urban micro-climate warming and defined as an environmental phenomenon where air and land surface temperatures (LST) of urban areas are higher than those of its surrounding areas (He et al., 2007; Trenberth, 2004). Growth of UHI has adverse effect on the urban climate change such as abrupt temperature rise, erratic rainfall, degrading air quality, causing calamities like flood, water logging, health outbreak, and water scarcity (Alam & Rabbani, 2007; Dewan & Yamaguchi, 2009; Hossain, 2008; Ifatimehin et al., 2010; Rizwan et al., 2008). Urbanization, the main driver of LULC change is one of the most significant factors of generation of UHI and changing LST (Chen et al., 2006; Kalnay & Cai, 2003). High spatial variability of LST has been shown in most of the urban areas, influenced by proportion of impermeable surface and vegetation mix associated with socio-economic variables such as, road and population density (Adams & Smith, 2014; Feizizadeha et al., 2013; Li et al., 2012; Zhang et al., 2013). The changing nature of LULC may influence the change in land surface temperature and urban micro-climate. So the trend of LULC should be an important topic to explore the trend of LST.

Several researchers have studied the LULC and LST change pattern for different areas and some have tried to establish the relationship between these two components, considering both linear and nonlinear relations (Ahmed et al., 2013; Chaudhuri & Mishra, 2016; Tran et al., 2017). Ahmed et al. (2013) studied the patterns of LULC changes and investigated their impacts on LST in Dhaka Metropolitan (DMP) area, using the satellite images of the year 1989, 1999 and 2009 and simulated LULC and LST for 2019 and 2029. Simulation results show that if the current trend continues, 56% and 87% of the DMP area will likely to experience temperatures in the range of greater than or equal to 30 °C in 2019 and 2029, respectively (Ahmed et al., 2013). Study of Chaudhuri and Mishra (2016) examined the spatiotemporal variability of LULC change and its relationship with LST, focusing on the southern part of the lower Ganges Brahmaputra Delta region along the international border of India and Bangladesh, with a comparison between Indian and Bangladesh part, revealing that LST changes were predominantly driven by LULC changes on both sides of the border. Dewan and Yamaguchi (2008) illustrated that the LULC of Dhaka Metropolitan had been drastically changed from 1960 to 2005, using topographic maps and multi-temporal remotely sensed data. The analysis indicated that the urban expansion of Dhaka Metropolitan resulted in the considerable reduction of wetlands, cultivated land, vegetation and water bodies, which are controlling factors of LST. Another research had been carried out to assess the relationship between the LST and LULC changes both in quantitative and qualitative ways in Dhaka Metropolitan Area using Landsat TM/ETM+ data over the period 1989 to 2010, revealing the direct correlation between these two parameters (Raja, 2012).

The knowledge of the existing LULC trends is one of the key necessities to address the challenges associated with land management (Chaudhuri and Mishra, 2016). Up-to-date, adequate and reliable LUCCs information from the past to present together with the future reasonable changes is vital to understand and evaluate several social, economic and environmental consequences of these changes (Foley et al., 2005; Wilson & Chakraborty, 2013). Being the capital of Bangladesh, Dhaka could be the best example of rapid population increase and associated environmental change, which is projected to be the third largest megacity in the world by the year 2020 (The World Bank, 2007). In Dhaka city, there is lacking or shortage of valid and up-to-date information on the type and intensity of LULC changes, which is essential for sustainable land use planning and management. If an important climatic parameter like LST can be explored along with LULC change, the more fruitful result will be gained. So this study aims to analyse the LULC and LST change in Dhaka City from the year 1988 to 2016 using Landsat images and to investigate the relationship between change in LULC and LST.

2. MATERIALS AND METHODS

2.1 Study Area

For this study, a portion of Dhaka Metropolitan Area has been selected, which can be extracted from the Landsat image scene (WRS2: 137/43) (Figure 1). Dhaka is one of the fastest growing megacities of the world and the rapid urbanization has a great impact on its LULC and LST (Ahmed et al., 2013; Dewan and Yamaguchi, 2008). The population of this city has increased by approximately 11 million in the past two decades and this causes the vertical and horizontal expansion of this city including significant change in its land use (Ahmed et al., 2013).

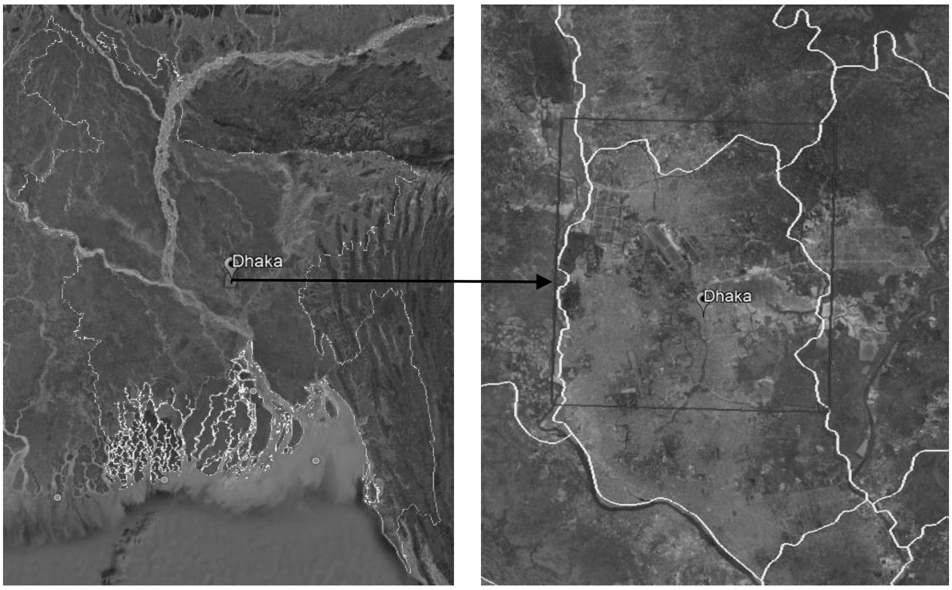


Figure 1. Location of Study area (Dhaka City)

2.2 Methodology

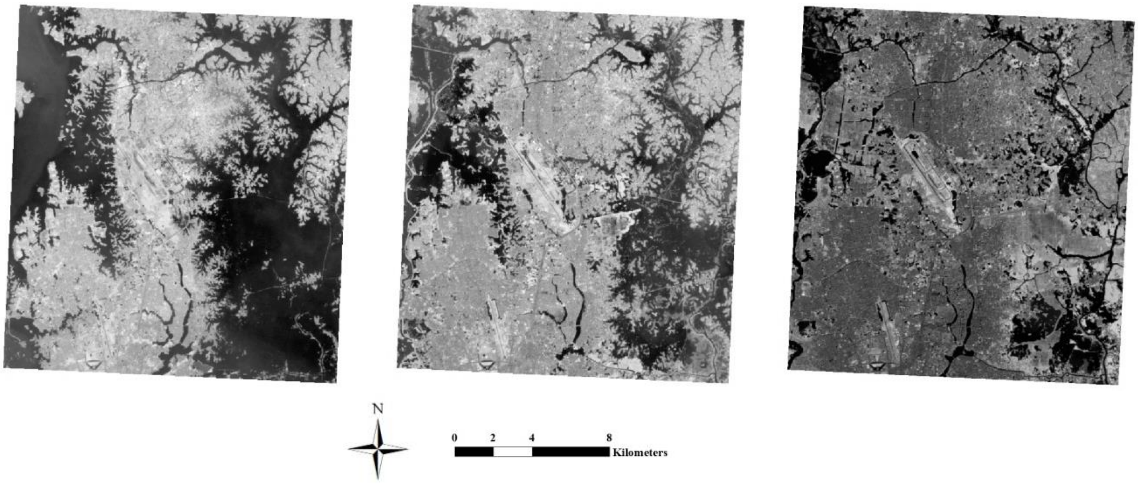
2.2.1 Acquisition and Processing of Satellite Images

To study the temporal dynamics of land use land cover (LULC) and land surface temperature (LST) in Dhaka City, Landsat Images of Dhaka city (WRS2: 137/43) for the year 1988, 2002 and 2016 have been collected from the United States Geological Survey (USGS) website (Table 1).

Table 1. Information regarding satellite images

Sensor	Path/Row	Acquisition Date
Landsat 5 Thematic Mapper (TM)	137/43	16 October 1988
Landsat 7 Enhanced Thematic Mapper (ETM+)		31 October 2002
Landsat 8 Operational Land Imager (OLI)		14 November 2016

All the spatial data layers will be registered to the same Universal Transverse Mercator (UTM) coordinate system and resampled to the same pixel resolution of 30 meter. In order to use satellite images of different periods, it is essential to acquire images of same dates, which has been followed in this study (Parsa and Salehi, 2016). Then necessary atmospheric and geometric corrections have been performed. Figure 2 shows the raw satellite images in false natural colour composite (in Grayscale).



a. b. c.

Figure 2. Thematic images of Dhaka City in False Natural Colour Composite (R(SWIR), G(NIR), B(Red)) a. in 1988, b. in 2002 and c. in 2016

2.2.2 Classification of Satellite Images

Maximum Likelihood Classification Technique of Supervised Classification has been used to identify the dominant LULC classes. Training samples have been prepared from observing false colour tone and connecting the window of ERDAS IMAGINE 2014 with Google Earth window. Researchers' prior knowledge about the LULC of the study area gained by field visits was proved very useful for this classification process (Rahman et al. 2017). Four LULC types have been classified named 'Vegetation', 'Built Up Area', 'Bare Lands' and 'Wetlands/Lowlands'. Table 2 describes the detail about LULC classes.

Table 2. Land use/land cover classification scheme

Land use/Land cover types	Description and color tone
Vegetation	Natural vegetation, parks, mixed forest, vegetated lands. Agricultural lands, crop fields etc. (green tone)
Built Up Area	All infrastructure – residential, commercial, settlements, road networks (purple tone)
Bare Lands	Unused empty lands, fallow lands, open space, earth/sand fillings, bare soil and others (tan/brown tone)
Wetlands/Lowlands	River, lakes, ponds, canals, low lying areas, marshy lands and swamps etc. (blue tone)

2.2.3 Calculation of Land Surface Temperature (LST)

Land surface temperature has been computed from the thermal band of the satellite image using the calibration of spectral radiance and emissivity correction of remote sensing. All the necessary data to calculate LST have been found in the header file (metadata) downloaded with the satellite images. At first, the Digital Number (DN) value of thermal bands of satellite images has been converted to radiance value (L_λ) and the radiance has been converted into At-Satellite Brightness Temperature. Thermal band data can be converted from spectral radiance to brightness temperature using the thermal constants provided in the metadata file (equation 1).

$$T = \frac{K_2}{ln\left(\frac{K_1}{L_\lambda} + 1\right)} \tag{1}$$

where,

T = At-Satellite Brightness Temperature (K) in Kelvin scale

L_λ = TOA spectral radiance

K_1 and K_2 = Band-specific thermal conversion constant from the metadata

After calculating the At-Satellite Temperature in Kelvin scale, it has been converted into degree Celsius scale. For Landsat 5 TM and 7 ETM+ thermal band (band 6) has been used to calculate land surface temperature. For Landsat 8 OLI, both thermal bands (band 10 and 11) have been used to calculate land surface temperature. Mean of cell values of these two bands has been used as final output.

2.2.4 Change Detection and Relationship of LULC and LST

Temporal changes in LULC has been analysed and change map between the period 1988 to 2016 has been prepared by the MOLUSCE Plugin of QGIS. Transition between different LULC types has also been calculated to present the transformation pattern (Rahman et al., 2017). Change in LST has been analysed by classifying the values in six groups and identifying the areas under these groups for the selected three years. Relationship between different LULC types and modal LST has been investigated by regression analysis.

3. RESULT AND DISCUSSION

3.1 Change in Land Use and Land Cover (LULC)

After performing the Supervised Classification technique in the raw images, they have been used to carry out the change detection study. Table 3 summarizes the change statistics between 1988 to 2016.

Table 3. Summary of Land Use/ Land Cover change statistics

LULC Types	**Area in percentage**			**Change in percentage**		
	1988	2002	2016	1988 - 2002	2002 - 2016	1988 - 2016
Vegetation	11.6	28.2	8.8	16.6	-19.4	-2.8
Built Up Area	34.4	41.4	50.7	7.1	9.3	16.3
Bare Lands	15	6.5	32.9	-8.6	26.4	17.8
Wetlands/Lowlands	39	23.9	7.6	-15.1	-16.2	-31.3

From the change analysis, it is clear that Dhaka is characterized by increasing ‘Built Up Area’ and ‘Bare Lands’. Though there is a little decrease in ‘Vegetation’ area, ‘Wetlands/Lowlands’ has experienced a significant reduction (31.3%) between 1988 to 2016. Figure 3 represents the classified images of Dhaka city for the year 1988, 2002 and 2016.

'Vegetation' areas had been increased during 1988 to 2002 by a significant portion. But it decreases in the recent period and becomes less in amount than 1988, which is an alarming threat for Dhaka city. Dhaka should conserve its natural vegetation and promote afforestation to maintain a healthy environment. Encroachment of vegetation area by other land use especially 'Built Up Area' should be prohibited.

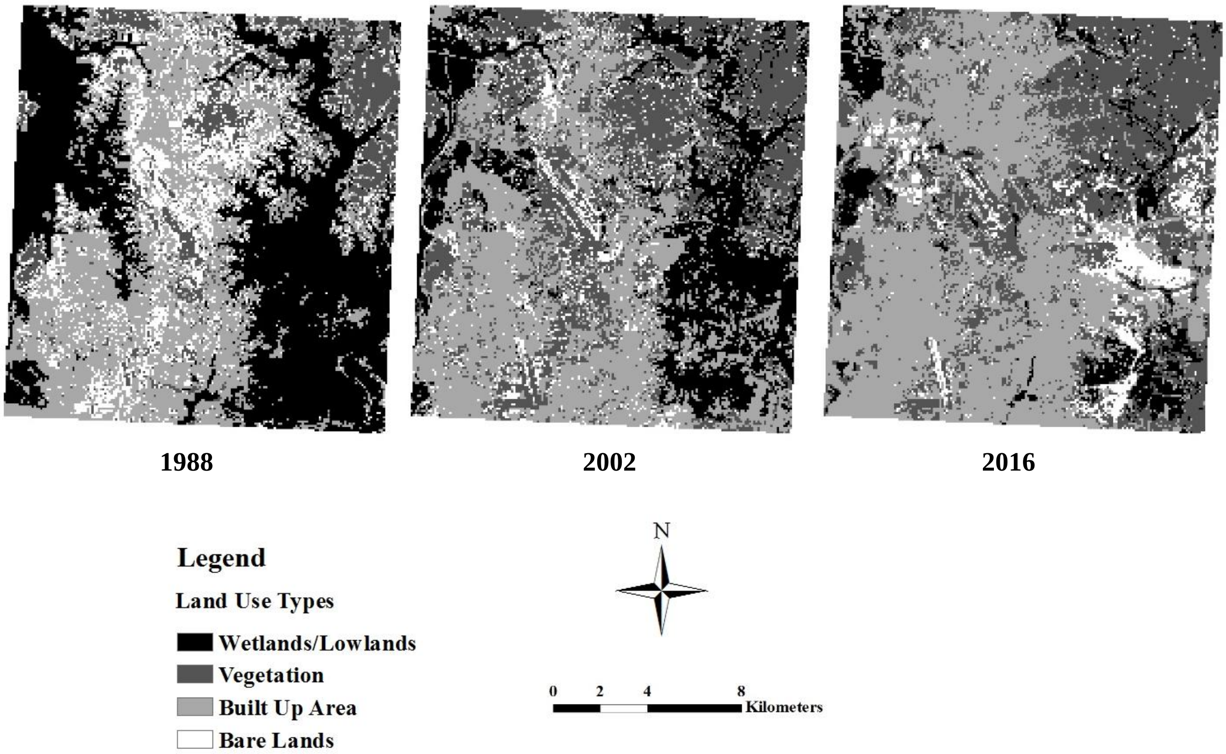


Figure 3. Classified images of Dhaka City showing four dominant LULC types

'Built Up Area' has showed an increasing trend during these 28 years. From this analysis, it has been found that half (50.7%) of the city is under 'Built Up Area' category. There was 7.1% increase during 1988 to 2002, which has increased to 9.3% during 2002 to 2016. Due to the huge population pressure, increasing 'Built Up Area' is justified. Dhaka is growing day by day not only for natural growth but also for the huge number of migratory people from the rural areas and other small urban areas. On the other hand, being the capital, Dhaka will grow to accommodate all the civil facilities. But it should not encroach other essential land uses like 'Wetlands' and 'Vegetation'.

'Wetlands' play a significant role in the environment. It influences the temperature of the atmosphere a lot. Moreover, for better circulation of waterbodies, connectivity among them is must, which can be affected through the reduction of 'Wetlands'. From the change analysis of LULC, it has been found that 'Wetlands' are decreasing day by day. In 1988 39% area was covered by 'Wetlands' which decreases to 7.6% in 2016. This huge change has substantial impact on the environment and local warming issue.

3.2 Transformation Dynamics of LULC between 1988 to 2016

By comparing the classified image, transformation matrix among the LULC types has been produced using MOLUSCE Plugin of QGIS. Table 4 shows the transformed areas in hectares from one LULC type to another. Figure 4 shows the LULC change map between the period 1988 to 2016.

Table 4. Transition between different Land Use/Land Cover

Transition Period		LULC Types (Area in hectares)				
		To	Vegetation	Built Up Area	Bare Lands	Wetlands/ Lowlands
1988 to 2002	From	Vegetation	2418.3	389.8	165.76	22.71
		Built Up Area	2343.36	5427.73	702.4	421.59
		Bare Lands	2038.33	1132.32	668.34	65.85
		Wetlands/Lowlands	499.55	3770.88	153.65	5658.58
2002 to 2016		Vegetation	38.6	2659.75	4249.24	351.96
		Built Up Area	485.93	7673.45	2000.49	559.35
		Bare Lands	973.37	513.94	0	202.85
		Wetlands/Lowlands	1748.44	1808.23	1750.71	857.57
1988 to 2015		Vegetation	18.92	889.36	1923.28	165
		Built Up Area	48.44	6264.86	2251.02	330.77
		Bare Lands	21.95	2110.24	1557.7	214.96
		Wetlands/Lowlands	2183.66	3850.35	2781.36	1261

1923.28 ha and 2110.24 ha areas have been transformed into ‘Built Up Area’ from ‘Vegetation’ and ‘Bare Lands’ area respectively between 1988 to 2016. Transformation from ‘Wetlands/Lowlands’ to other LULC types was significant. 2183.66 ha, 3850.35 ha and 2781.36 ha ‘Wetlands/Lowlands’ have been transformed into ‘Vegetation’, ‘Built Up Area’ and ‘Bare Lands’ respectively between these 28 years.

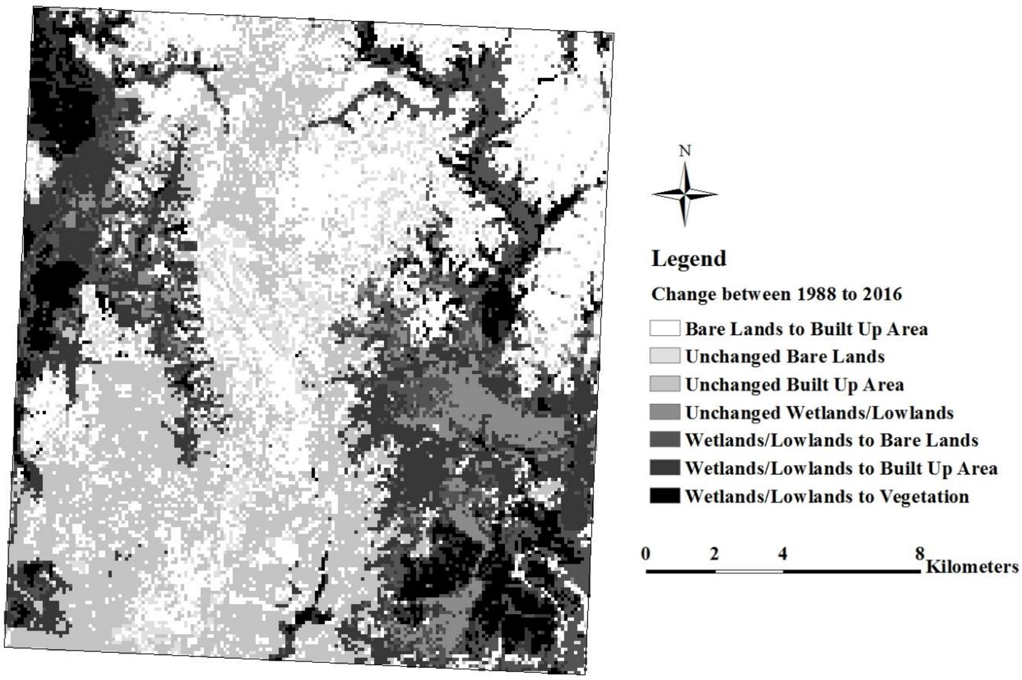


Figure 4. LULC Transformation map between 1988 to 2016

3.3 Change Pattern of Land Surface Temperature (LST)

Thermal bands of Landsat images show the spatial distribution of Land Surface Temperature (LST). Analysis of LST for Dhaka City has shown that LST is gradually increasing. LST has been divided into six groups to represent the spatial distribution visibly (Figure 5).

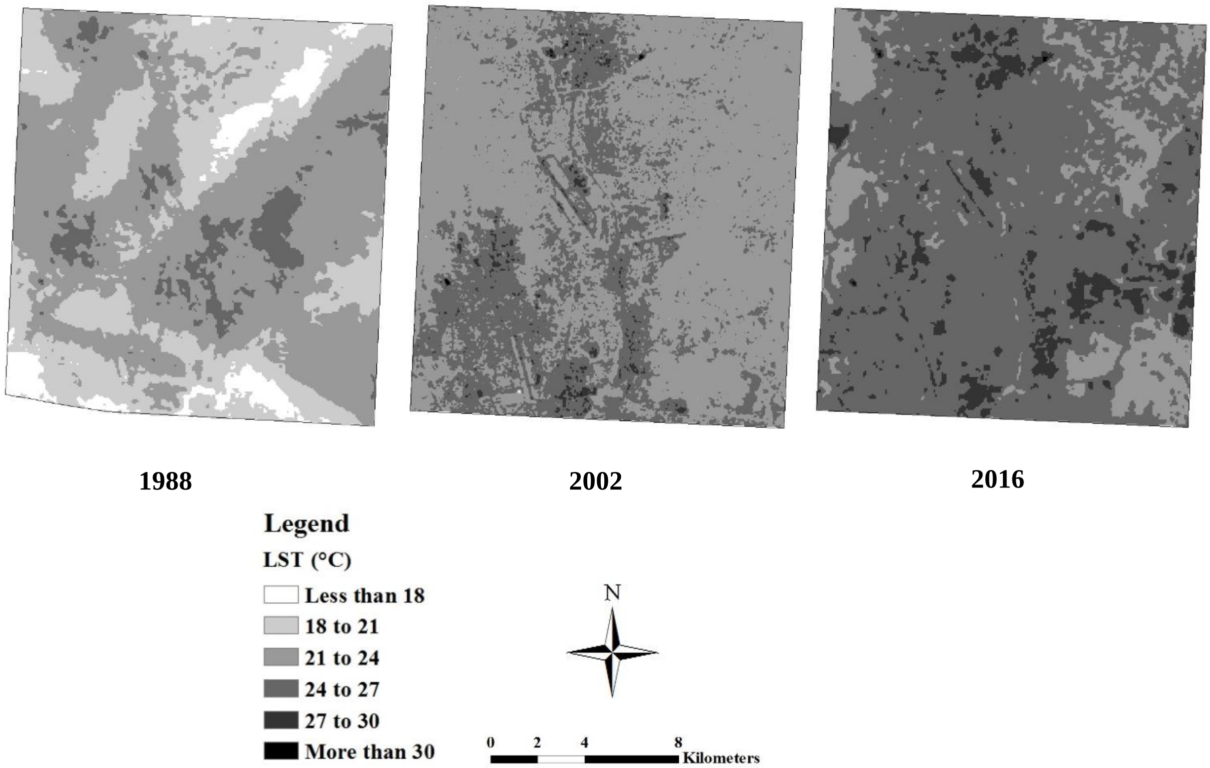


Figure 5. Spatial distribution of LST in Dhaka City

From the LST analysis, it is found that in 1988 there were some part of the City which had LST less than 18°C. In 2002, most of areas (around 70%) had LST within 18 to 21°C. But the LST distribution of 2016 has showed that around 75% areas have LST within 24 to 27°C (Figure 6).

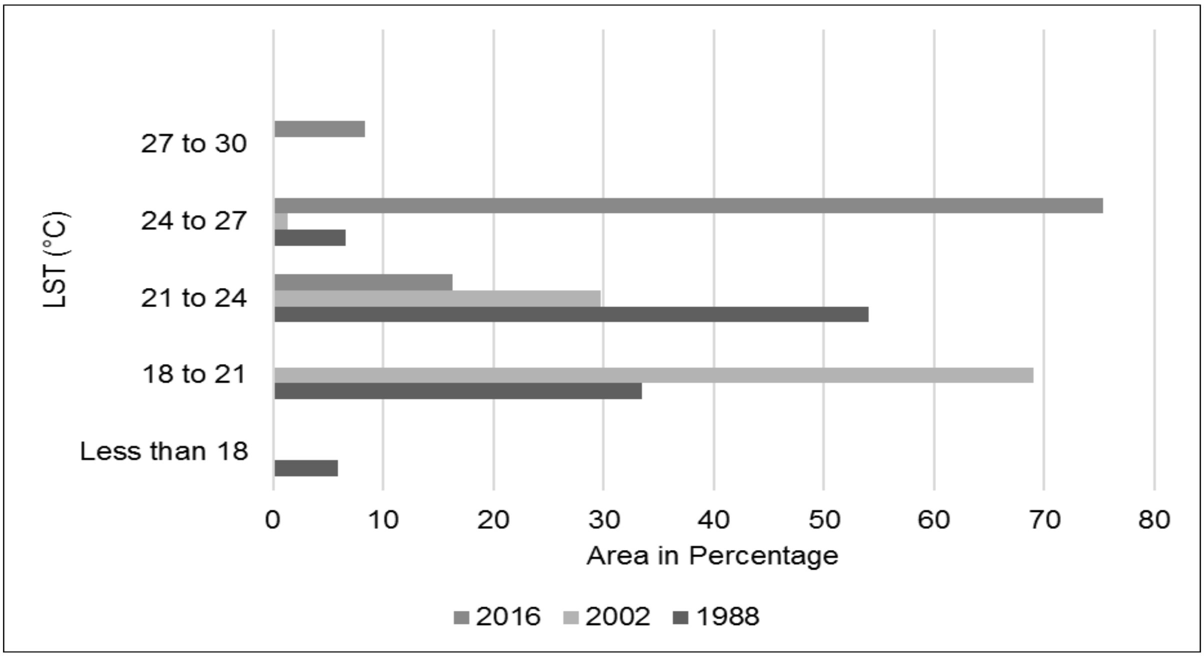


Figure 6. Changing pattern of LST (°C) in Dhaka City

3.4 Relationship between LULC types and LST

The images were during post monsoon season (October to November). Surface temperature should be less enough. But the analysis shows the increased surface temperature, which can be related to the land use distribution of Dhaka city. Impervious surface causes more heat trap and exacerbate the Urban Heat Island Effect. Half of the city is under 'Built Up Area' category, which explains the increasing trend of LST. This study tries to build up correlation among the LULC types and the LST. For the correlation study, areas under each LULC type and modal value of LST have been used. A strong positive correlation between 'Built Up Area' and modal LST has been found (r^2 = 0.9281). 'Wetlands/Lowlands' and modal LST share a strong negative correlation (r^2 = 0.9556). Ahmed et al. (2013) conducted study on Dhaka city and found similar results. This analysis shows that by controlling the amount of 'Built Up Area' and 'Wetlands/Lowlands', LST can be under control, so the UHI.

Several researchers have also studied the relationship among LULC types and LST. Spatial distribution of different types LULC has significant influence on the LST distribution (Bakar et al., 2016; Callejas et al., 2011; Sun et al., 2011; Tran et al., 2017). High land surface temperature would find in dense urban areas, followed by bare lands (Callejas et al., 2011). LST decreases with vegetation areas and wetland areas (Bakar et al., 2016; Sun et al., 2011; Tran et al., 2017).

4. CONCLUSIONS

This study focuses on the rapid land use change occurring in Dhaka City, resulting the increasing LST. If the present trend continues, Dhaka will no longer be sustainable and the environment will be severely affected due to the effect of local warming. Policy makers and the land use managers should focus on this issue. Future planning of this city should focus on ensuring more urban 'Vegetation', conservation of the existing 'Wetlands/Lowlands' and guided development of 'Built Up area'. Change of LULC should be always under monitoring and any haphazard development should be strictly prohibited. Moreover, the excessive pressure on the Capital city should be lessened through the sustainable and effective land management system like decentralization.

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SOLID WASTE MANAGEMENT THROUGH 13RS IN SYLHET CITY

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ABSTRACT

In the rush towards urbanization and industrialization as well as with emerging consumption, many developing countries have witnessed the overflow of waste and depletion of the inexhaustible natural resources at an alarming rate. The purpose of this study is to assess the existing management system in Sylhet city and review the types of solid waste that can be used for renewable sources, with an aim to maximizing resource recovery and minimizing landfilling by implementing 13Rs. The study involves a structured questionnaire and interview encompassing 150 households from different socioeconomic groups (low, lower middle, upper middle and high) for data collection. In Sylhet, Sylhet City Corporation (SCC) is the only responsible organization for the collection and disposal of the solid waste though some community-based organizations (CBOs), Non-Governmental Organizations (NGOs) and private sectors are also working. The waste generation rate here is 0.48 kg/cap/day as per estimation. About 200-250 tons of solid waste is disposed of every day in the low lying land and Hawor, situated in Lalmatia, Mogla bazar in an uncontrolled manner. This situation has contributed clogging of drains resulting in localized flooding and unhygienic condition. Again the uncollected wastes are disposed of locally which results in drainage congestion, water pollution and degradation of the overall environment. Shortage of land for landfill is also a physical constraint here. The overall condition necessitates proper solid waste management. Implementation of the 13Rs will have a profound impact on this combat with a view to protecting the environment.

Keywords: *Solid waste, SCC, environment, pollution, 13Rs.*

1. INTRODUCTION

Bangladesh is the world's 11th most populous country (United Nations, 2017) and one of the fastest urbanized countries in Asia (Anon, 2004). Because of the rapid growth of population, unplanned urbanization, industrialization and economic development, many developing countries are facing a colossal challenge of managing municipal solid waste (Damghani et al., 2008). It is estimated that approximately 13,1332 tons of waste is produced each day in the urban areas of Bangladesh, which is above 4.86 million tons annually. From the growth of population and increase in per capita waste generation, it is estimated that this amount will grow up to 47,000 tons/day and nearly 17.2 million tons per year by 2025 (Sujauddin et al., 2008). Although improper solid waste management (SWM) is one of the most burning and serious environmental problems in Bangladesh, solid waste disposal is a challenging issue for a fast-growing city like Sylhet.

Inadequate waste disposal causes environmental degradation which in turn can be provoked by the contamination of surface and groundwater through leachates, soil contamination through direct waste contact or leachates, air pollution by waste burning, spreading of diseases by different vectors like birds, insects and rodents or the uncontrolled release of methane by anaerobic waste decomposition (Zurbrugg C., 2002). Again the illegally dumped uncollected waste in open spaces, water bodies or even roadside burning is ascending serious threat to the environment. Developing countries are facing several major problems with the generated solid waste such as-

- Health hazard from uncollected waste,
- Health hazard from collected but poorly disposed of waste,
- Economic burden of waste disposal in towns and cities.

(Pearce D,Turner R.,1994).
Uncontrolled disposal of solid waste causes degradation of urban environment which has manifested the necessity of solid waste management in Sylhet city. Again a total number of nine natural drainage channels (locally called Chara) (Chowdhury R.J., 2005) are being filled up by the wastes from most of the households (situated along or near the Chara) as well as the street sweeping, which eventually affects the natural drainage system and the environment. Treating waste as a resource is the first step towards waste management and conserving resources (C. Visvanathan et al, 2007). US EPA has given emphasis on using 4R (reduce, reuse, recycling, and recovery) for achieving low use of raw materials but Bangladesh stressed on 3R (reduce, reuse and recycle) in the National 3R workshop held in February 2007 for minimizing solid waste (Chowdhury M.A.I., 2013). Afterward, 3R or 4R, other Rs such as refuse, repair, return, remanufacture, replace, renew, refill, recharge, reconditioning, recovery can be utilized to alleviate the solid waste according to Chowdhury M.A.I. (2013). An approach to implementation of these 13 Rs will have an inferential efficiency in managing and lessening the waste hazard.

Solid waste management is a worldwide problem. Many journals, books, conference papers, reports have revealed about solid waste management and resource recovery. To gain further knowledge about to solid waste management through Rs some of the studies are emphasized here.

The technical and methodical issues of solid waste management, as well as the non-technical and specific management of solid waste, have been detailed in a book by Chowdhury M.A.I., (2013). Also, solid waste minimization through Rs and cost and financial aspects of solid waste management are highlighted in this book. A study on the amount of recovery and recycling of wastes in Chittagong city was conducted and recommendation of promoting 3R strategy was made by R.B.Chowdhury et al., (2013).

The Department of Environment (DoE), Bangladesh has adopted a project on Reduce, Reuse and Recycle (3Rs) at some selected locations of both Dhaka and Chittagong city, where source segregation is a major issue (Nishita Ivy et al., 2013). A study of F. A. Samiul Islam (2016) stated that recycling can solve the unemployment problem offering an admirable environment. Moghadam et al, (2009) revealed in a study that, about 60% of MSW is transferred to the composting plant for recycling, rendering only 40% to be transferred to the dumping station. In India, various recyclable items which are readily marketable (paper, cardboard, plastics, glass and metal scraps etc.) are collected by the itinerant collectors, while the rag pickers and scavengers collect these items from the waste enclosures, platforms or the open dumps and earn their livelihood by selling them (Visvanathan, C. and Trankler, J., 2003). A recommendation of solid waste management system was made by a study of Esra Tınmaz and Ibrahim Demir (2005). Also, the comparison between the operating cost of the recommended management system and the market price of the recyclable materials was conducted in that study.

1.1 Problem Statement

In Sylhet, SCC has taken initiatives to manage solid waste by collecting, transporting and disposing of. But these practices are being challenged due to the uncontrolled collection system, inadequate space and increasing value of land. All the solid wastes are disposed of together without segregation. This is ultimately emerging a threat to the environment as well as to human health.

In the existing Solid Waste Management (SWM) system undertaken by SCC, some notified problems are:

- Inadequate service coverage,
- Operational inefficiency of services,
- Improper management of clinical (hazardous) waste.

The roadside collection system as shown in figure 1 creates nuisance to the pedestrian.

Figure 1: Roadside waste collection by SCC

Again the Lalmatia landfill is going to be completely filled up requiring new landfill sites, which is so uncertain due to the NIMBY (not in my backyard), BANANA (build absolutely nothing anywhere near anything), LULU (locally unacceptable land use) and NOTE (not over there either) syndrome (A.J. Morrissey, J. Browne, 2004) in the local community. Indigent management of solid waste results in intense urban, sanitary and environmental problems such as clogging of drains, emission of greenhouse gases, contamination of surface water, soil quality deterioration, deployment of infectious diseases, risk of explosion in landfill areas, groundwater contamination through leachate percolation, unpleasant odors as well as aesthetic aggravation (Pokhrel, D. and Viraraghavan, T., 2005). Reduction in waste before it is generated reduces the municipal and commercial cost involved in waste collection and disposal and also helps in protecting the local environment (NEERI, 1983). So, this study intends to develop the concept of 13Rs in order to solve the existing problems of solid waste management in Sylhet city like the requirement of sites for landfill, the overburden of increased amount of solid waste, cost of management, health and hygiene and finally detrimental environmental and sanitary conditions. In addition, it will also help to solve the unemployment problem by involving the poor people in resource recovery operations.

1.2 Study area, Sylhet city

Sylhet is a city in eastern Bangladesh, on the Surma River. It is one of the largest cities in Bangladesh. During the colonial period, Sylhet experienced rapid growth and expansion of the city. Sylhet was changed to a city corporation from a municipal board in 2001 and currently, the city is administrated by the Sylhet City Corporation. The latitude of the city is 24˚ 54'' North and the longitude is 91˚ 52'' East. It covers an area of 26.50 km^2 with a population of about 800,000 (Bangladesh Bureau of Statistics, 2015). Figure 2 shows the study area

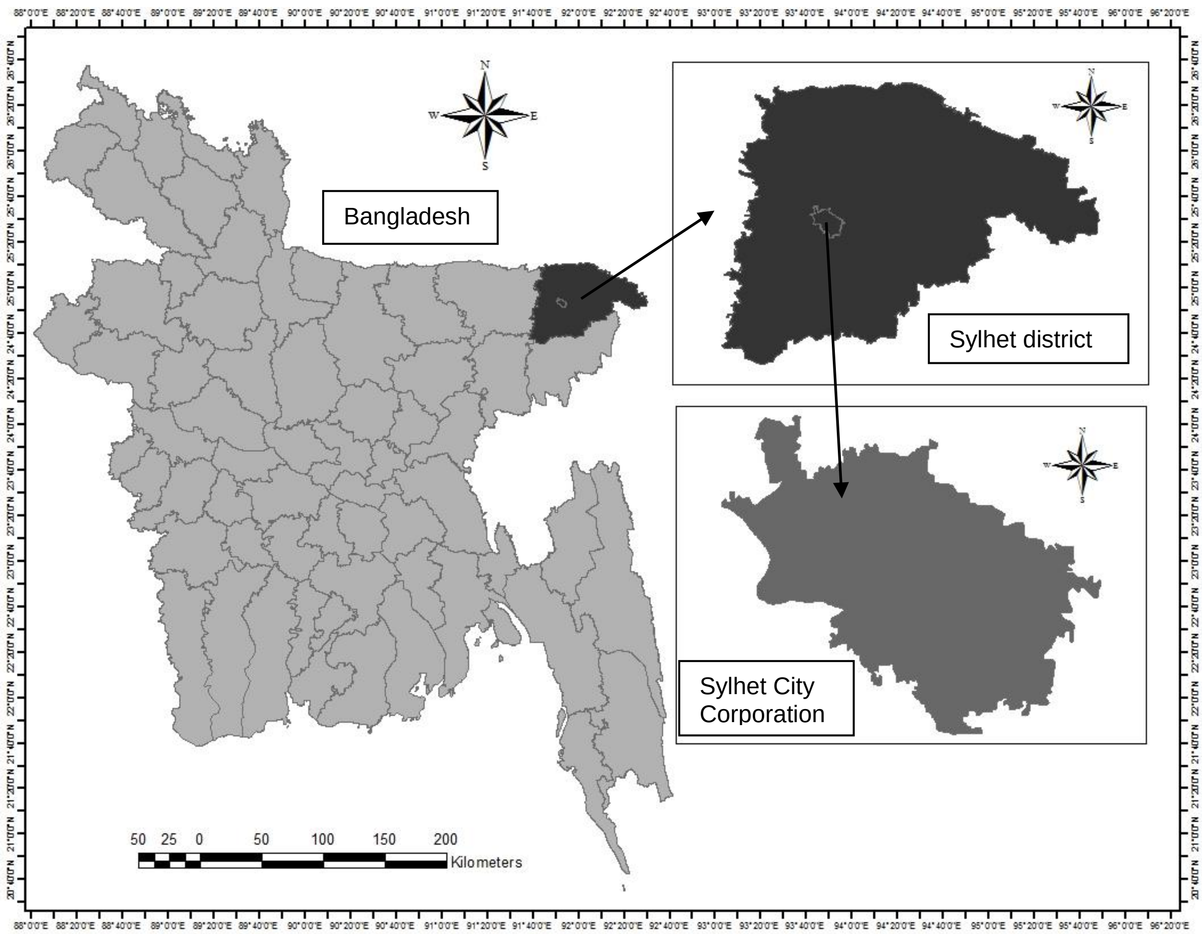

Figure 2: Study Area

1.3 Objectives of the study

General objective:

- To minimize the solid waste through 13 Rs.

Specific objectives:

- To investigate the waste generation rate and composition of wastes in Sylhet city,
- To assess the existing solid waste management system in Sylhet city,
- To evaluate the current practice of Rs in minimizing waste.

2. MATERIALS AND METHOD

2.1 Materials

A structured questionnaire with open-ended and close-ended questions has been designed, tested and modified to the final shape to collect data. The questionnaires were served, and information was collected correspondingly though in some cases face-to-face interviews were taken to get information.

2.2 Method

The study involves both primary and secondary data collection. Data were collected in order to estimate the waste generation rate and to investigate the composition of the generated wastes. By the time, the existing management system of solid waste and practice of using Rs are also assessed to meet the aim of this study by recording the views of the respondents. Then data was analyzed, and findings have been made.

2.2.1 Primary data collection

Primary data collection means practical field observation and field-based data collection. This includes Pilot study and Field study.

2.2.1.1 Pilot study:

To determine statistically sound household sample and to derive the socioeconomic information needed for the research, a pilot study of 150 households from 27 wards in SCC has been conducted. It is done to categorize the waste producers into groups viz. Low, lower middle, upper middle and high based on their income.

2.2.1.2 Field study:

The field study has been conducted from April 2017 to June 2017, using cluster sampling method representing four socioeconomic group of the pilot study, including low, lower middle, upper middle and high-income categories. A survey by questionnaire has been conducted to collect required data. Also, formal and informal interviews have been taken along with identification of problems, efficiency, and limitation of the existing management system. The field observation is depicted in figure 3 together with some existing waste segregation practice in figure 4.

2.2.2 Secondary data collection

Secondary data has been collected from SCC conservancy wings, related NGOs, CBOs and published papers.

2.3 Data analysis

The collected data has been overviewed and classified according to the contents. Amount of the generated waste and waste composition has been recorded. A representative sample of 100kg waste was taken and then each type of materials in the waste content was weighed to determine by implementing which R(s) it can be managed. Also, the percentage of waste can be processed through Rs has been determined.

Figure 3: Data collection

Figure 4: Existing practice of waste segregation (locally)

The study method is shown in figure 5.

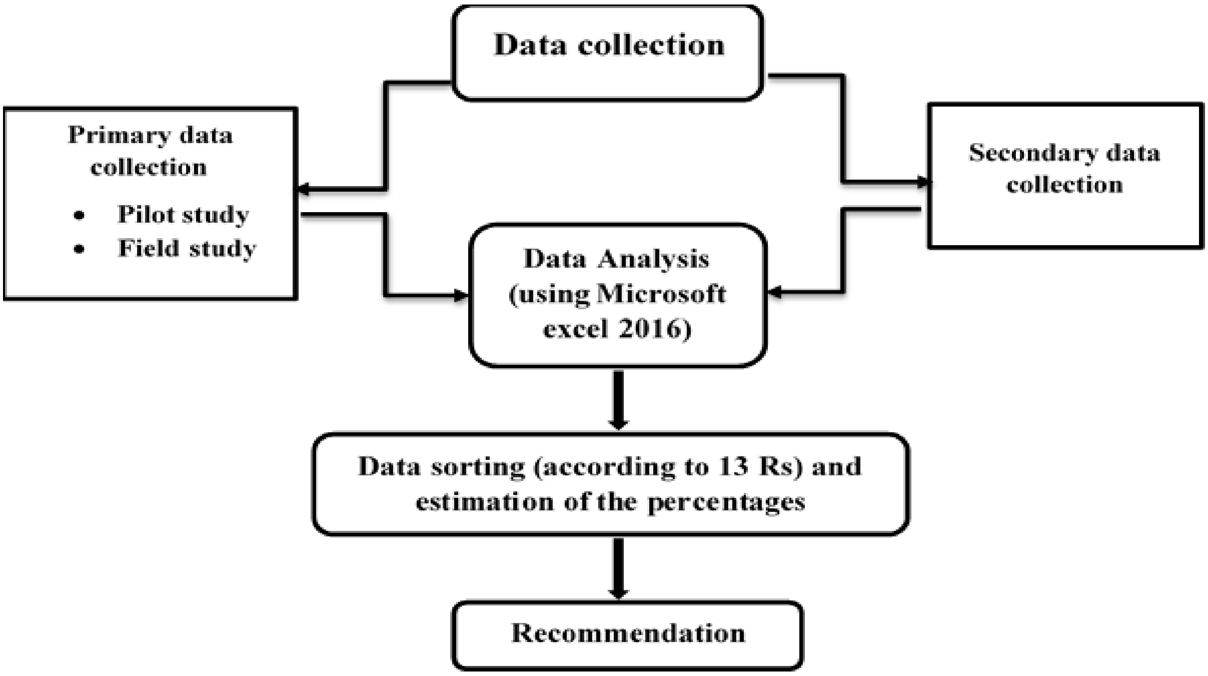

Figure 5: Flowchart of study method.

2.4 Concept of 13 Rs

13 Rs are nothing but the ways we can follow with a view to maximizing resource recovery and minimizing landfilling. These are refuse, reduce, reuse, repair, replace, remanufacture, reconditioning, recovery, refill, return, renew, recharge and recycle. By following these Rs, waste stream following landfill can be reduced to a great extent. Figure 6 shows the 13 Rs and those Rs are explained in table 1.

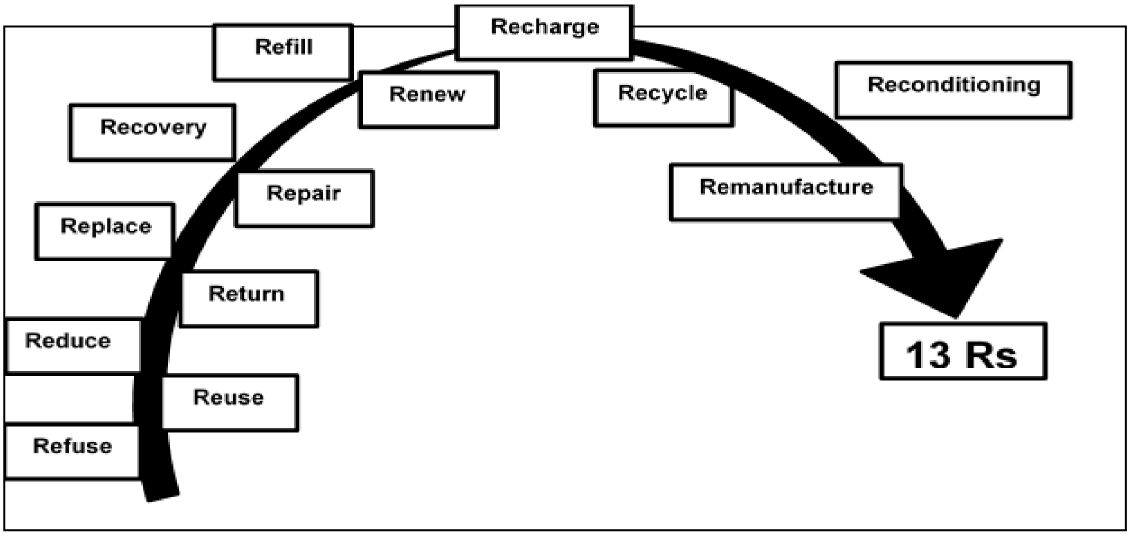

Figure 6: 13 Rs

Table 1: Explanation of 13 Rs

R type	Explanation
Refuse	Avoiding the practice of buying or using anything that becomes misuse. It is the first way to avoid the production of waste.
Reduce	Decreasing the amount of waste when mixed, of resources when sorted, and of materials when an action is applied. It minimizes the amount of waste to a great extent.
Reuse	Giving things or products a second chance by using them for their original or a different purpose more than once.
Repair	Minor renovation of the part or parts of any inactive industrial or utility plants. Repair makes a broken thing operational again.
Replace	Changing of non-working faulty parts of a plant, machine or equipment with the same parts from some type of another source.
Remanufacture	The practice of taking end-of-life goods and re-engineering them back to as-new or better condition.
Reconditioning	Second time or third-time use of anything by changing or altering the original or previous condition whatever it is deteriorated or destroyed by the use of first time.
Recovery	The process of retrieving and regaining products components and materials.
Refill	Replenishing or filling up anything to make it usable again.
Return	Returning used products to suppliers.
Renew	Conversion of waste to energy as an alternative waste management option
Recharge	Reviving or refreshing anything to get its full power for an extended period
Recycle	Reprocessing/s of used materials of an item converting into new product/s or a new raw material/s for use in a new product/s through a number of conversion/s.

3. RESULTS AND DISCUSSION

The main purpose of this study is to find out a feasible approach to solve the existing problems related to solid waste in Sylhet City. The main two parameters here are the waste generation rate per day and the percentage of wastes that can be managed by using one or more Rs. According to SCC conservancy wing, about 250 tons of wastes are collected every day from the 27 wards which are disposed of directly in Lalmatia landfill without any type of segregation. In this study, it is found that the waste generation rate is 0.48 kg/cap/day. In accordance with the finding, about 72.46 % i.e. 181.15 tons of wastes can be minimized by implementing 13 Rs. As a result, each day only 27.54 % i.e. 68.85 tons of wastes will need to be dumped in the landfill.

3.1 Existing waste management system

According to SCC, each of the 27 words has 2 collection vans which collect domestic waste from door to door. Again some CBOs have their own collection vans. All these vans collect waste from their assigned area and take them to the solid waste transfer station in Rikabi Bazar. There the wastes are filled in the trucks provided by SCC and directly taken to Lalmatia landfill without any segregation. It is worth mentioning that, there is a separate space in Lalmatia landfill for the dumping of medical waste and some of the wastes are segregated by the workers. Another noticeable thing is that in this landfill wastes are openly burnt either partially or completely to reduce the volume which is very detrimental to the environment. The overall existing system is shown in figure 7.

Figure 7: Existing system of waste management

3.2 Waste generation rate

Being not an industrial city, most of the generated wastes in Sylhet are of domestic, commercial and clinical types. The estimated waste generation rate here is 0.48 kg/cap/day including all types of wastes. The major portion of the daily generated wastes consists of 42% food waste, 11% metals, 6% paper and paper products, 5.7% plastic products, 5.5% glass, 4.2% tires and rubber, 3.8% e-wastes, 3.5% ceramics and tiles etc. as per estimation. The percentages of the generated waste with the composition are shown in figure 8.

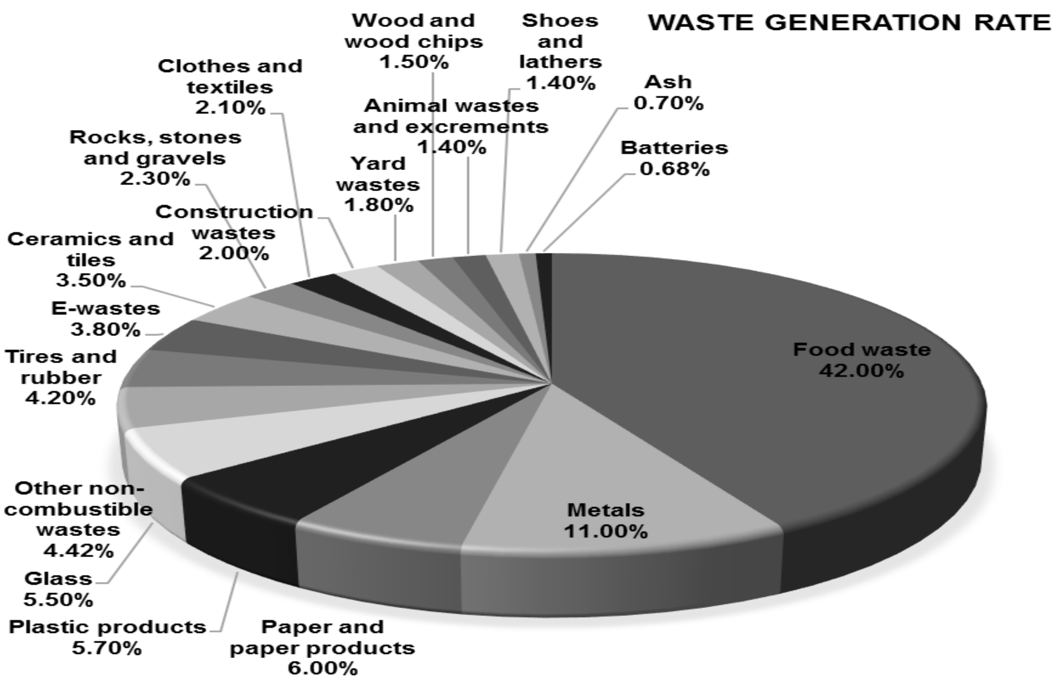

Figure 8: Waste generation rate per day

3.3 Waste minimization rate through 13 Rs

In the existing management system undertaken by the SCC, there is no systematic use of Rs. In fact, there is hardly any initiative to adopt the concept of Rs. But it is evident that, if this situation is continued, within a few years, a new landfill site will be required which is very difficult to find due to the increasing cost of land and public views towards the landfill. Though local hawkers collect wastes (paper, plastic, metal etc.) from door to door which is re-processed by some of the Rs, this percentage is not significant enough. In this study, it is estimated that 72.46% of the waste can be processed by using Rs, which will be very effective to meet the challenge of managing solid waste. The implementation of Rs in total manageable wastes is shown in figure 9.

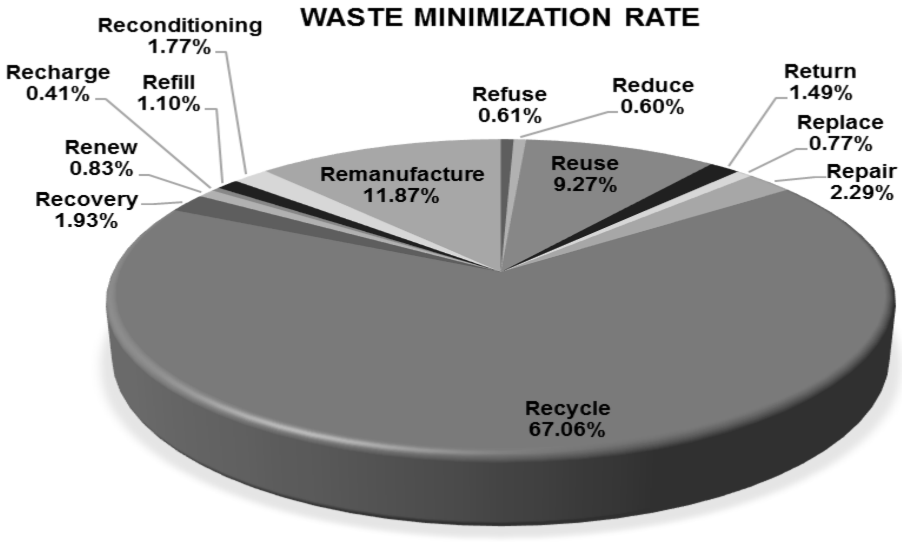

Figure 9: Waste minimization rate through 13 Rs.

3.4 Recommendation

Based on the findings here, some recommendations are made-

- As people are seemed to be reluctant to separate the wastes at source, it is tenacious to minimize the waste hazard. So, raising public awareness and ensuring public participation is the first action to achieve the goal.
- The uncollected wastes should be taken under collection scheme.
- SCC should undertake proper initiatives to implement the Rs.
- Study on financial viability and economic feasibility for cost-effectiveness of implementing the Rs is to be conducted.
- The success of adopting the concept of 13 Rs also depends on the marketing opportunity of the re-processed things. To improve the use of reusable materials, authorized people, as well as the entrepreneurs, should be encouraged to use the re-processed materials as raw material. Also, they must be informed about where and how they can find those materials.

4. CONCLUSIONS

The increasing rate of solid waste has a hostile effect on the environment as well as the social and professional life of the city dwellers, urban planners, developers and other concerned stakeholders. The waste generation rate here is 0.48 kg/cap/day as estimated which has increased than before. The study indicates that the existing waste management system in Sylhet city is not sufficient enough to manage the generated wastes. The reduction in the percentage of solid waste for disposal in landfill attained by segregating the waste contents and implementing the concept of 13 Rs is 72.46% (i.e. only 27.54% will be dumped in landfill). This will, in turn, reduce the volume of landfill required. With the technology available, the operating cost of implementing 13 Rs is less than the market price of the re-processed products which will add revenue. Some locally arrangements are made to segregate the wastes which can be enhanced to ensure the implementation of 13 Rs. Moreover, employment opportunity can be made by engaging the local folk in waste management through Rs which will solve the unemployment problem.
The result warranted that if the strategy of 13 Rs is accomplished, the problems regarding solid waste will be lessened to a great extent and the environment will be benefited a lot.

ACKNOWLEDGEMENTS

At first, the authors wish to express their deep acknowledgment to the Almighty Creator, the merciful and beneficent for enabling them to complete the study successfully. The authors are also thankful to the lab staff of the Department of Civil and Environmental Engineering, SUST for their assistance and to the SCC conservancy wings for providing valuable data.

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INVESTIGATION ON QUANTITY OF MUNICIPAL SOLID WASTE TRANSPORTATION OF KHULNA CITY CORPORATION IN BANGLADESH

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ABSTRACT

In the modern world huge solid waste is generated by the cities; hence sustainable disposal of solid waste is a big challenge for most of the cities. Khulna, the third largest city of Bangladesh is not an exception. The aim of the study is to determine the amount of municipal solid waste transported by the Khulna city corporation (KCC). In order to recognize the present situation of transported municipal solid waste a number of field surveys have been conducted in Khulna city and questionnaire surveys have been carried out with the employees of KCC and non-government organizations involved with transportation. The study finds that KCC workers collect waste from 11 small hauled container points (SHCP) of capacity 3 ton each, 21 large hauled container points (LHCP) of capacity 5 ton each, 11 distinct collection routes (DCR) and 17 secondary disposal sites (SDS) at different locations in Khulna city. The study also finds that KCC workers transport waste about 374 ton/day from above mentioned sites and dump it to 3 final disposal sites. Besides that, from final dumping site 18.00 ton/day of solid waste are used for composting purposes in the city by a NGO. The quantity of transported waste at different SDS, LHCP and DCR in the wet season are about 25%, 26% and 22% respectively, which are higher than that of dry season because of a large amount of seasonal fruits in summer season. Conversely the total quantity of transported waste at SHCP in the wet season is about 8% lower than that of dry season because of the absence of the 2 container points. For this transportation and dumping purpose daily diesel consumption is 623.26 liter/day as fuel. In the wet season the daily diesel consumption is 10% greater than that of the dry season.

Keywords: *Municipal Solid Waste, Secondary Disposal Sites, Hauled Container Points, Waste Transportation, Landfill.*

1. INTRODUCTION

The rising volume of municipal solid waste (MSW) generated, and the inclusion of harmful chemicals and additives in different waste fractions lead to waste management becoming one of the most prioritized problems for urban areas (Tulokhonova and Ulanova, 2013). Solid waste management of is one of the major environmental concerns in the most of the cities in the world (Demirbas, 2010). The first purpose of waste management is to protect human health as well as the environment from the uncontrolled dumping of waste and the second goal is to recover resources from the waste stream (European Commission, 2008).

In Khulna city. The total amount of solid waste generation is 450 ton/ day (Khulna City Corporation [KCC], 2017). The Khulna city corporation (KCC) authority is responsible for waste management in this city. Wastes are generally deposited in the community bins and secondary disposal sites (SDS) either by the dwellers themselves or community based organizations or non-government organizations (NGO) through their door to door collection system (Alamin and Hassan, 2013). The KCC staff generally does not collect waste from household. They collect waste from SDS and transport it to the final disposal sites in Rajbandh, about 7 km away from the main city (Moniruzzaman et al., 2011). For this collection and transportation purpose the average distance driven by the collection trucks of KCC is about 2500 km/day (Islam et al., 2017). The existing trends in production, consumption and waste management have led to numerous emissions of heat-trapping greenhouse gases, ranging from carbon dioxide released during the extraction and production of new materials to methane from the decomposition of organic waste in landfills (Bari et al., 2012). Likewise uncontrolled disposal of solid waste without any waste treatment generates a countless potential for water pollution, public health problems, explosion and landslide.

A very few study has been found to assess the quantity of solid waste transportation to final dumping sites in Khulna city. The aim of the study are (i) to determine the quantity of transported MSW to landfill, (ii) seasonal variation of the quantity of MSW and, (iii) seasonal variation of the daily diesel consumption of the transportation truck.

2. METHODOLOGY

2.1 Data Collection Method

In order to achieve the objective of the study, the overall methodology being used is shown in Figure 1. Two types of data are mainly gathered to conduct this research. First one is primary data which have been collected by field survey, questionnaire survey, key informant interviews (KII) and focus group discussion (FGD).The second one is secondary data which have been gathered from different journal papers, reports, and online resources.

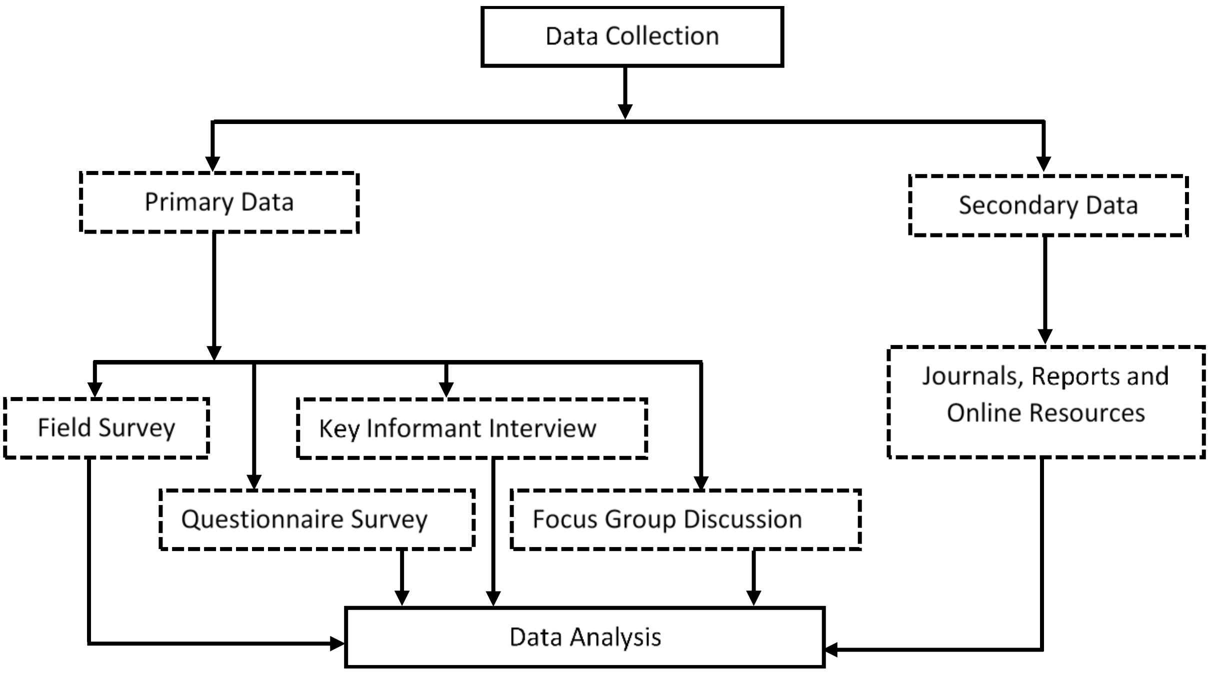

Figure 1: Flow diagram of the data collection

2.2 Selection of the Study Are

Khulna, the third largest city in Bangladesh, is located at the southwest of the country and is situated below the tropic of cancer, around the intersection of latitude 22.49^0 N and longitude 89.34^0 E. It is the second port entry in Bangladesh. The city has an estimated total area of 45.65 km^2, the population of 1.5 million and the population density of 67,994 per km^2 (KCC, 2017). There is a separate department for the solid waste management in Khulna city corporation namely conservancy department. There are 31 wards throughout the city which are selected for the survey area. The Location of study area in Khulna city of Bangladesh is shown in Figure 2.

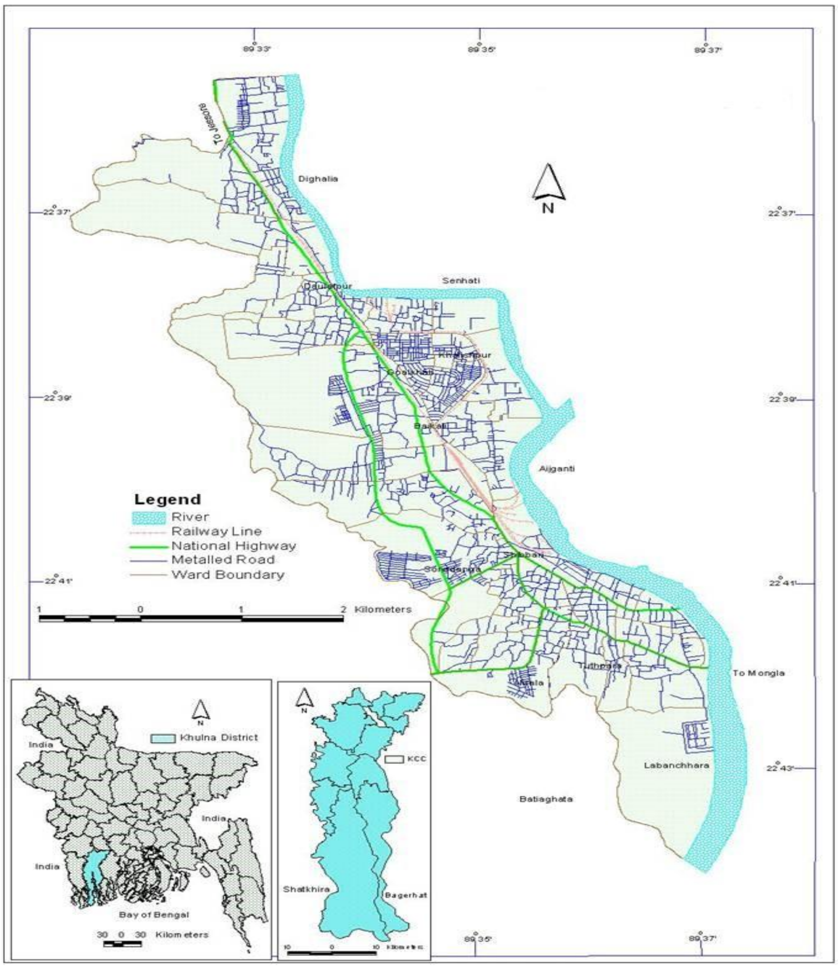

Figure 2: Location of study area in context of Bangladesh (Source: Map of Khulna, 2017)

2.3 Location and Number of Sites

The selected sites or transfer stations are final disposal sites (FDS) or landfills, secondary disposal sites (SDS), large hauled container points (LHCP), small hauled container points (SHCP) and distinct collection routes (DCR). In order to know the number of sites present throughout the city, questionnaire survey have been done to the drivers and helpers of waste collection truck. In this regards key informants interview and several meeting have been done to officers and relevant staff in KCC. Then the field survey have been performed throughout the city to find out the location of the sites. At the same time the location have been justified to the ward wise map of KCC.

2.4 Quantity of Transported Waste

With the aim of determination of the amount of transported solid waste, a series of field surveys have been conducted throughout the city. The field surveys have been conducted at each site of FDS, SDS, LHCP, SHCP and DCR. For the simplicity of research, the year is sub-divided into the two seasons i.e. dry season (October to March) and wet season (April to September). Moreover the amount of transported waste from each site of SDS, LHCP, SHCP and DCR have been recorded on throughout the entire November 2016 for the dry season and on throughout the entire July 2017 for the wet season.

3. RESULTS AND DISCUSSION

3.1 Quantity of Transported MSW

The field survey reveals that there are 11 SHCP having capacity of 3 ton each, 27 large LHCP having capacity of 5 ton each, 12 DCR and 17 SDS at different locations in Khulna city. The study also finds that the amount of transported MSW by KCC is about 374 ton/day as shown in Table 1.

For the large quantity of transported waste, SDS is considered as the major sites. The field investigation yields that the quantity of transported waste from SDS, LHCP, SHCP and DCR to final dumping sites is found as 50% (183.75 ton/day), 26% (99.125 ton/day), 4 % (15.875 ton/day) and 20% (75.25 ton/day) respectively of total transported waste by KCC

Table 1: Summary of transported municipal siolid waste by KCC in Khulna city

Name of the Sites (Number of Sites)	Daily Transported Waste (ton/day)		
	Dry Season (Oct-Mar)	**Wet Season (Apr-Sep)**	**Average**
Secondary Disposal Sites (17)	158.00	209.50	183.750
Large Hauled Container Points (27)	84.25	114.00	99.125
Small Hauled Container Points (11)	16.50	15.25	15.875
Distinct Collection Routes (12)	68.50	82.00	75.250
		Total	374.00

3.2 Seasonal Variation of the Quantity of Transported Waste

The seasonal variation of the quantity of transported waste at different sites of SDS is presented in Figure 3. The total quantity of transported waste at different SDS in wet season is about 25% higher than that of dry season because of large amount of seasonal fruits in summer season. However, at Goalkhali Koborstan SDS, quantity of transported waste in wet season is less than that of dry season because of the addition of new large hauled container point. In wet season the maximum transported waste find at PTI Mor which is about 51.0 ton/day. In dry season there is no SDS at Zilla School and Sadar hospital but in wet season new SDS found and quantity of transported waste is recorded.

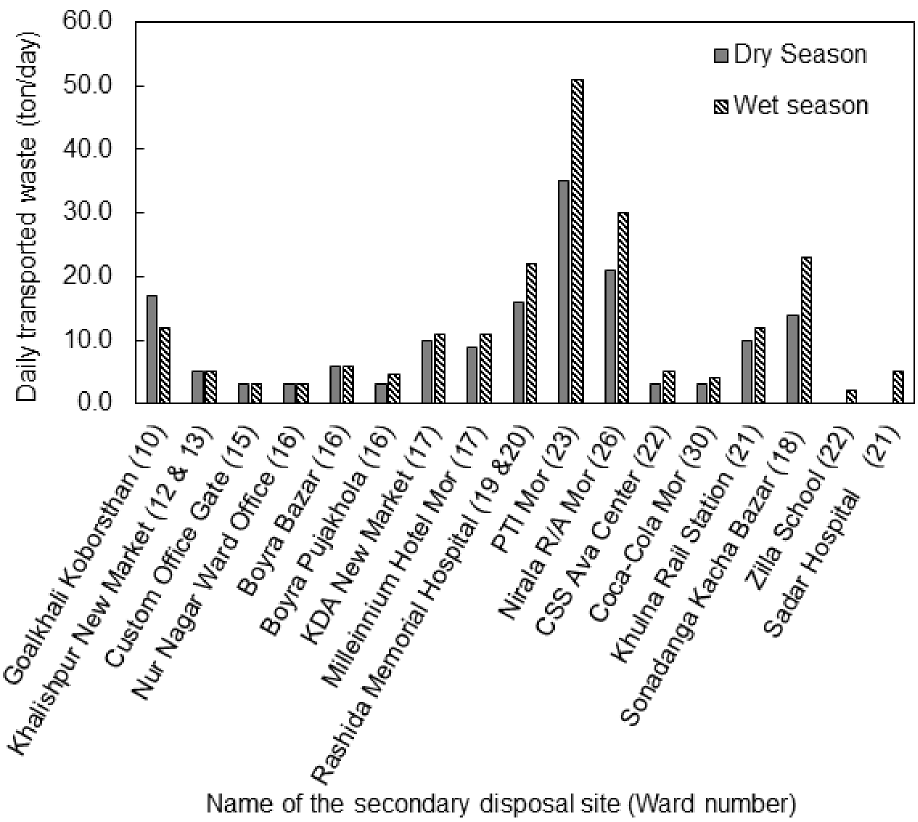

Figure 3: Seasonal variation of the quantity of waste transported waste at different SDS

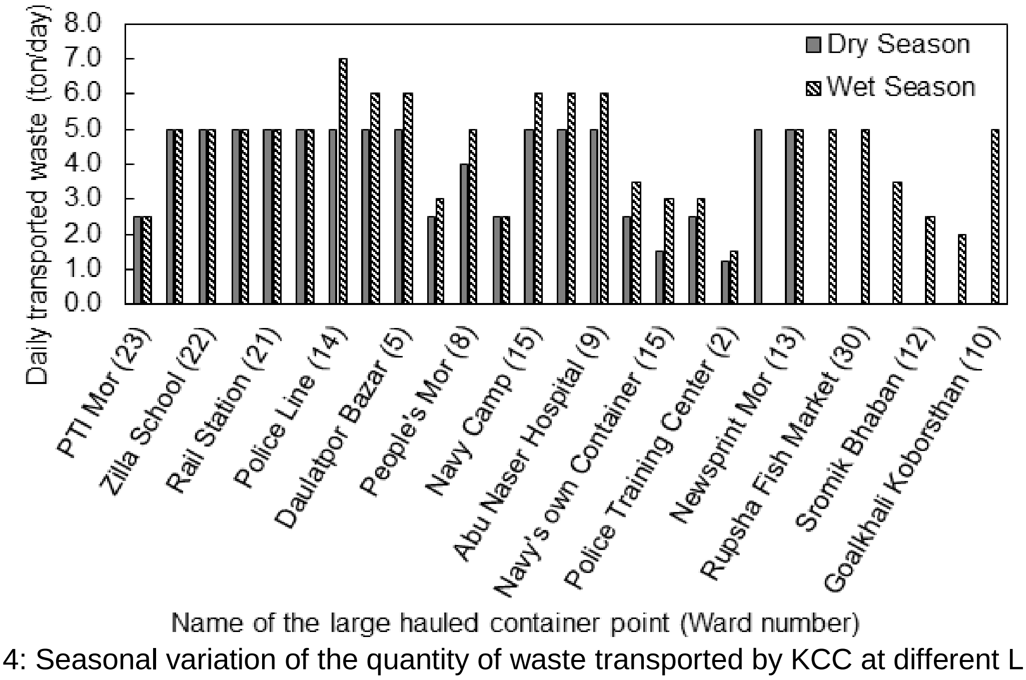

Figure 4: Seasonal variation of the quantity of waste transported by KCC at different LHCP

The seasonal variation of the quantity of transported waste at different sites of LHCP is presented in Figure 4. The total quantity of transported waste at LHCP in wet season is about 26% higher than that of dry season because of large amount of seasonal fruits in summer season. From the Figure it is found that there are 8 number of LHCP where amount of transported waste are same in both season because of the presence of SDS at the same location. Similarly there are 6 number of LHCP where quantity of transported waste is larger than the capacity of the container because the data are recorded on the basis of total number of container emptied in a week. Especially in fruit season, the KCC staff transported waste at the early morning as well as evening in a day. In dry season there is no existence of LHCP at South central road, Rupsha fish market, Kulibagan, Sromik bhaban, Janata cinema hall and Goalkhali koborstan but in wet season new LHCP found and quantity of transported waste is recorded.

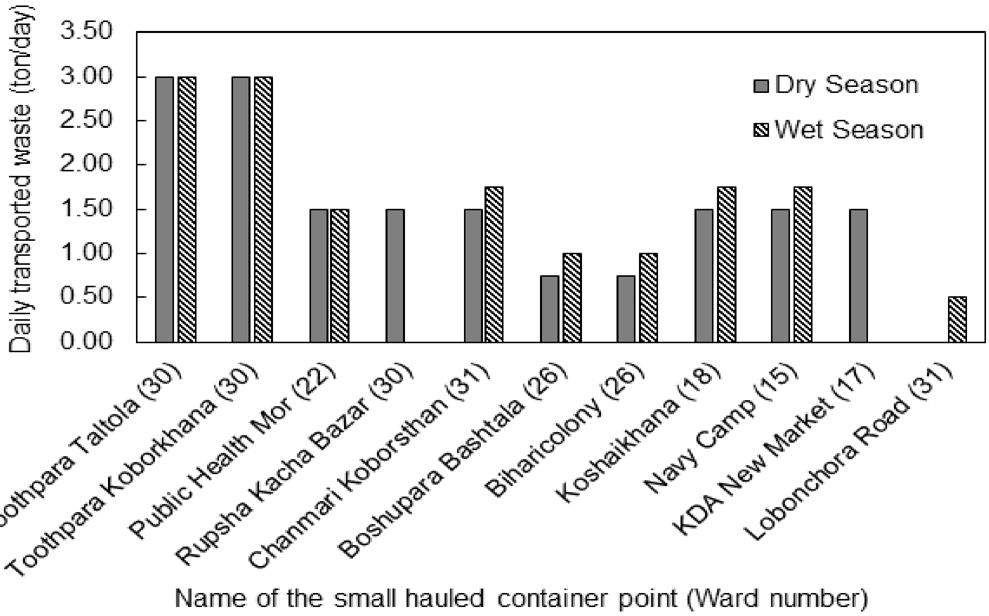

Figure 5: Seasonal variation of the quantity of waste transported by KCC at different SHCP

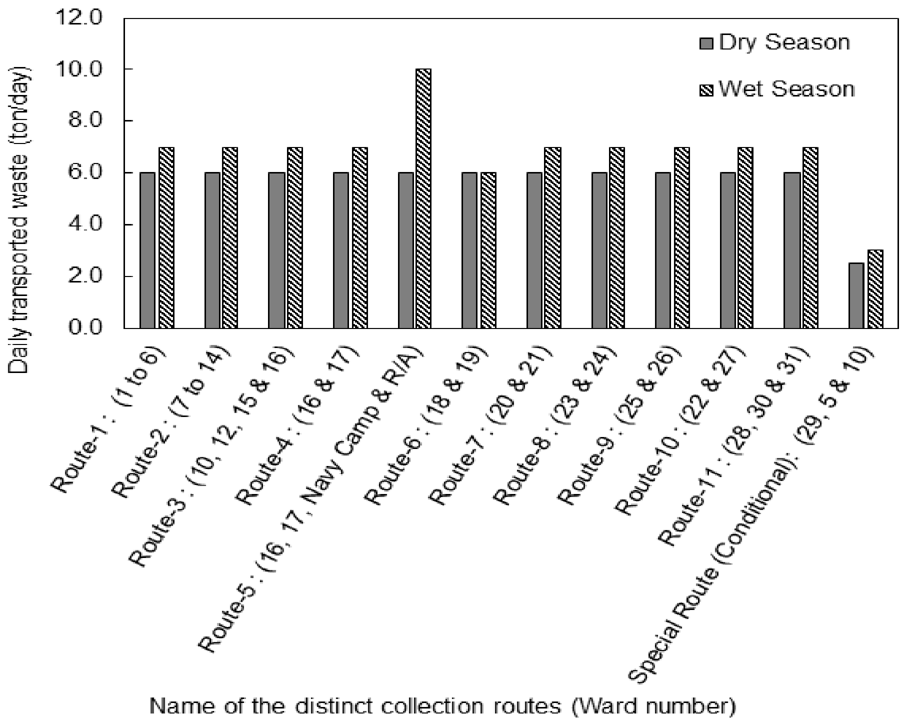

Figure 6: Seasonal variation of the quantity of waste transported by KCC at different DCR

The seasonal variation of the quantity of transported waste at different sites of SHCP is presented in Figure 5. The total quantity of transported waste at SHCP in wet season is about 8% lower than that of dry season because of the absent of the 2 container points.

From the figure it is clear that the seasonal variation of transported waste at different container points is insignificant.

In Figure 5, the total quantity of transported waste at different DCR in wet season is about 22% higher than that of dry season. In wet season the maximum transported waste found at Route-5 which is 10.0 ton/day.

3.4 Daily Diesel Consumption of the Transportation Truck

Table 2 represent the daily diesel consumption of transportation truck. The total diesel consumption of transportation truck is of 227489 liter/year. Hence the daily diesel consumption is found as 623.26 liter/ day.

Table 2: Daily diesel consumption of transportation Trucks

Name of the month	**Name of the season**	**Monthly diesel consumption (liter/month)**	**Daily diesel consumption (liter/day)**
April-2016	Wet Season	21857	623.26
May-2016		20250	
June-2016		25493	
July-2016		22176	
August-2016		18161	
September -2016		17825	
October-16	Dry Season	17760	
November-16		19671	
December-16		17496	
January-17		14624	
February-17		14973	
March-17		17203	
	Total	227489	

Figure 7 represent the seasonal variation of diesel consumption. The daily diesel consumption in the wet season and dry season are 689.11 liter/ day and 557.41 liter/ day. From Figure, in wet season the daily diesel consumption is 10% greater than that of the dry season because of greater amount of waste due to seasonal fruits.

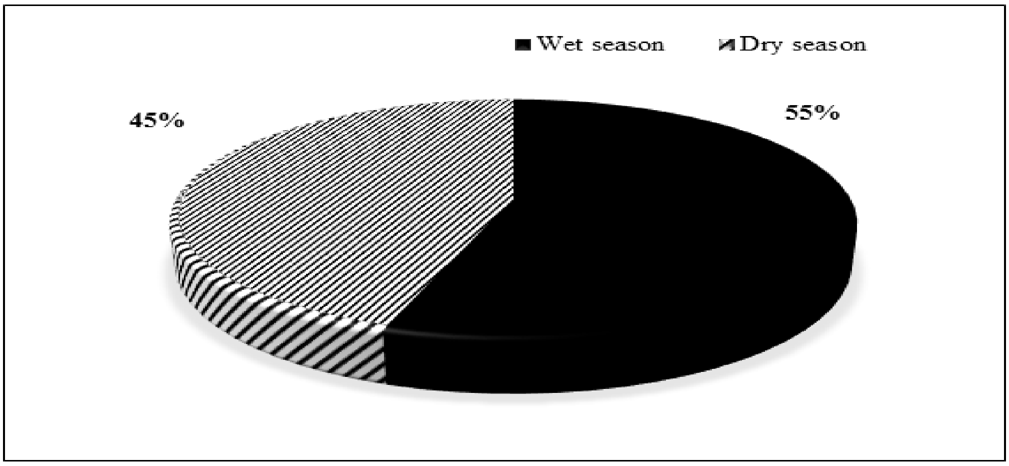

Figure 7: Seasonal variation of diesel consumption of the transportation Trucks.

4. CONCLUSIONS

The main conclusions drawn from the present study are as follows:

- The amount of transported MSW is 374 ton/day.
- The quantity of transported waste at different SDS, LHCP and DCR in the wet season are about 25%, 26% and 22% respectively higher than that of dry season. Conversely the total quantity of transported waste at SHCP in the wet season is about 8% lower than that of dry season.
- In the wet season the daily diesel consumption is 10% greater than that of the dry season.

ACKNOWLEDGEMENTS

We wish to express our deepest thanks to Executive Engineer and Sub-assistant Engineer of conservancy the department of Khulna City Corporation for providing data and information, assistance rendered and interest in this study.

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Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), 9~11 February 2018, KUET, Khulna, Bangladesh (ISBN-978-984-34-3502-6)

INVESTIGATION OF OPTIMUM INITIAL MOISTURE CONTENT OF CO-COMPOSTING PROCESS IN KHULNA CITY OF BANGLADESH

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ABSTRACT

Composting is the biological degradation of highly concentrated biodegradable organic wastes in the presence of oxygen (aerobic decomposition) to carbon dioxide and water, whereby the biologically generated waste heat is sufficient to raise the temperature of the composting mass in the thermophilic range (50°C to 65°C). In this study, temperature variation and Volatile Solids reduction of the composting process in different initial moisture content were investigated. Also determine the optimum initial moisture content in co-composting process. Organic solid waste was prepared according to waste proportion vegetable wastes: food wastes: waste paper: sawdust as 40:35:10:15. Organic solid wastes (OSW) and faecal sludge (FS) was mixed ratio 90:10 (OSW: FS). Total seven initial moisture content of organic solid wastes and faecal sludge were taken such as 20%, 30%, 40%, 50%, 60%, 70% and 80%. To investigate the effect of initial moisture content on volatile solids (VS) degradation and temperature parameters for total 14 reactors were used. Composting tests were performed in 30 days duration every initial moisture content. Temperatures at composting mass were continuously monitored. Maximum temperature of composting process was 55°C to 65°C which raised within 7 days in the moisture range between 50% and 70%. The area under the temperature curve in °C.h was highest in the initial moisture range between 50 and 70%. It should be noted that a higher value of the area under the temperature curve indicates higher heat production and thereby higher VS degradation. For detemination of optimum moisture content, the area under the temperature curve in °C.h and %VS reduction was highest in the initial moisture content range between 55% and 70%. VS reduction sharply decreased at an initial moisture content below 30 to 40%.

Keywords: *Organic solid waste (OSW), Temperature, Co-composting, Moisture content and volatile solids reduction*

1. INTRODUCTION

Khulna is the country's third largest city in Bangladesh and has been known as an industrial city with a port. The whole city area is only 2.5 meters above the mean sea level. Khulna has a history of about one hundred years. Composting is the best option for solid waste management. However, composting offers a cost-effective sustainable solution for the biodegradable organic wastes. This is a very effective process for recovering waste materials and for minimizing environmental emission by stabilizing the organic wastes in the shortest period of time. In practice, the main biological process applied for solid wastes is composting (Haug, 1993). Although this biological decomposition can take place under aerobic or anaerobic conditions, composting is mainly considered as anaerobic process. Anaerobic composting has higher odor potential because of the nature of many intermediate metabolites (Haug 1993), whereas aerobic composting minimizes the potential of nuisance odors (Metcalf & Eddy,1979). The decomposition rate in anaerobic composting is also very slow.The use of organic solid waste has a long history mainly in areas of the world. The biodegradable portion could be managed either by recycling and recovering through biological treatment, or disposal to landfills. Solutions for effective and sustainable Faecal Sludge Management (FSM) presents a significant global need. FSM is a relatively new topic, however, it is developing rapidly and gaining acknowledgement. FSM can be managed together with composting process and the find process is usually named as Co-composting.

Co-composting is a resource recovery technique resulting in production of soil conditioner from the combined organic solid waste and Faecal Sludge. Co-composting is the term used to indicate the composting of two different materials together. In this case Faecal Sludge (FS) and organic solid waste (OSW), both are composted together. Other organic materials, which can be used or subjected to Co-composting, comprise animal manure, sawdust, wood chips, bark, slaughter, sludges and solid residues from food and beverage industries. Cocomposting of Faecal Sludge and organic solid waste is advantageous as these two materials complement each other. Faecal sludge is relatively high in nitrogen content on the other hand organic solid waste is high in Carbon content. Both materials can be converted into a useful product by doing Co-composting. High temperatures attained in the composting process are effective in inactivating excreted pathogens contained in the FS and will convert both wastes into a hygienically safe soil conditioner-cum-fertilizer. The key factors affecting the biological decomposition processes are carbon to nitrogen ratio, moisture content, oxygen supply, aeration, particle size, pH, temperature, turning frequency, microorganisms and invertebrates, control of pathogens, degree of decomposition and nitrogen conservation (Strauss et al, 2003 and Diaz et al., 2002) consequential products of biological metabolism are compost, carbon dioxide, water and heat (Bari and Koenig, 2001). A general rule of thumb for pathogen the high temperature during the composting of various materials is effective for the pasteurization of pathogenic microorganisms in the materials, for the promotion of water evaporation from the composting solid materials, and for the acceleration of the rate of degradation of organic matter in the composting materials. Microbial activity and the physical structure in the composting process can be affected by moisture content; also it has a central influence on the biodegradation of organic materials (Zhang et al., 2013). A moisture content of 50 to 70 percent of total weight is considered ideal (Daniel, 2014). To a moisture content below 40%, microbial activity decreases and to greater than 65% water expels air most of the interstices between the particles of biomass, which hinders the diffusion of oxygen and can lead to conditions microaerophilic or anaerobic (Scoton et al., 2013). By filling voids between waste particles and increasing the potential of compaction, the high moisture content reduces the free air space and lessens the oxygen accessible to microorganism leading to anaerobic conditions (Zhang et al., 2013). Most compostable materials have a lower- than- ideal water content, the composting process may be slower than desired if water is not added (Daniel, 2014). High or very high moisture content, more than 80%, does not compromise the nutrient content of the compost (Vázquez and Soto, 2017).

In wet and dry season, the moisture content always decrease after composting in most of the composting process. The volatile solid was always decreases after composting process (Alamin et at., 2017). In wet and dry season’s maximum temperature of passively aeration inside reactors were almost same (Alamin et at., 2017). A comparison of the areas under the temperature curves for different composting layers and their respective self-heating tests confirm the biological degradation results obtained by the multilayer analysis (Bari & Koenig., 2000). The total initial mass of Biodegradable volatile solids (BVS) for different pilot-scale tests was estimated from the sum of the volatile solids degraded in the first stage, second stage and a further self-heating test (LAGA., 1985; Koenig & Bari., 1998) after the second stage. Turning also reduces particle size (Bari, 1999) and increases biodegradation rates (Tiquia et al., 1997; Hamelers., 1993). Using a linear relationship between outlet air temperature and mean internal temperature of the composting mass the extent of degradation in the composting mass was predicted on the basis of outlet air temperature alone (Bari et. at., 2000). Finstein & Miller (1985) noted that, for any given processing duration, the higher the rate the more stable and easily handled the residue and this facilitates storage, transport, and final disposal with a minimal cost. The aim of this study was (i) to investigate temperatura variation and volatile solids degradation of the Co-composting process in different initial moisture content and (ii) to determine the optimum moisture content in co-composting process.

2. MATERIALS AND METHODS

2.1 Source, type and preparation of wastes

In forced aeration composting process, total seven initial moisture content such as 20%, 30%, 40%, 50%, 60%, 70% and 80% of organic solid wastes and faecal sludge. Two reactors were taken for every initial moisture content. Total seven initial moisture content was selected and taken 14 reactors. Suitable organic solid wastes were collected from a student's hall of KUET and solid waste management plant. Sawdust was collected from a local sawmills and waste paper from offices. Sawdust was used as a bulking agent in the composting process. The faecal sludge was collected from a septic tank. Organic solid waste was prepared according to waste proportion vegetable wastes: food wastes: waste paper: sawdust as 40:35:10:15. Organic solid waste (OSW) and faecal sludge (FS) ratio are 85:15. In the Co-composting process was done using a series of reactors. All the wastes were mixed uniformly. Collected different waste was mixed at the roof of the Civil Engineering Department in KUET are shown Figure 1. Water was added to prepare different initial moisture content of dry mixed waste and to put into the reactor.

Figure 1: Collected different waste mixing at roof of Civil Engineering Department in KUET

2.2 Bench scale Reactor

Bench-scale tests were conducted using vacuum flasks of 1L volume (Shimizu Brand, Japan) as a bench-scale reactor. About 400 g of waste mixtures is necessary to fill each of the reactors. The waste inside the reactor was compacted loosely to provide proper porosity for composting process. The opening of the flasks were closed by pieces of cork and the thermometers were inserted into the flask for taking reading time to time until the temperature reached the ambient temperature. Before and after experiments the selected physical tests like total solids, moisture content and volatile solids were performed. The temperature reading was collected for these reactors for 28 days. It was also observed in the variation of temperature during the process. Then total solids, moisture content and volatile solids were determined and variation in different moisture content calculated.

2.3 Experimental program

The study was concluded by means of different initial moisture content of the bench scale reactor in accord with the specifically designed experimental program as described in Table 1.Then composting tests were done using a series of reactors, according to a planned experimented program. Total 14 reactors are used for experiment.

Table 1. An experimental program of Co-composting process

weight proportion Organic Solid Waste : Faecal Sludge	Percentage of Initial Moisture Content	Number of reactors
85 : 15	20%	2
	30%	2
	40%	2
	50%	2
	60%	2
	70%	2
	80%	2

3. RESULTS AND DISCUSSION

3.1Temperature variation in forced composting process

When moisture content 20% temperature was almost same to ambient temperature. Maximum temperature of composting process was 65ºC which raised within 7 days in the moisture content 60%. Moisture content 50% reactor maximum temperature was raised 58ºC within 6 days. After 18 days all reactors temperatures were the same which is very close to ambient temperature. when the initial moisture content of the reactor increased the temperature was increased until moisture content 70% but when moisture content increased 70% temperature of the reactor was not increased. It can be concluded that Maximum tempearture increased initial moisture content 55% to 70%. The initial moisture content below 30% of mixed waste do not to work for the composting process. Temperature variation in different moisture content of co-composting process was presented in Figure 2.

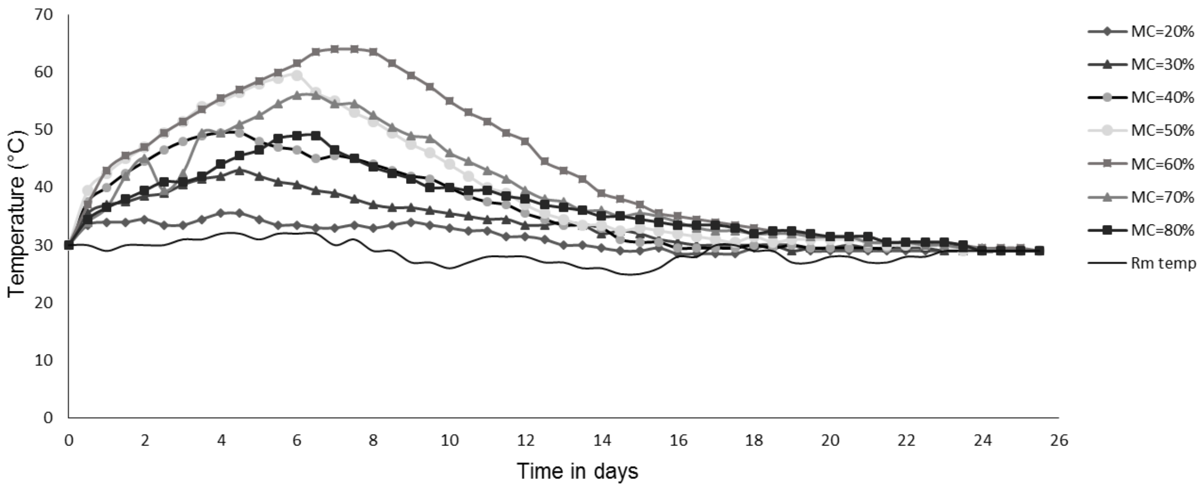

Figure 2: Temperature variation in different moisture content of Co-composting process

3.2 Mass balances for different initial moisture content

The change in total mass (TM), moisture content (MC) and volatile solids (VS)during bench scale Co-composting tests of different initial moisture content was present in Table 2. The moisture content (MC) reported on a wet basis and volatile solids (VS) on a dry basis. Different initial moisture content of the waste mixtures are taken such as 20%, 30%, 40%, 50%, 60%, 70% and 80%. In initial MC 20%, 30%, 40%, 50%, 60%, 70% and 80% forced aerated Co-composting process, the average percent reduction of total mass were 17.1%, 18.4%, 17.3% and 11.9% respectively. In third stage percent reduction of total mass, moisture content volatile solids and fixed solids were 6.5%, 11% 11.4%,14%, 15.5%, 18%, 21% and 15.7% respectively. In the average percent reduction of volatile solids of different initial moisture were 6.5%, 11%, 14.4%, 16.2%, 19.7%, 17.3% and 12% respectively. When moisture content 50% to 70% average total mass and volatile solids reduction were reached maximum. Maximum volatile solids reduction varied 16 % to 20% of moisture content 50% to 70%. When initial moisture content are increased to 80% then average total mass and volatile solids reduction were decreased. Initial moisture content 20% to 40% of waste mixture total mass reduction are sharply decreased.

Table 2: Change in total mass, moisture content and volatile solids of forced aeration process in different moisture content

Initial MC	Reactor No	Total mass initial (gm)	Total mass final (gm)	Reduction %	MC initial (gm)	MC final (gm)	Reduction %	VS initial (gm)	VS final (gm)	Reduction %
20%	R-1	318	295	7.2	64	58	8.9	220	204	7.2
	R-2	335	315	6.0	67	62	8.0	231	218	5.9
30%	R-3	385	343	10.9	116	99	14.6	232	208	10.5
	R-4	370	326	11.9	111	94	14.9	223	198	11.3
40%	R-5	423	354	16.3	169	133	21.4	214	184	14.0
	R-6	420	366	12.9	168	151	10.0	213	181	14.8
50%	R-7	560	475	15.2	280	233	16.8	231	193	16.5
	R-8	559	470	15.9	280	229	18.2	230	193	16.0
60%	R-9	720	586	18.6	432	347	19.8	241	194	19.5
	R-10	705	575	18.4	423	343	18.9	236	189	20.0
70%	R-11	634	494	22.1	444	331	25.5	163	134	17.5
	R-12	694	550	20.7	486	371	23.6	178	147	17.2
80%	R-13	742	627	15.5	594	493	16.9	127	111	13.0
	R-14	735	623	15.2	588	488	17.0	126	112	11.4

3.3 Relationship between Moisture Conteent VS Degradation

Total seven initial moisture content from 20% to 80% of organic solid wastes and faecal sludge were selected to test using conduct under run 14 reactors to investigate the effect of initial moisture content on VS degradation and on temperature parameters. The %VS reduction was highest in the moisture range between 50 and 70%. VS reduction sharply decreased at an initial moisture content below 30 to 40%. Maximum volatile solids reduction percentage 19.72% of initial moisture content 60%. Relationship between % VS reduction and initial % moisture content in bench-scale test is illustrated in Figure 3.

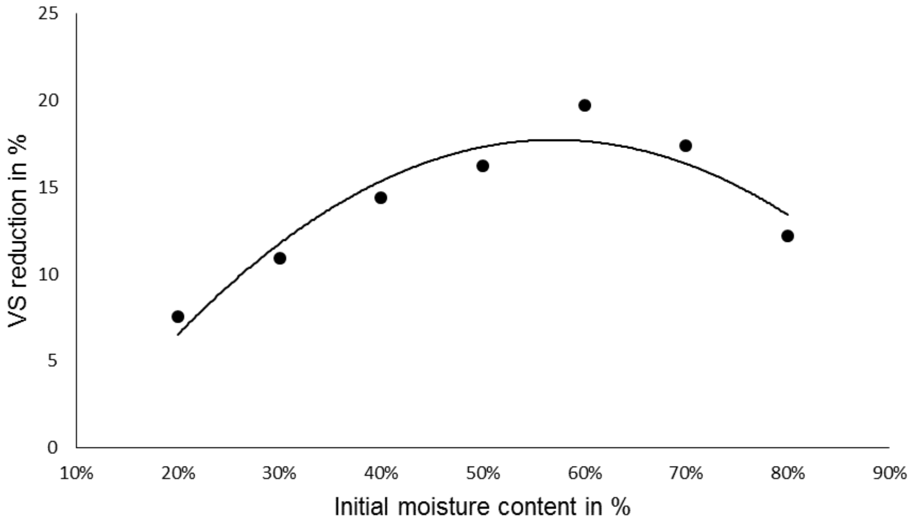

Figure 3: Relationship between % VS reduction and initial % moisture content in bench-scale test.

3.4 Relationship between Moisture Content and Temperature

Maximum temperature of composting was 55°C to 65°C which raised within 7 days in the moisture range between 50% and 70%. The area under the temperature curve in °C.h was highest in the initial moisture range between 55 and 70%. °C.h mean that °C is temperature and h is time of co-compost process in hour. Temperaure (°C) with co-composting period (h) is area under temperature (°C.h). It should be noted that a higher value of the area under the temperature curve indicates higher heat production and thereby higher VS degradation. The relationship between the area under the temperature curve and the initial moisture content in bench-scale tests using 14 reactors is illustrated in Figure 4.

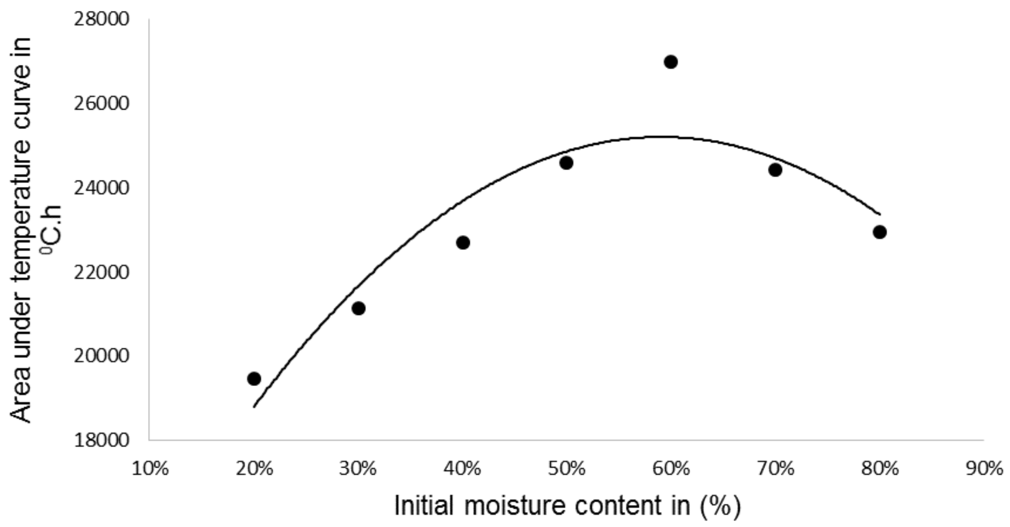

Figure 4: Relationship between the area under temperature curve and initial % moisture content in bench-scale test

3.5 Relationship between Volatile solids reduction (%) and Arean under temperature

An attempt have been made so far to establish the relationships among the area under the temperature curves and VS reduction (%) according to Bari(1999) using data of more than 14 reactors which were applied for similar type waste mixture different moisture content of compost. For forced aeration composting process, the correlation between $A_{total-ambient}$ (area under net temperature increase curve) in °C.h and volatile solids reduction (%) is presented Figure 5. The correlation co-efficient was R^2 = 0.9446 which followed a linear relation. In forced aeration Co-composting process can be determined more exactly volatile solids degradation from the correlation between area under temperature curve and VS reduction (%) with different moisture content.

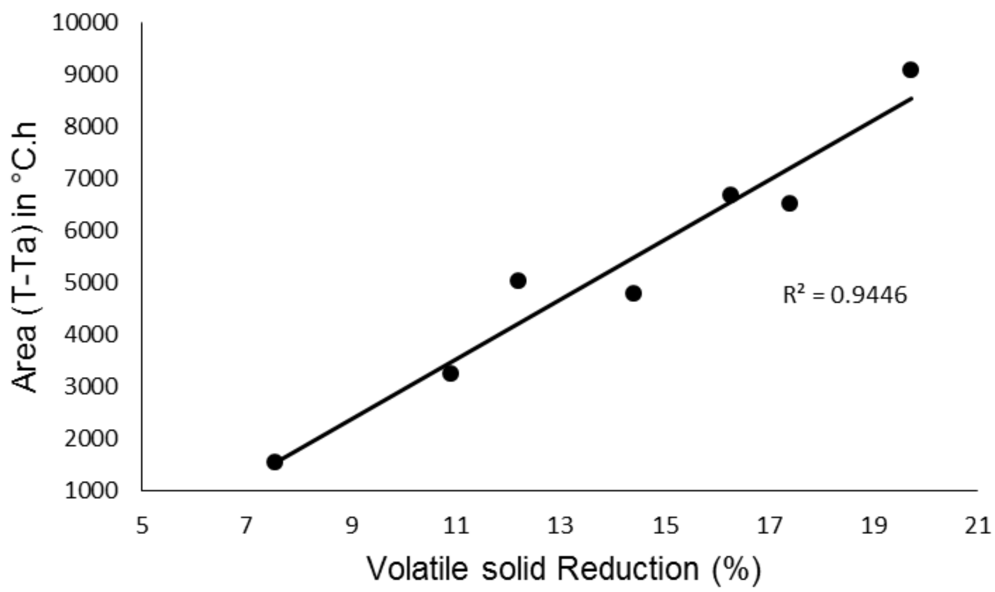

Figure 5: Correlation between $A_{total-ambient}$ (area under temperature curve after completion) in °C.h and Volatile solids reduction (%) in co-composting process.

4. CONCLUSIONS

Based On The Result Of This Study The Following Conclusions Are Drawn:

- Maximum temperature of composting was 55ºC to 65ºC which raised within 7 days in the moisture range between 55% and 70%.
- In the volatile solids reduction sharply decreased at an initial moisture content below 30 to 40%. Maximum volatile solids reduction percentage 19.72% of initial moisture content 60%. The %VS reduction was highest in the moisture range between 55 and 70%. Volatile solids reduction sharply decreased at an initial moisture content below 30 to 40%.
- In forced aeration co-composting process can be determined more exactly volatile solids degradation from the correlation between area under temperature curve and VS reduction (%) with different moisture content.
- The area under the temperature curve in ºC.h and %VS reduction is found to highest in the initial moisture content range between 55 to 70%. It should be noted that a higher value of the area under the temperature curve indicates higher heat production and thereby higher VS degradation.

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PRESENT SCENERIO OF INDOOR AIR POLLUTION IN RURAL AREAS OF JESSORE DISTRICT

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ABSTRACT

This study was conducted in the rural areas of Jessore district in Bangladesh to investigate the sources of indoor air pollution and its impact on human health. A quantitative approach followed by questionairre survey was employed to determine the critical factors responsible for indoor air pollution. Biomass cooking fuel (wood and cowdung) was found as significant source of indoor air pollution. Besides outdoor dust, emissions from nearby buildings, solidwaste debris, mosquito coils, aerosol spray, cigarette smoking also contribute highly to indoor air pollution in the study areas. Women and children were the worst sufferers of indoor air pollution. Asthma was found in women. According to the survey, 17% women suffer from asthma in which only 7% patients have asthma from childhood and the rest had asthma afterwards may due to the indoor air pollution. According to the Jessore sadar hospital, around 20% of the patients have been suffering from asthma from childhood and the rest patients suffer later in life. This study will assist to develop concern among the people especially in rural areas to reduce the harmful effects of indoor air pollution.

Keywords: *Indoor air pollution, Asthma, Wood smoke, Smoking, Mosquito Coil.*

1. INTRODUCTION

Indoor Air Quality (IAQ) refers to the air quality within and around buildings relating to the health and comfort of building occupants. Indoor air pollution (IAP) is one of the greatest health hazards in the developing countries and causes 180 fatalities in an hour (Smith *et al.*, 2005). Population exposure to various air pollutants can be higher in the indoor environment than outdoors due to the time spent indoor (Ian Colbeck et al., 2010). There are noticeable differences in the types and strength of air pollution sources across the globe and they are closely linked to socio-economic developments. Higher indoor concentrations can occur in developing countries. The types, concentration, and sources of indoor air pollutants can vary considerably from one micro-environment to another. Hence, an understanding of the concentration of pollutants in different micro-environments is of great importance of improving exposure estimates for developing efficient control strategies to reduce human exposure and health risk.

Epidemiological studies have linked exposure to indoor air pollution from dirty fuels with at least four major categories of illness such as acute respiratory infections (ARI) in children, chronic obstructive pulmonary disease (COPD), lung cancer and pregnancy related problems. In addition, evidence has now emerged showing a link of IAP with a number of other conditions, including asthma, cancer of the upper airway, cataracts, low birth weight, otitis media, preinatal mortality (stillbirth and deaths in the first week of life), and tuberculosis (WHO, 2000). Besides these, a plethora of studies in both developed and developing countries have found the same associated relationship between IAP and certain diseases. For instance, the association of IAP with ALRI5, asthma (Smith *et al.*, 2004) COPD6, lung cancer (WHO, 2000) low birth weight (WHO, 2000; Donna and Harding, 2005) and tuberculosis (WHO, 2000; Bruce *et al.*, 2002) was found.

In Bangladesh, it is reported that there are significant negative health effects of indoor smoke exposure on women and children. Women with less monthly household income (below 5000 BD Taka) and minimum level of education, using solid fuels and mud-ovens in poor ventilated environment, are more likely to be exposed to IAP and, as a consequence, have greater health risks than others (Bijoy Krishna Banik, 2017). It is highly likely that millions of people are unaware of the threats in their homes, similar as millions of smokers were unaware of the hazards of tobacco until the 1960s (Donna and Harding, 2005). This study was done to see the current scenario of indoor air pollution in the rural areas of Jessore and it's impact on health especially on women and children. It is expected that this study will assist to raise consciousness of indoor air pollution.

2. RESEARCH METHODS

The study was conducted in Sajiali, Pultadanga, Abdulpur villages (at ward 7, in Churamonkathi union), Dougacia and Ahsannagar villages (at ward 6, in Churamonkathi union), Kolabagan, Kapalipara, Bombelar math, Suparibagan, Sahapara in Nilgonj village (ward 9), Fatepur village, (at ward 7, in Fatepur union) and Satiantola village (in Dorajhat union) between November, 2016 to April 2017. A significant number of households (167) were surveyed from the villages to find out the sources of indoor air pollution and it's impact on human health. These areas were selected because all the villagers especially women, children and elderly persons in households are prone to indoor air pollution in many ways which was found from a preliminary survey. It is prospected that the survey will be helpful to develop concern among the people especially in rural areas about the harmful effects of indoor air pollution.

A quantitative method approach followed by questionairre survey from various data sources was employed to investigate how many factors are responsible for indoor air pollution and what percentage of women, children and elderly persons are suffering from diseases which can be caused by indoor air pollution in Bangladesh. A numerical data will give us a more conspicuous conception about all the respects of the study like which factors contribute the most for indoor air pollution, which diseases govern among people due to indoor air pollution. The houses surveyed were categorized in four types. Kaca, Semipacca, Pacca Type-1 and Pacca Type-2. Kaca houses were defined as the houses made of Palm-leaves, Straw or Hay and Tin. Semipacca houses were defined as the houses made of Brick and Tin. Pacca Type-1 houses were made of Bricks only and Pacca Type-2 houses are made of concrete. 20.96% houses surveyed were kaca, 43.71% were semipacca. Pacca Type-1 and Pacca Type-2 houses were 26.35% and 8.98% respectively. Questions were asked about the outdoor and indoor sources of indoor air pollution and health condition of women to find the impact of indoor air pollution on their health.

3. RESULTS AND DISCUSSION

3.1 Outdoor sources of IAP

Dust, vehicles, landfill, nearby buildings and solidwaste debris were found as outdoor sources of IAP. Presence of dust was found 100%. That means in every houses presence of dust particles was found. The sources of dust were yard and nearby roads. So, dust played a very significant role in contributing to indoor air pollution in those areas. Solidwaste debris was found outside in 75% cases out of 167 numbers which also plays a big role as far as IAP is concerned. A multi response was found the survey given in Table-1. It is found that in every house there is presence of dust which is a significant pollutant causing Asthma. Industrial pollutants aren't found although it was taken into consideration. Because the survey was conducted in rural areas and there was no such industries in those areas.

Table 1: Percentage of Sources of IAP outside the Building

Sources Outside the building	Nos	Total	%
Dust	167	167	100
Industrial Pollutants	0	167	0
Vehicles	10	167	6.0
Landfill	2	167	1
Nearby Houses	16	167	10
Solidwaste Debris	126	167	75

3.2 Indoor sources of IAP

Mosquito coil, aerosol spray and cigarette were found as indoor sources of IAP. 83% people used mosquito coils out of 167 in their houses (Table 2). Most of them use coils in their bedrooms whereas one family was found to use coils in the cowhouse too. Mosquito coils are considered to be safe insecticides for humans and mammals, although some studies highlight concerns when they are used in closed rooms. Coils sold in China and Malaysia were found to produce as much smoke $PM_{2.5}$ as 75-137 burning cigarettes and formaldehyde emission levels in line with 51 burning cigarettes (*Liu, Weili et al, 2003).* The findings from the previous studies suggest that exposure to the smoke of mosquito coils can pose significant acute and chronic health risks. On the other hand 6% families used aerosol spray in their houses.

Table 2: Percentage of Sources inside the Building

Sources Inside the building	%
Mosquito Coil	83
Aerosol spray	6
Cigarette	38

Smoke of cigarettes is one of the vital sources of indoor air pollution. That's why question about smoking cigarette was included in the survey. 38% families were found where cigarette smoking prevailed (Table 2). 63 families were found to consume cigarettes. 54 families consumed 2 to 10 cigarettes a day (Table-3). Maximum 30 cigarettes were found to be consumed and 104 families did not consume cigarette.

Table-3: Numbers of cigarettes consumed per day

No of cigarettes consumed per day			
Range	2 to 10	>10 to ≤20	>20 to ≤30
No of houses	54	7	2

Cooking place plays a very significant role for indoor air pollution. Women and children are the most vulnerable in this case. Many times it was seen that women were directly exposed to smoke coming from cooking fuel. Sometimes children were also seen exposed to smoke coming from cooking fuel. In the survey, smoke condition (Poor/Moderate/ Good) were included and 85.63% ventilation systems of cooking place were found moderate (presence of medium amount of smoke in the kitchen while cooking). 6.59% ventilation systems of cooking place were found good (presence of little or no smoke in the kitchen while cooking) and 7.78% ventilation systems of cooking place were found poor (presence of intolerant smoke in the kitchen while cooking).

Cooking time per day is shown in table 4. 49.70% women were exposed to smoke for 1 to 2.5 hours a day. Maximum cooking hour was found 6.0 hours, minimum cooking hours were found 1.0 hour and the average cooking duration was found 2.54 hours per day. More cooking hours mean more time of exposure to harmful ingredients of woodsmoke and increased risk of diseases.

Table-4: Duration of Cooking (hours) per day

Range	1.0-2.5	>2.5 to ≤4.0	>4.0 to ≤6.0
No of Houses	83	74	10
Percentage (%)	49.70	44.31	5.99

3.3 Health effects

Asthma, nose bleeds, irritation of eyes/nose/throat, headache and blood pressure were observed among women. 135 numbers of women had health issues out of 167. Among them 40% women had headache, 17% women had been suffering from asthma, 15% had blood pressure and the rest had nose bleeds and irritation of eyes/nose/throat.

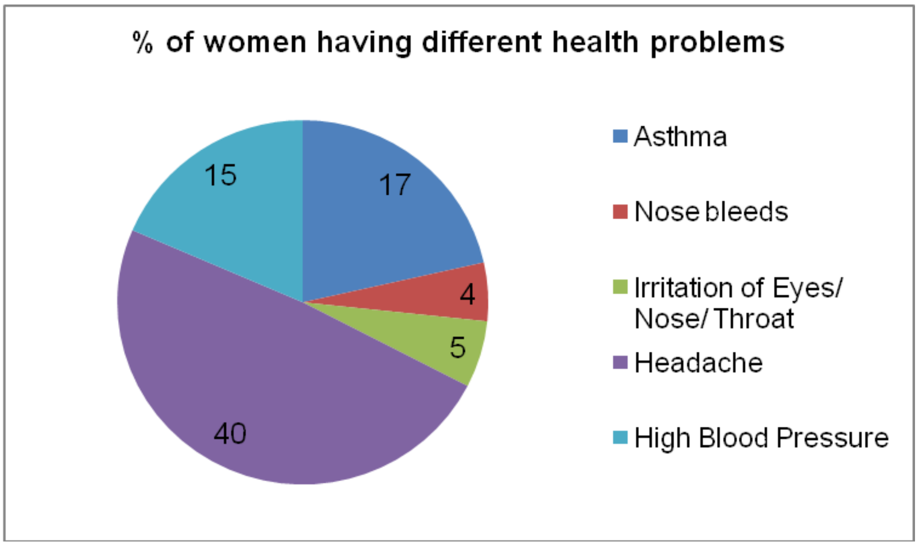

Figure 1: Percentages women having different health problems

Children had also been suffering from various health issues. 13% children had cough, wheeze, 9% had asthma and the rest had bronchitis, chronic sinus infection and pneumonia. (Figure 2). While 9% children have have asthma, 17% women were found having asthma. This value shows that the number is increasing with age and indoor air pollution plays a very significant role here.

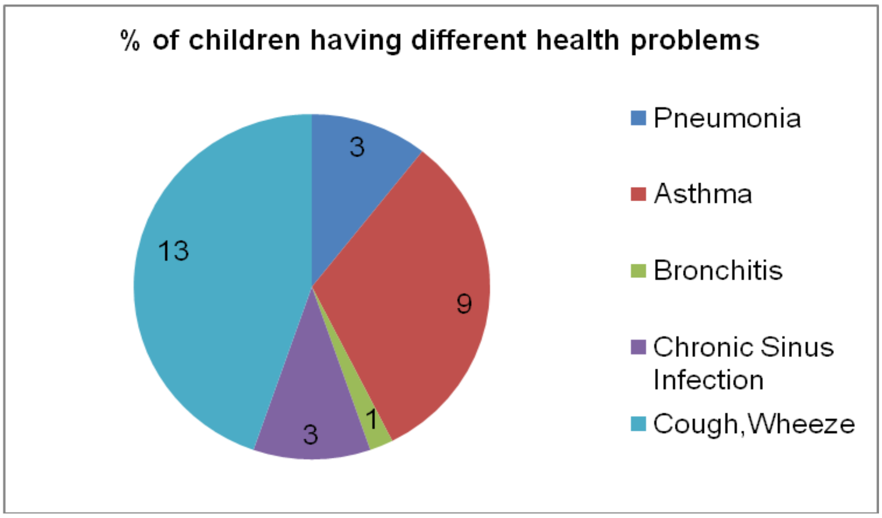

Figure 2: Percentages children having different health problems

According to the Jessore sadar hospital, it has been found that about 40 to 50 numbers of patients get admitted to the hospital per month. About 20% of the patients have been suffering from asthma from childhood which means 80% patients suffer from this disease later in life. The main reasons of asthma are considered the family positive history and allergic history of the patients. According to the survey, 17% people had been experiencing asthma in which only 7% patients had asthma from childhood and 93% had afterwards (figure 3).

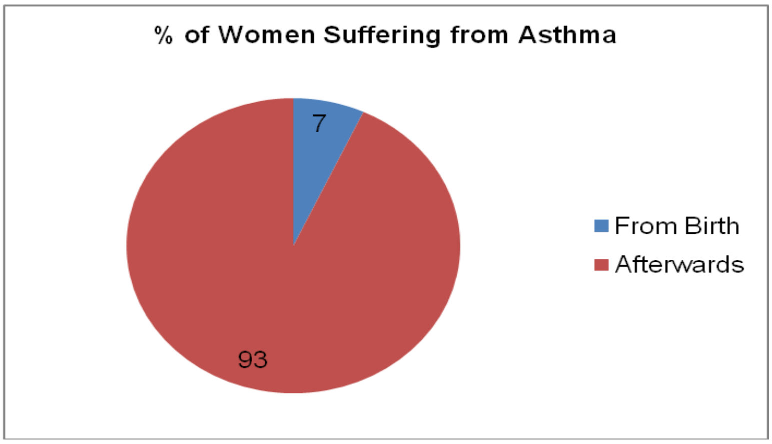

Figure 3: Percentages of women having different Asthma

Among Women having asthma 58.62% used wood as cooking fuel, 31.03% used wood and cowdung together as cooking fuel, 3.45% and 6.90% women used gas and cowdung simultaneously and only gas as their cooking fuel respectively (Figure 4). Women having asthma afterwards are mostly exposed to wood and cowdungstick smoke. So, it can be concluded that, woodsmoke and cowdung smoke can cause asthma afterwards.

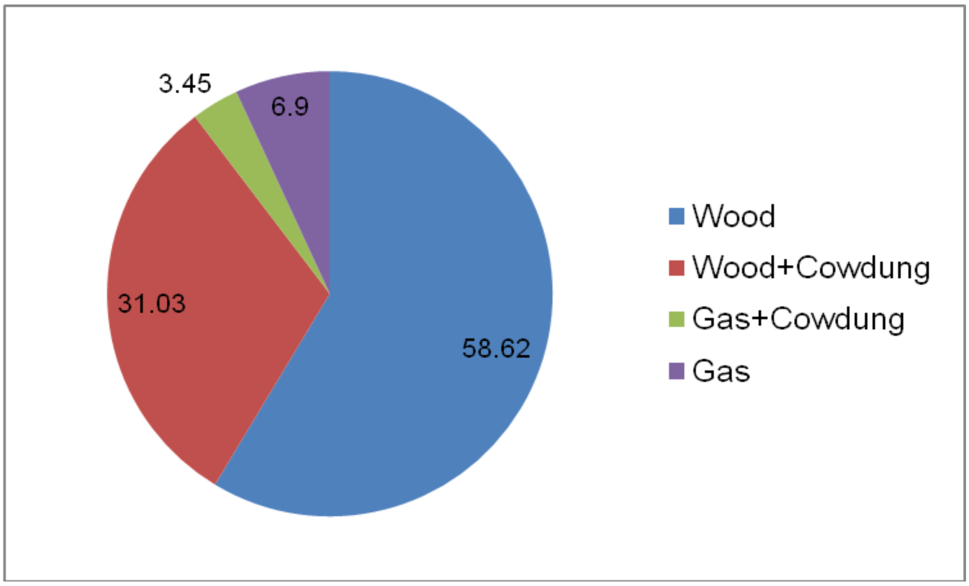

Figure 4: Percentage of types of fuel used by women having Asthma

4. CONCLUSIONS

Outdoor dust, Vehicles, landfill, emissions from nearby buildings, solidwaste debris, use of mosquito coil, aerosol spray, cigarette smoking and use of biomass as cooking fuel were found as the sources of indoor air pollution. Among these biomass fuel was considered as the crucial factors for indoor air pollution. Use of mosquito coil (83%), cigarette smoking (38%) and use of biomass as cooking also contributed significantly to indoor air pollution. Women were exposed to the pollution more than others. Asthma was found as a critical disease for women and children. Most women having asthma (58.62%) use wood and 31.03% wood and cowdung together, as their cooking fuel. The concerned authority should take necessary initiatives and consciousness must be raised among the general people to mitigate the harmful effects of indoor air pollution on human health.

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REUSING AND RECYCLING PRACTICE OF E-WASTE IN SOME MAJOR CITIES OF BANGLADESH

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ABSTRACT

Reusing and recycling of electronic hardware can trigger a range of environmental, social and economic benefits. This study helps to scrutiny the existing e-waste management process in selected areas of the Dhaka, Chittagong and Mymensingh City Corporation and Munshigonj district. Outcome of this study shows i) total reusing and recycling process of e-waste's, ii) the price of the secondhand electronic products are 30-50% less than the new ones and identify reused or recycled electronics items, iv) both shopkeepers and customers are mostly unaware of their contribution to environmental benefits through this process, v) approximate yearly collection and selling amount of e-waste in these study areas with selling percentage. In Bangladesh e-waste recycling is mostly dealt by the informal sector with suboptimal procedures resulting in lower recovery rates and dangerous exposure to environment and health risks. In this paper a sustainable recycling model is proposed for recycling and reusing of e-waste.

Keywords: *Reuse, Recycle, Sources of e-waste, Yearly collection and selling of e-wastes, Selling rate*

1. INTRODUCTION

In recent years, Bangladesh indicates a rapid economic growth with emerging market for consumers of electric, electronic gadgets, home appliances. Rapid population growth with rapid discarded product due to the increased access of modern technology with increased purchasing power resulted the generation of electronic waste (E-waste). Electronic waste defined as secondary computers, electronics device, mobile phones, and other entertainment items such as television, refrigerators, whether sold or discarded by their original owners. Bangladesh is a market for electronic goods in having exponential growth due to rising disposable income and increasing demand for the latest electronics products. In this country a large proportion of waste generation comprise E-waste. In general E-waste includes cell phone, television, telephone, washing machine, air conditioners, printer, light, electronic toys, etc. ' E-waste contain (Sinha et al., 2007) different toxic materials which are hazardous, and are consequently a threat to the environment and to the human health'. 'More than 1,000 hazardous and non-hazardous components (Wath et al., 2011) like ferrous material (38%), non-ferrous material (28%), plastic (19%), glass (4%) and others (including wood, rubber, ceramic) (11%) contain in the electric and electronic waste'. 'Some heavy metals like lead, mercury, cadmium, chromium (VI), halogenated constituents (e.g., CFCs), polychlorinated biphenyls, Antimony, brominated flame retardants (BFRs) can also be found as a substance in those compounds. All these may react as catalyst for the formation of dioxins (DEFRA, 2004; Wath et al., 2011) and in turn act as a harmful ingredient for both environment and human health'. Cadmium has toxic effects on the kidney, the skeletal system and the respiratory system. Cobalt has toxic effects on skin and lungs. Copper is very hazardous for eyes, skin, lungs and mucous membranes. 'Bangladesh consumes (Hossain et al., 2010) around 3.2 million tons of electronic products each year'. Of this amount, only 20 to 30 percent each recycled and the rest is released in to landfills, rivers, ponds, drains, lakes, channels and open spaces which are very hazardous. Improper monitoring system relating to dumping does not raise the human health issue only. This paper aims to focus on the present reusing and recycling condition of e-waste considering four different areas of Bangladesh and arising awareness among the general mass about the environmental significance of it.

2. METHODOLOGY

The present study is consists of selection of the study areas in the Dhaka, Chittagong, Mymensingh City Corporation and Munshigonj district. Preparation of comprehensive questioner form and door to door survey to collect selective data as described in the following sections.

2.1 Survey Method and Aelection of Study Areas

The study was carried out in door to door survey method. The main object of the door to door survey process was to have the significant information of the reusing and recycling scenario of the study areas. Most prominent e-waste reusing and recycling places of four districts were selected as the study area. In total 2572 shops were identified among the four areas in which 1360, 715, 370 and 127 shops were found at Dhaka, Chittagong, Mymensingh and Munshigonj respectively. Among the 2572 shops belonging to these four areas 400 shops were surveyed. The survey was carried out in questioner method. A series of questioners were decorated in such a way which are appropriate for the study reusing and recycling process. Questioner method is the best way to collect the root based Intel’s. The survey was carried out in two groups. Shopkeepers and customers were questioned considering them as the two different group. Two distinct sets of questions were prepared for the supposed two groups. The shopkeepers are questioned as they are actually the ones who reuse and recycle the e-waste. And the customers are the complimentary part of this process. Both poses equal significant role in this manner. Based on this method the collected data, discussion and findings are represented in the succeeding section and subsection.

3. SURVEY OBSERVATION AND DISCUSSION

3.1 Source of E-Waste

In the case of Dhaka, Mymensingh and Munshigonj some items of e-wastes are collected either from local customers or some are directly bought from the Chittagong port in a legal way through the tendering process or some are imported from India and China in an illegal way. These imported electronic products are called "reconditioned electronic parts". For having the port in Chittagong; generates the high quantity of e-waste due to existence of ship breaking industry and other heavy industry. The main source of e-waste in Chittagong is the ship breakage industry. Almost 90-95% of the e-waste generated in Chittagong is from this particular sector. Thus it can be commented that, without this particular ship breakage industry, Chittagong would have been less burdened with toxic e-waste problem.

3.2 Collection and Selling Process

The reusing and recycling system in Dhaka, Mymensingh and Munshigonj are quite same. The e-waste reusing and recycling unit in three areas are mostly unregulated and the process of repairing and recuperating valuable materials take place in small workshops are called secondhand shops in this study. The recycling process is carried out in this sector in a simple way. This practice used in these areas are often intensify pollution by creating hazardous and additional pollution. In these secondhand shops of electronic products both the old and new products are available. According to the survey in Dhaka, Mymensingh and

Munshigonj most of the shop owner have started this business since 8-10 years from now. There are many customers or agents who bring e-products becomes useless to them. If the shopkeeper think that this e-product is purchasable; than they buy the waste product in a cheap rate and run a check to see the entire condition. If the product is functioning than they sell it to a customer who looks for secondhand parts or break it into pieces for sorting out iron, copper, lead, silver, plastic etc. and sell these to a purchaser of these individual items. They break these e-wastes without any safety measures which have a bad impact to their health and circumfluous environment. Most of these secondhand shops are using pliears, hammer, chisel, screw driver as a tool to break e-waste. Recycling as a profession is less financially paying in spite of being hazardous. Workers and shop owners don't think that these process is unsafe due to lack of discernibility of toxic materials exist in e-waste by naked eyes. Which ratify them that these are toxic free. Which indicates the lack of knowledge of the shopkeepers and workers. In Dhaka city PC, Laptops and Mobile parts are exported to China and India. After repairing these are again imported in Bangladesh. These export and import channels of electronic products in Bangladesh are done in an illegal manner. The cable wastes are directly bought from the Chittagong port legally though the process of tendering. In case of Mymensingh and Munshigonj obsolete PC, Laptops and Mobile parts were sent to Dhaka and after repairing these are again sent back to the shops in the Mymensingh and Munshigonj. The lead acid battery recycling in Dhaka, Chittagong, Mymensingh and Munshigonj City is performed in two ways are direct and indirect recycling processes are named in this study. Batteries used in ships, vehicles, generators, IPS, UPS, solar panel are recycled in these secondhand shops. Direct recycling process is a process where whole recycling process is performed in the secondhand battery shops. During this process lead is melted in an environmentally unfriendly way; which produce lead oxide (PbO) and lead dioxide (PbO2) and other toxic gases; has detrimental impact on environment. In case of indirect process collected battery waste is conveyed to the battery manufacturing industry and whole recycling process is accomplished in the industrial periphery. According to shopkeeper and workers in four study areas almost 20-30 items of e-waste are reused or recycled in a significant number. The weight of different electronic products are varies in shopkeepers to shopkeepers.

The recycling process in Chittagong most of second hand electronic products are purchase by recycling shop owner from auction which is held in the vatiary area of the Chittagong city. CDA market, Coxy market, Ice factory road, Vatiary and Kadamtali are the key areas dealing with shipyard e-waste where reusing and recycling is performed. CDA market, Coxy market, Ice factory road, Vatiary and Kadamtali consists of 60, 20, 30, 100 and 40 recycling shops respectively. Electronics products such as auto pilot, printer and ship navigation related products, fridge, air conditioner, generator hydraulic pump, panel board, and compressor, different types of light to horn, radio, television fan, washing machine, IPS etc products are deals in these areas.Recycling process is almost similar in each area. The shop owners buy the old electronics products from the auction held in shipyard. This auction accrues various items retrieved after ending the life cycle of ship as scrap. After buying and taking this delivery they clean and repair the e-products. The repaired useable products are sold to retailer, and wholesalers. The non-recoverable item are also valuable as include metal such as iron steel, bronze cables etc. Then these are sold to scrap dealers. According to the shop owner and workers almost all the purchase item are either sold by repairing or sold as scrap and residual parts are thrown away as a waste.

In Dhaka city mainly lead acid battery, AC, refrigerator, iron, washing machine, cable waste, car audio set, table fan, wall fan, telephone, electric heater etc. are available in Dholaikhal, Doyagonj, Sdarghat, Kakrail, Mirpur, Gulistan. Television, radio, LCD screen, video recorder are obtainable in Mosjid Market at Gulistan. Multiplan center at Elephant Road is selected for PC and laptop products and Motalab Plaza and Eastern Plaza at Sonargoan where mobile sets are available. In Chittagong mainly (excluding shipyard e-product) lead acid battery, AC, refrigerator, iron, washing machine, table fan, wall fan, telephone, electric heater, Television, radio, LCD screen, video recorder, PC, laptop products and mobile etc. are available in Chowmuhani, Agrabad, Jublee Road, Newmarket, Reazuddin Bazar, Sahamanat Market, EPZ, Kathgar, City College Road. In Mymensingh mainly lead acid battery, AC, refrigerator, iron, washing machine, table fan, wall fan, telephone, electric heater, Television, radio, LCD screen, video recorder, PC, laptop products and mobile etc. are obtainable in Maharaza Bazar, Rambabur Bazar, Ganginarpar, Notun Bazar. In Munshigonj mainly lead acid battery, AC, refrigerator, iron, washing machine, table fan, wall fan, telephone, electric heater, Television, radio, LCD screen, video recorder, PC, laptop products and mobile etc. are obtainable in Mukterpur, Sipahipara, Thanarpoal (Super Market, Pouro Market, Mollah Plaza), Chowdhury Market (Kali Bari Road), Mosjid Market (Kachari), College Road (College Road Market, Stadium Market).

In total 2572 shops were identified among the four areas in which 1360, 715, 370 and 127 shops were found at Dhaka, Chittagong, Mymensingh and Munshigonj respectively. According to the Table 1 approximately 17826 tons and 11297 tons of e-wastes has been collected and sold yearly in these study areas of Dhaka city at the selling rate of 63%. In an average 23964 tons and 18007 tons of e-wastes has been collected and sold yearly in these study areas of Chittagong city at the selling rate of 75%. Roughly 11818 tons and 7313 tons of e-wastes has been collected and sold yearly in these study areas of Mymensingh city at the selling rate of 62%. Approximately 2767 tons and 1466 tons of e-wastes has been collected and sold yearly in these study areas of Munshigonj at the selling rate of 53% represented in Table 1.

Table 1: Yearly collection and selling amount of particular e-waste in tons

Items	**Yearly collection**				**Yearly selling**				**Percentage of selling (%)**			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Television*	504	1234	305	95	208	802	138	71	41	65	45	75
Radio*	348	895	160	17	181	510	96	13	52	57	60	75
LCD Screen*	177	675	27	-	52	304	22	-	29	45	80	-
Video recorder/ DVD Player	539	357	234	35	206	161	141	25	38	45	60	70
Cable Waste*	40	250	-	-	32	213	-	-	80	85	-	-
Mobile	1296	870	576	40	770	566	260	24	59	65	45	60
Desktop	1350	656	450	200	900	492	261	64	67	75	58	32
Mouse	9	3	2	1	6	2	1	0.5	67	67	50	50
Keyboard	210	120	80	12	150	54	40	7	71	45	50	56
Laptop	368	234	145	34	263	162	52	8.5	71	69	36	25
(AC)*	442	1256	678	12	165	942	440	2.5	37	75	65	20
Refrigerator *	2097	3756	3256	678	1259	3004	2344	468	60	80	72	69
Washing Machine*	378	1678	890	-	167	1258	498	-	44	75	56	-
Iron	28	20	12	45	13	10	5	27	47	50	45	60
Telephone	37	24	13	25	17	8	3	7.5	45	35	25	30
Wall Fan*	114	245	102	87	74	191	68	61	64	78	67	70
Table Fan*	153	466	125	90	91	373	75	67	59	80	60	75
Electronic	168	125	45	68	119	75	36	30	70	60	80	45

Heater												
Printer*	420	880	245	36	282	704	147	9	67	80	60	25
Mobile Charger	28	20	17	3	21	16	12	1	75	80	70	33
Car Audio Set	420	-	-	-	231	-	-	-	55	-	-	-
Lead Battery*	8700	10200	4456	1289	6090	8160	2674	580	70	80	60	45
In total	17826	23964	11818	2767	11297	18007	7313	1466	63	75	62	53

Here in Table 1, 1=Dhaka, 2=Chittagong, 3=Mymensingh, 4=Munshigonj and (*) means particular products are both local shipyard in Chittagong

The questioner survey was performed on 125 customers. Normally the male customers appear in the secondary electronic market and female customers are not seen usually. Customers comes to the secondary shops not only for buying the secondary electronic products but also for selling their electronic product which are wastage to them. Their age vary in a tremendous range from 15-50 years. The reused or recycled electronic products have a huge demand to the customer due to its cheaper price. Customers from all phases of occupations are gather here. In an average 5-25 retail customer visit shops and 15-20 electronic parts are sold in retail every day. Though customers appreciate this reusing and recycling items selling process they are not aware at all about the environmental significance and rather emphasis on the good quality and cheap value of the e-product.

3.3 Data Analysis

From the above discussion it appears that e-waste reusing and recycling is a popular practice in these study areas. Approximately 17826 tons and 11297 tons of e-wastes are collected and sold respectively in these study areas. The selling percentage is 63% which also indicates the reusing percentage. The reusing and recycling process of e-waste is done in informal sector. Surveying the study areas of Dhaka City Corporation a qualitative flow diagram is proposed in Figure 1.

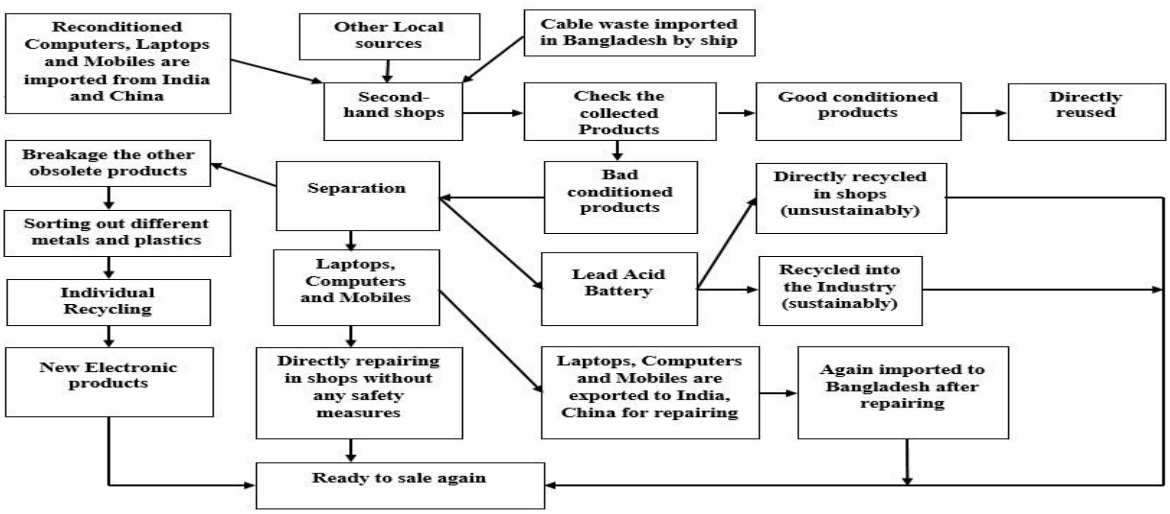

Figure 1: Qualitative flow diagram of reusing and recycling of e-waste in Dhaka City

Reusing and recycling process in Mymensingh and Munshigonj are quite similar to Dhaka. Roughly 11818 tons and 7313 tons of e-wastes has been collected and sold yearly in these study areas of Mymensingh city, at the selling rate of 62%. Approximately 2767 tons and 1466 tons of e-wastes has been collected and sold yearly in these study areas of

Munshigonj at the selling rate of 53%. Surveying these two study areas a qualitative flow diagram is proposed in the Figure 2.

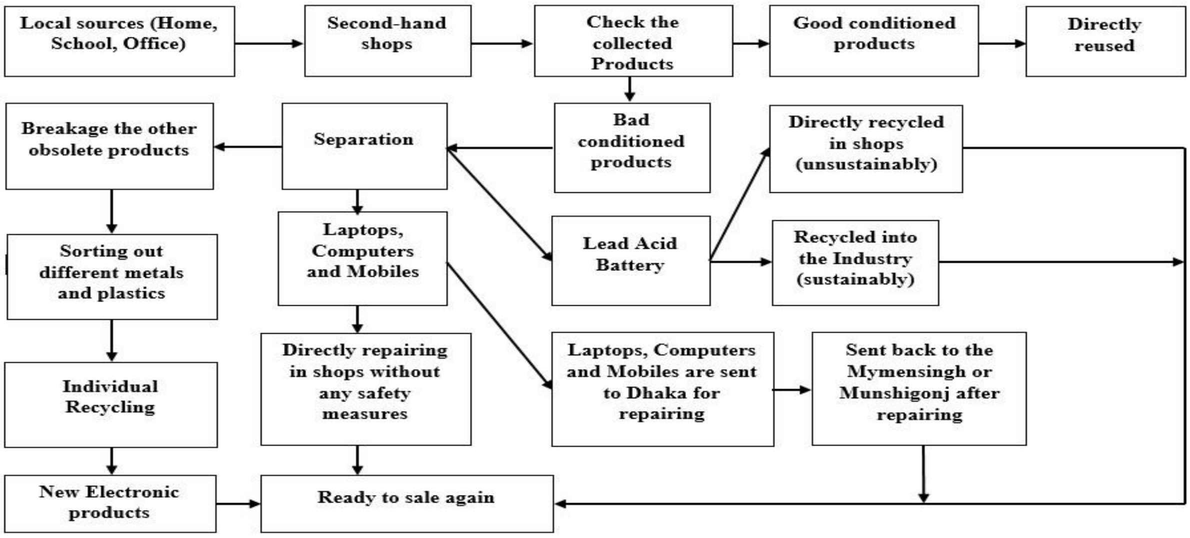

Figure 2: Qualitative flow diagram of reusing and recycling of e-waste in Mymensingh and Munshigonj

Recycling pattern of Chittagong is quite different from other three study areas represented in Figure 3. In an average 23964 tons and 18007 tons of e-wastes has been collected and sold yearly in these study areas of Chittagong city at the selling rate of 75%.

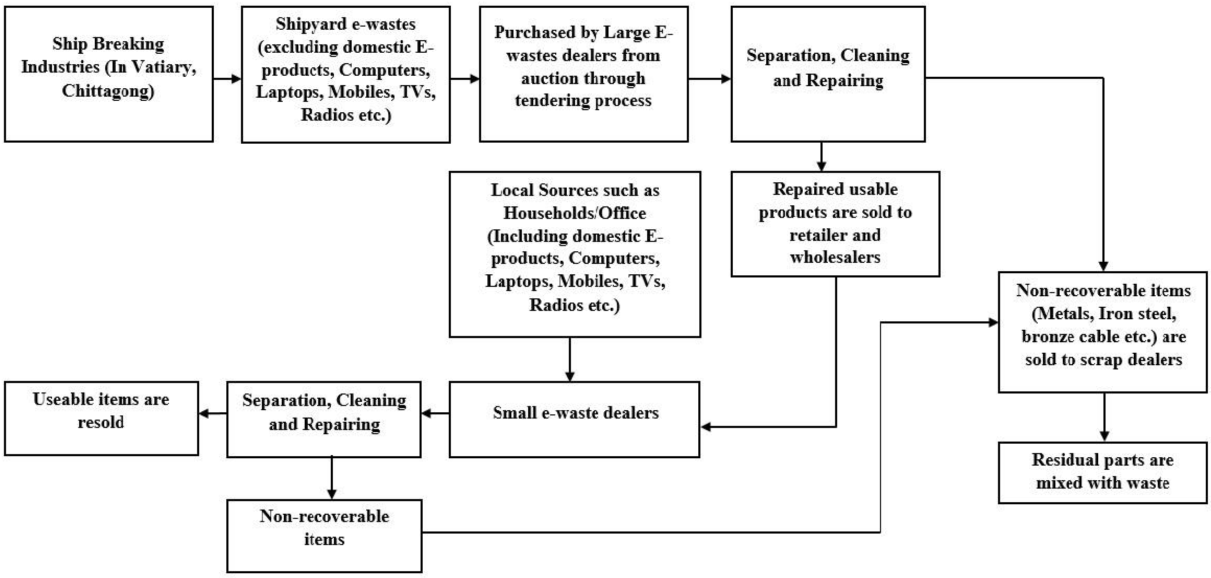

Figure 3: Qualitative flow diagram of reusing and recycling of e-waste in Chittagong

Recycling process in these four areas are less efficient because of the only use of the poor qualities breaking tools. The process of recycling in four study areas has the potential to be hazardous to recycler's health and environment. Due to the knowledge gap of shopkeepers and workers, recovery of precious metals are very insignificant. Thus this process is unable to occupy the economic support of Bangladesh. According to the shopkeeper the price of the second hand electronic products are 30-50% less than the new ones. The less price of products attract people much and is high demanded among the all classes of people. The reusing and recycling process of e-waste have combined positive and negative impacts on environment. If the obsolete electronic products are dumped or incinerated it gives bad impact on environment. On the other hand if these process is performed environmentally unfriendly manner can also have bad impact on health and environment. Only sustainable reusing and recycling process is eco-friendly. The present reusing and recycling system in these four areas which are not performed in sustainable way. A proposal of sustainable and legal reusing and recycling model of e-waste for these study areas are given in Figure 4. This model can also be applicable for any other division or districts of Bangladesh. The reusing percentage can be increased if it is done by formal sector with proper infrastructure of it.

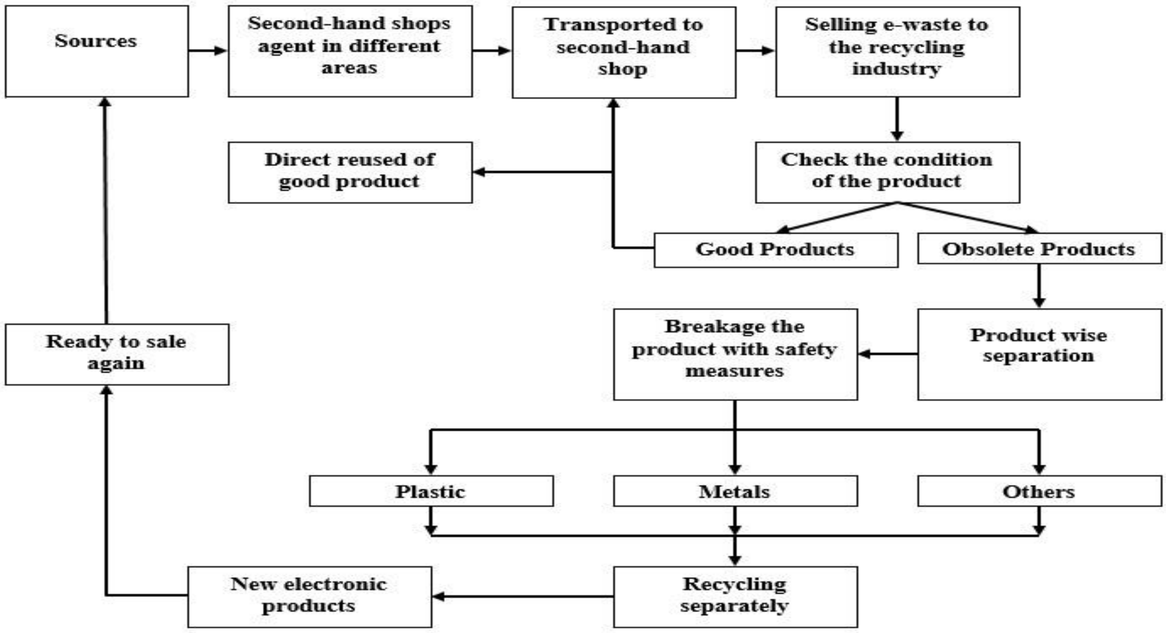

Figure 4: Proposed model for sustainable reusing and recycling of e-wastes

4. CONCLUSIONS

The study was undertaken considering root level recycling and reusing of e-waste. Currently no proper guidelines are follow regarding the e-waste management of these study areas. The demand of second hand electronic products among the people of all stages is significantly high due to its 30-50% lesser price than new ones. The selling or reusing rate of e-wastes in Dhaka, Chittagong, Mymensingh and Munshigonj are 63%, 75%, 62% and 53% respectively. This paper has included four qualitative flow diagram and some quantitative information of existing situation in the field of e-waste reusing and recycling segment of these study areas. The study tried only to develop a survey based and theoretical model for better e-waste recycling process in these study areas. Workshop on proper and sustainable repairing and training on the health issue is mandatory for the workers in reusing and recycling system. Government with different NGOs can work together in this matter and encourage people for selling their e-waste. Again, inspire people for donating their electronic products which are wastage to them. To investigate the possibility of this model a complete empirical study is necessary.

ACKNOWLEDGEMENTS

The support provided by Shopkeepers and customers in this study is very much appreciated.

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Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), 9~11 February 2018, KUET, Khulna, Bangladesh (ISBN-978-984-34-3502-6)

A STUDY ON PAPER REUSING IN DHAKA CITY

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ABSTRACT

Reusing paper conserves natural resources, saves energy, reduces greenhouse gas emissions, and keeps landfill space free. The purpose of this study is to view the paper reusing scenario in Dhaka city. A structured questionnaire survey has been carried out in the five study areas were surveyed. Each day 3000 tons household waste are producing in Dhaka city. About 9.73% of total waste are paper waste. In the studied location about a total of 61400 kg paper waste are prepared for reusing. To acknowledge more about the reusing system information was collected from feriwalas and retailers. The result shows i) informal reusing pattern of paper, ii) generation of paper waste in each study area, iii) people involved in this reusing process have no idea of its environmental benefits, iv) people perform this reusing on economic issues.

Keywords: *Reus, paper waste, informal sector, old used books, cartoon*

1. INTRODUCTION

Solid waste management is now becoming one of the major problems because of the social, economic and environmental implementations are not properly managed (Riyad, 2014). Studies show that only 30-50% of the waste generated in developing countries is collected and managed properly (Dawit and Alebel, 2003). Reusing and recycling is a waste management strategy. Thus, an appropriate solid waste management process is necessary to face the global environmental challenges. More specifically, solid waste problems in developing countries are aggravated by the malfunctioning of traditional waste management systems due to the rapid development and the concentration of the population (Deshmukh et al., 2002). Dhaka is one of the largest city of Bangladesh with a large population has been a place of commercial importance for more than 400 years. Each day Dhaka city is producing over 3000 tons of household waste, whereas Dhaka City Corporation collects almost less than half of it (Chowdhury and Afza, 2006). Paper waste forms almost 9.73% of this total waste (Waste concern, 2009). Average total per capita waste generation rate of Dhaka city is estimated at 0.45 kg/cap/day. The main purpose of this study is to depict a picture of the overall scenario of the reusing paper waste in five study areas. The study areas are Mohakhali, Nakhalpara, Farmgate, Agargaon and Lalmatia.

2. METHODOLOGY

Dhaka, is one of the largest city of Bangladesh, is located in the middle part of the country, having latitude 23°40´N and longitude 90° 23´ E. The area of Dhaka city is 270 square km with a population 7 million. With regards to investigating the activities of paper waste reuse, a field survey was conducted in the Dhaka city area. The selected study sites for collecting data in Dhaka city were includes Mohakhali, Nakhalpara, Farmgate, Agargaon and Lalmatia. Figure 1 shows the location of the survey area. The data were collected in doing this research. Primary data, such as the opinion from waste collectors, recyclable dealers, industry workers through in depth interview.

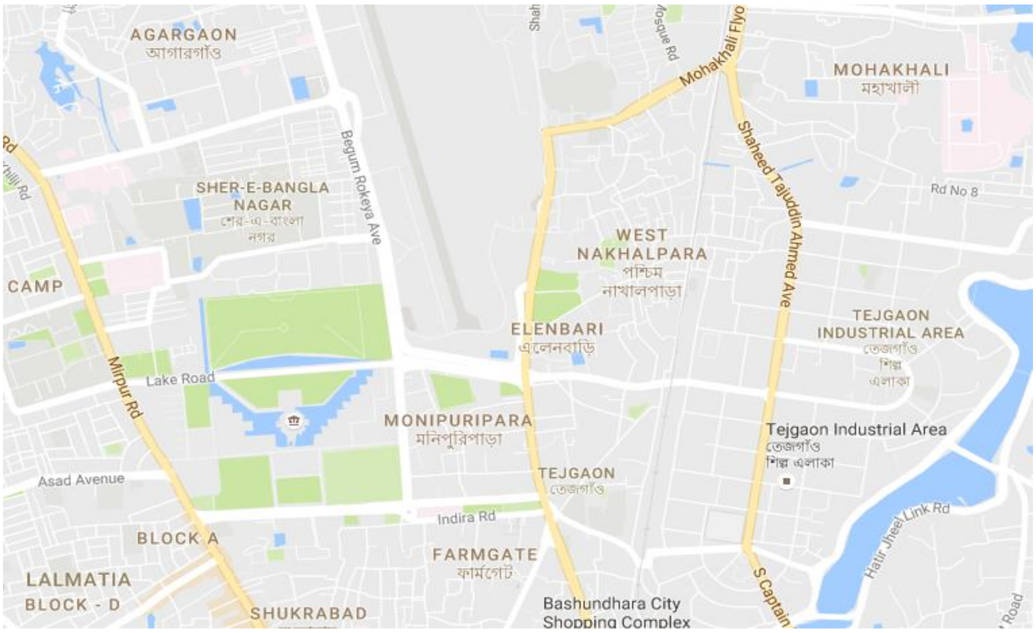

Figure 1: Location of the sites (Google map)

3. REUSE AND RECYCLING TRADE CHAIN IN DHAKA CITY

Private sectors are responsible for reusing and recycling of solid waste in Dhaka city. The waste collectors from private sectors are playing a vital role in collection of recyclables as a main source of income. They are known as tokais and are visible in every community of the city and come from nearby slums and squatter settlements. It is estimated that at present 6500 tokais are working in Dhaka city area. Feriwallas are the buyers of separated recyclable items stored for selling at the primary source. This study reveals that there are around 3600 feriwallas involved in the chain of recycling network of Dhaka. The small recyclable dealers (SRDs) purchase waste materials from tokais and feriwallas in exchange of money. All types of waste from tokais and fer-iwallas and sell the recovered materials to medium recyclable dealers (MRDs). The MRDs usually deals with more than two kinds of specific wastes and passes these recyclable to the large recyclable dealers (LRDs) that essentially specialize in specific wastes. They clean and sell the recovered materials to industries both in the formal and the private sectors. Table 1 shows the average waste collected per day by different collectors.

Table 1: Average waste collected per day by different collectors

Collectors	Average quantity collected per day (kg)
Wastebin Tokais	30
Feriwallas	50
Vangari Shops	200
Wholesale shops	500

From the field survey in the selected location it was found that the major reusable materials were different types of cartoons, books, papers etc. The average number of vangari and wholesale shops for Mohakhali is 60, Nakhalpara is 30, Farmgate is 65, Agargaon is 45 and Lalmatia is 50.

3.1 Cartoons

Different types of cartoons are seen for reusing. Table 2 represents the total amount of cartoon collected per day and their buying and selling price. They used to buy cartons about @Tk 15 per kg and sale @ Tk 18 per kg. The activities had been continuing smoothly under a systematic chain which gradually increased the reuse of the materials and hence reduced the total waste generation.

Table 2: Total amount of cartoon collected per day and their buying and selling price

Locations	Average number of vangari and wholesale shops	Total amount collected (kg/d)	Buying price (Tk/d)	Selling price (TK/d)
Mohakhali	60	12000	180000	216000
Nakhalpara	30	3200	38400	57600
Farmgate	65	13000	195000	234000
Agargaon	45	4600	69000	82800
Lalmatia	50	8000	120000	144000
Total	205	40800		

3.2 Old Books

Most of the old books were found in close proximity to Railway market area and foothapth. Table 3 represents the total amount of old books collected per day and their buying and selling price. They used to buy books about @Tk 30 per kg and sale @ Tk 40 per kg. The activities had been continuing smoothly under a systematic chain which gradually increased the reuse of the materials and hence reduced the total waste generation. Figure 2 depicts the scenario of the old books selling shops.

Table 3: Total amount of old books collected per day and their buying and selling price

Locations	Average number of vangari and wholesale shops	Total waste collected (kg/d)	Buying price (Tk/d)	Selling price (TK/d)
Mohakhali	45	6000	180000	240000
Nakhalpara	25	1200	36000	48000
Farmgate	75	9000	270000	360000
Agargaon	20	1000	30000	40000
Lalmatia	40	3400	102000	136000
Total	205	20600		

Figure 2: Scenario of the old book shops

3.3 Paper Reuses

Paper packets have been used traditionally by all the shop keepers to sell consumer goods. These packets were made of new papers or used papers (including newspaper, books and used office paper) by informal cottage industries. Used papers were collected directly from the community in residential areas and offices. The total number of different sizes of paper packets per kg for the selected five locations was given in Table 4. The number of packets varied widely according to their size. The price of the packet was not assigned according to the sizes, but to the weights. The price of different sized paper packets were approximately Tk 40-60 per kg.

Table 4: Different sizes of packets made of waste paper

Different sizes of packets	Number of packets per kg
Tiny	17000
Small 1	13500
Small 2	1100
Medium 1	8300
Medium 2	5550

4. CONCLUSIONS

In Bangladesh, Solid waste generation scenario in urban area has changed due to population growth, urbanization and ignorance. Municipal waste management services are unable to cope with over-burden Solid waste generation and its management facility due to lack of manpower, insufficient materials and support. Among the different types of solid waste, 30% of all municipal waste covers residential, household and industrial waste. The solid waste production rate has increased where it may reach 0.49 kg/person/day to 0.6kg waste by 2025. Therefore a proper management is needed. Reusing of paper is not a new term in this modern technology. In case of Bangladesh reusing of paper, or anything is not well developed like other countries. But with the time being it is improving day by day. Reusing of paper plays an important part in environmental benefits. It reduces the production of solid wastes. A total of solid paper waste 61400 kg per day from 5 locations in Dhaka city is reusing. It indicates the reusing of paper waste. Another important part is that many families are depended in this reusing process. They take it as their career. Therefore unemployed persons are reducing. Details research should be carried out. New technologies should be bring. Paper collection process should be improved. Separated bin can be established. Traing to the collector can also be carried out. They should understand the importance of what they are doing.

ACKNOWLEDGEMENTS

The support provided by waste collectors, recyclable dealers, industry workers in this study is very much appreciated.

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Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), 9~11 February 2018, KUET, Khulna, Bangladesh (ISBN-978-984-34-3502-6)

COMPARTMENT-WISE VARIATION OF HYDRODYNAMIC CHARACTERISTICS OF THE MODIFIED ANAEROBIC BAFFLED REACTOR

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ABSTRACT

The anaerobic baffled reactor (ABR) possesses many advantages such as high removal efficiency, outstanding working stability, and lower operating cost. These include better residence to hydraulic and organic shock loadings, longer biomass retention times, lower sludge yields, and the ability to partially separate between the various phases of anaerobic catabolism. In this study, a reactor having effective volume 45.0 L was designed with seven compartments. The compartments had major two parts: first five chambers called anaerobic baffled reactor (ABR) and last two chambers called fluidized bed reactor (FBR). The external dimensions were 90, 19, and 29cm for length, width, and depth, respectively. The residence time distribution analyses was carried out by using tap water on clean reactor through tracer Pulse Input Experiment technique, to investigate compartment-wise mean residence time, mixing patterns, dead spaces and hydraulic efficiency in this novel type of reactor. The results show that the hydrodynamic characteristics of the anaerobic baffle reactor directly depends on the number of compartments. The mean residence time increases with the increase in the ABR compartments. The dead spaces in 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber of the ABR were 54.01, 36.56, 21.75, 11.42, 9.57, 6.27 and 0%, respectively indicates that the dead space decreases with the increase in the ABR compartments. In addition, the increase in ABR compartments also resulted in the decrease in back-mixing and $1/Pe_z$ values (from 0.53 to 0.07), which made the fluid in the reactor approach to the plug flow state.

Keywords: *Anaerobic baffled reactor, mean residence time, dead space, back-mixing, hydraulic efficiency*

1. INTRODUCTION

Sanitation is the hygienic means of promoting public health through prevention of human contact with the hazards of wastes. Without proper sanitation, people cannot attain to avoid proper preventable disease. It is the utterly important role of proper sanitation in achieving and maintaining good public health. The need for proper sanitation was made explicit in the United Nations Millennium Development Goals. Goal number 7 urges for the reduction by half of the population living without proper sanitation. Despite significant efforts, progress on sanitation targets is very slow and still lacking behind. Acknowledging the impact of sanitation on public health, poverty reduction, economic and social development and the environment. Important in this is to not only connect people to sanitation solutions, but to make this connection last in an environmentally sustainable way (Henze, 2008).

Besides improved sanitation, hygiene and safe water save millions of lives, accelerate economic growth, enhance people's dignity, and create a better future for all. Many countries are challenged in providing adequate sanitation for their entire populations, leaving people at risk for water, sanitation, and hygiene (WASH) related diseases. Throughout the world of 7.3 billion people, 2.4 billion lack access to adequate sanitation that it is more than 35% of the world's population and 1 billion have no choice but to defecate in the open, without access to even basic toilets or hand washing facilities (EMI: Water Sanitation & Hygiene, 2016). One out of every three in rural areas are defecated in the open and their neighbors are affected to fecal bacteria that lead to diarrhea and other diseases. Roughly half a million children die every year from diarrhea caused by unsafe water and poor sanitation. Half of the hospital beds in the developing countries are filled with people suffering from diseases caused by poor water, sanitation, and hygiene (The Sanitation Crisis, 2016). Most people without adequate sanitation live in Sub-Saharan Africa and South Asia. Without immediate acceleration in progress of sanitation, the world will not achieve the United Nations' Sustainable Development Goals (SDGs) by 2030.

Bangladesh is one of the most densely populated countries in the world, with more than 1222 per square kilometre. As Bangladesh experiences one of the fastest urbanization rates in Asia, most of the 7 million people living in urban slums – the population of which is rapidly increasing but they have no access to improved sanitation. Overall 39 percent people lack of improved sanitation facilities in rural areas, overcrowded conditions, and a lack of healthy ways of disposing waste in urban centers (Bangladesh Water Crisis, 2014).

One of the main concern of sanitation is wastewater treatment. Wastewater can be treated both aerobically and anaerobically. Anaerobic treatment of wastewater is most popularly used due to: (a) zero consumption of oxygen which cuts down the cost and energy requirements; (b) sludge production rate is very low which reduces the cost of sludge handling, stabilization, and final disposal; (c) production of biogas which can be used as a fuel; and (d) high COD removal efficiency (Xu et al., 2014). The advent of the high rate anaerobic treatment methods in which solids/sludge retention time (SRT) is long period occurs at low hydraulic retention time (HRT). Good contact between the biomass and substrate at low reactor volume is ensured by immobilizing the biomass as a result of granulation of biosolids.

Anaerobic treatment of wastewater has existed as a practical technology for over 100 years. It gradually evolved from a simple uncontrolled septic tank system. Septic tank usually fails to sanitize and contribute to groundwater pollution. In addition, septic systems often discharge into the environment with little or no sanitization or nutrient removal due to faulty design. Faulty design means poor hydraulic characteristics and mixing pattern. Moreover, the hydraulic flow regime in such a system is in the horizontal direction. This hydraulic phenomenon increases the possibility of short circuiting and dead spaces which reduce the actual or mean hydraulic retention time (HRT). As a consequence, the reduced HRT with the horizontal flow mode significantly diminishes the contact between the incoming substrate and the active biomass accumulated at the bottom of the septic tank, resulting in reduction of the treatment efficiency (Sharma & Kazmi, 2015). Now a days, completely controlled reactors used for treating wastewater. In anaerobic systems, the key microbial populations have a lower reproductive growth rate than aerobic reactors. But a longer sludge retention time (SRT) is to be provided in order to allow a stable equilibrium to be achieved between the diverse microbial community members in the anaerobic sludge (Xu et al., 2014). The loading rates permissible in an anaerobic waste treatment process depend on the concentration of active biomass within the digester. The major point of interest in the practical application of anaerobic process is the maintenance of a high solids retention time (SRT 20-100day), while keeping the hydraulic retention time (HRT) to a minimum (1.3~20 h) (Langenhoff et al, 2000). The solids retention time (SRT) is to be maintained well in excess of the hydraulic retention time (HRT). This results in higher biomass densities within the system. To accomplish the higher treatment efficiency and reliability associated with a long SRT, a number of novel anaerobic reactor configurations have been developed. Among of them the Anaerobic Baffled Reactor (ABR) is a novel type of reactor first described by Bachmann *et al* (1983), which allows high rates of hydraulic throughput with very little loss of biomass from the reactor, and a high reaction rate per unit volume (Krishna et al., 2009). The ABR achieves this by means of a design which is both simple and cheap to construct, since there are no moving parts or mechanical mixing devices. High residence times of bacterial cells within the reactor have been found, together with good mixing, providing a high rate of contact between the cells and their substrate (Grobicki & Stuckey, 1992).

The performance of the anaerobic baffled reactor (ABR) mainly depends on hydrodynamic characteristics of the reactor. The flow patterns of the reactor greatly influence back-mixing, dead spaces, and volumetric efficiency of the reactor which consequently affects treatment efficiency, working stability, reaction time, and equipment investment (Li et al., 2016). A good flow pattern promotes the substrate transferring to microorganisms, maintains uniformity of environmental factors thereby assuring the effective use of the reactor volume. Therefore, it is imperative to understand the performance of the flow patterns of the ABR and the correlation between the flow pattern and back-mixing, dead spaces and volumetric efficiency (Xu et al., 2014). So the flow patterns and optimization of compartments for anaerobic baffled reactor is an important issue.

So tracer experiments are often conducted to estimate the residence time distribution (RTD) and the time distribution for particles entering and leaving the system. Residence time distribution (RTD) analyses are carried out to investigate the hydraulic characteristics of the ABR (Sarathai et al., 2010). Therefore, RTD curves obtained from tracer tests. The curves can be used to analyse the compartment-wise residence time, mixing pattern, dead spaces, and hydraulic efficiency of the modified reactor.

2. METHODOLOGY

2.1 Experimental Set-up

A bench scale reactor used in this experimental study was constructed with clear acrylic plastic. The reactor has seven chambers. The external dimensions were 90, 19, and 29 cm for length, width, and depth, respectively. The reactors were rectangular, containing standing baffle, hanging baffle, and inclined baffle shown in figure-1. The standing baffles divided each reactor into seven identical compartments. The length of the compartments was varying according to its position. The first chamber length was 22cm, second to fifth chamber length 11cm, and last two chamber length 12cm. The hanging baffles which were designed in the compartments of the ABR divided each compartment into a down-flow section and an up-flow section. The up-flow/down-flow ratio was 4:1. The lower portion of the inclined baffles was bent at 45° to route the flow to the centre of the up-flow chamber, thus achieving better contact and greater mixing of feed and bio-solids. The total working volume of the reactor was 45L. The treatment of wastewater in a baffled reactor were the inability to produce a floating sludge layer which would enhance solids retention and the high velocities associated with the baffles caused significant washout of solid material. So that the 1st chamber of the ABR was doubled in size than other chambers. The flow rate was adjusted by dosing pump.

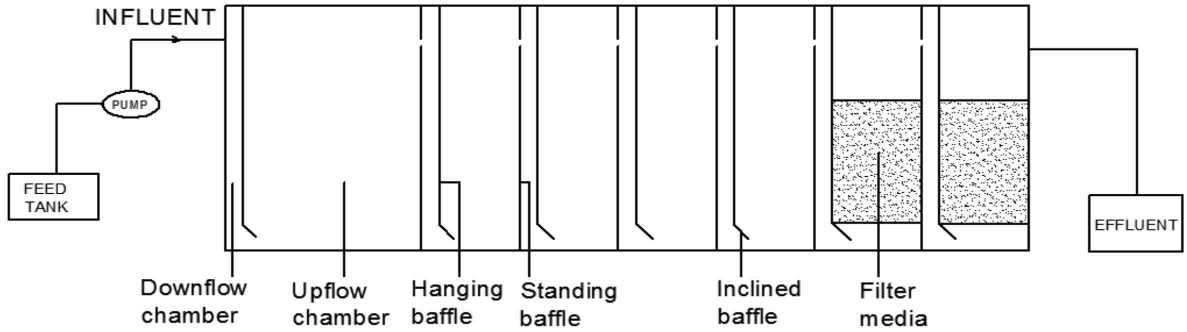

Figure 1. The schematic diagram of experimental setup.

2.2 Anaerobic Filter

The last two chambers of the baffle reactor were used as fluidized bed reactor. The anaerobic filter chambers of each unit were packed with Shredder plastic bottle cork shown in figure-2. The bottle cork used as a filter media is low specific gravity and floating in water so that its porosity is high. Also specific surface area is high. Also the bottle cork are locally available. The amount of bottle cork used in each chamber was 400gm. The figure of shredded plastic bottle cork given below:

Figure **Error! No text of specified style in document.**. Filter media used in the study.

2.3 Pump Calibration

A dosing pump was used to feed the reactor shown in figure-3. A dosing pump is a small positive displacement pump. It was designed to pump a very precise flow rate. Dosing pumps was used in a variety of applications from agriculture, industry, manufacturing to medicine. The pump used in this study was operated 0~360 stocks and maximum flow 334 ml/min at 360 stocks. For 3 hours residence time distribution (RTD) analysis, the baffle reactor was feed 15 L/hrs. In order to achieve the required flow the pump was calibrated. From calibration curve, the required stock was obtained.

Figure 3. Dosing pump

2.4 Experimental Design

The experimental setup of the tracer study shown figure-4. The hydraulic characteristics of the system were determined by residence time distribution (RTD) curves. The RTD curves, the time distribution for particles entering and leaving the system was obtained from tracer studies and further analysed for mixing pattern. Tracer studies were performed by using pulse input technique. Sodium chloride (NaCl) was selected as the tracer due to its various favourable features. In the study, the ABR was feed only tap water in the influent and the tracer was pulsively injected (t=0) at the inlet of the ABR. The tracer was quickly injected into the reactor in less than 5 sec. Samples were collected at the tracer collection point for at least twice during the designed hydraulic retention time (HRT). The EC of the collected sample was measured by multimeter and using EC calibration curve the concentration of NaCl was obtained. It was expressed as C(t). Then normalized time vs. tracer concentration of each chamber was plotted. The resulting response curve, referred as the C-diagram, provided an accurate representation of the hydraulic regime of the system.

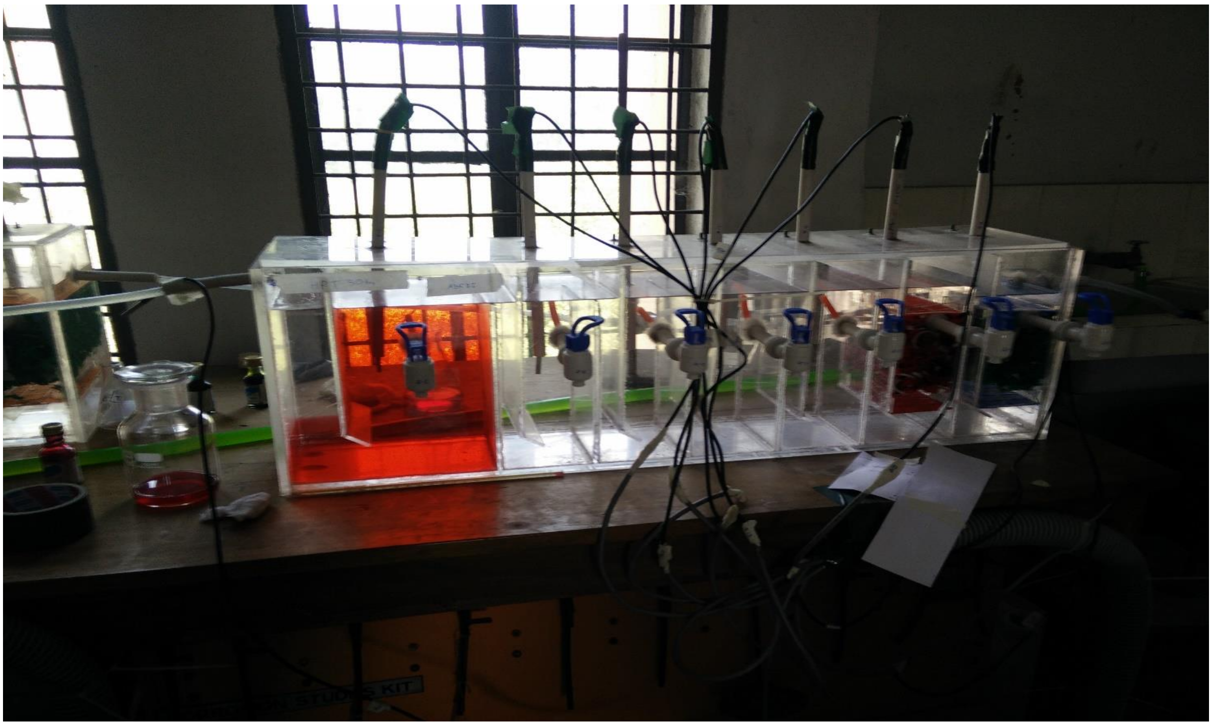

Figure 4. Experimental setup during tracer test.

2.5 Theoretical analysises

To analyze the behavior of the reactor the normalized RTD functions $E(t)$, mean residence time (τ) and distribution variance (σ^2) were calculated by the following equations:

$$E(t) = \frac{C(t)}{\int_0^\infty C(t)dt} \qquad (1)$$

$$\tau = \frac{\int_0^\infty tE(t)dt}{\int_0^\infty E(t)dt} \qquad (2)$$

Where $\int_0^\infty E(t)dt = 1$

$$\sigma^2 = \int_0^\infty t^2 E(t)\,dt - \tau^2 \qquad (3)$$

The dead spaces present in a reactor reduce the active volume of system. The percentage of the dead space can be calculated by the following equation:

$$V_d = \left(1 - \frac{\tau}{HRT}\right) \times 100\% \qquad (4)$$

σ_θ^2 is the dimensionless variance of the RTD and $\sigma_\theta^2 = \sigma^2/\tau^2$

$$\sigma_\theta^2 = 2\left(\frac{D}{uL}\right) - 2\left(\frac{D}{uL}\right)^2 \left(1 - e^{-uL/D}\right) \qquad (5)$$

Where, D/uL is the dispersion number (dimensionless), which characterizes the degree of back-mixing in the direction of flow. If D/uL = 0, the reactor approximated to the ideal plug-flow reactor (PFR, D/uL = 0). If D/uL =∞, the reactor approximated to the ideal continuous-flow stirred-tank reactor (CSTR, D/uL = 1).
The tank-in-series model could be calculated by

$$N = \frac{1}{\sigma_\theta^2} \qquad (6)$$

If $N = 1$, then the reactor approximated to the CSTR, and if $N = \propto$, then the reactor approximated to the PFR.
The hydraulic efficiency (λ) expressed in Eq. (7) reflects two basic features: the effective volume and near-plug flow condition. Values of both terms range from 0 to 1, providing equal weighting for effective volume and pollutant hydraulic residence time distribution. The hydraulic efficiency can be categorized into three groups:

(i) Good hydraulic efficiency with $\lambda > 0.75$;
(ii) Satisfactory hydraulic efficiency with $0.5 < \lambda \leq 0.75$; and
(iii) Poor hydraulic efficiency where $\lambda \leq 0.5$

$$\lambda = e\left(1 - \frac{1}{N}\right) \qquad (7)$$

Where, e is the effective volume, calculated as one minus dead space and *N* is the number of on continuous stirred tanks in series.

3. RESULTS AND DISCUSSIONS

3.1 RTD of ABR

The RTD curves obtained by plotting normalized time vs. concentration (mg/L). Fig. 5. shows the RTD of 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber and effluent of the ABR, respectively. As shown in the figure, the reactor residence time curve firstly rises and then drops, forming one single peak. The calculated peak concentrations of 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber and effluent of the ABR were 1021, 684, 593, 548, 506, 463, 447, and 417 mg/L, respectively. Further analysis of the RTD of 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber and effluent of the ABR showed that, with the increase in the ABR chambers, the peak value of the RTD curves decreased as well, while the distribution width of the RTD curves turned wider on the time axis.

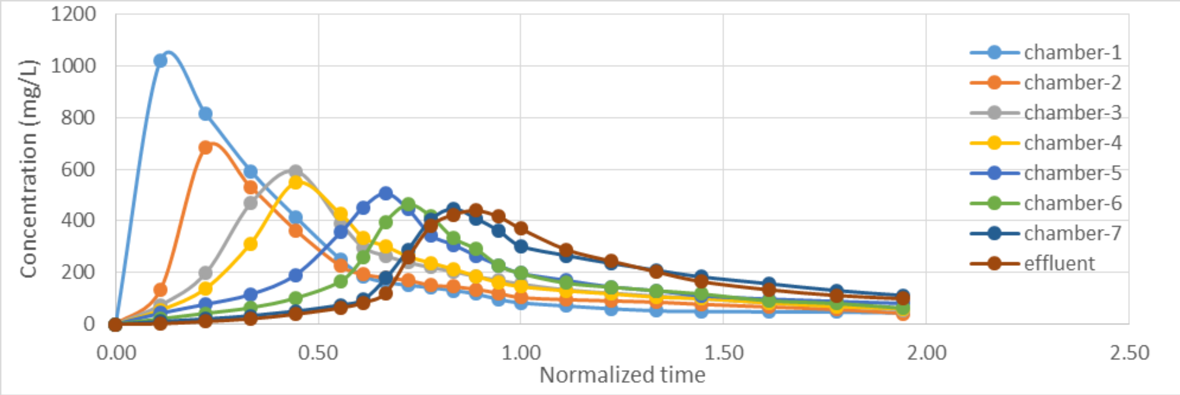

Figure 5. RTD results of various chambers.

3.2 Mean Residence Time

The mean residence time of 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber and effluent of the ABR were 82.8, 114.2, 140.9, 159.4, 162.8, 168.7, 181.7, and 184.1 min, respectively shown in fi. The analysis of the RTD of 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber showed that, with the increase in the ABR chambers, the mean residence time also increase. For 3-hour HRT study, the mean residence time was obtained at chamber-6. That's mean the atoms leave the reactor to spend enough time.

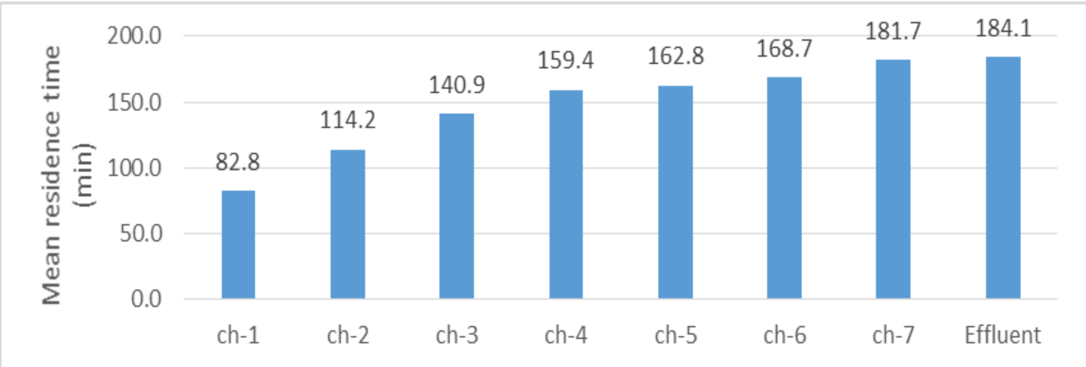

Figure 6. Mean residence time of various chambers.

3.3 Back-mixing

Peclet Number of quasi (Pez) is the ratio of the rate of the convective flow to the rate of the axial diffusion, which is often used to indicate the degree of back-mixing. When Pez tends 0 (namely, $1/Pez$ tends to ∞), the advection is much greater than the diffusion; that is to say, the fluid is completely in the form of mixed flow. On the contrary, when Pez tends to ∞, (Namely, $1/Pez$ tends to 0), the influence of the diffusion upon the convection is negligible; that is to say, the fluid is in the form of plug flow.

Analysis of the hydraulic characteristics of 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber and effluent of the ABR under the same operating conditions showed that, keeping the HRT value constant, the number of chambers had greater impact on the hydraulic characteristics of the ABR. The $1/Pez$ values of 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber and effluent of the ABR were 0.53, 0.29, 0.17, 0.14, 0.12, 0.10, 0.08, and 0.07, respectively (Fig 7). There was a great drop between the $1/Pez$ of chamber-1 and chamber-7 of the ABR; while the difference between the $1/Pez$ of chamber-7 and the effluent of the ABR was negligible.

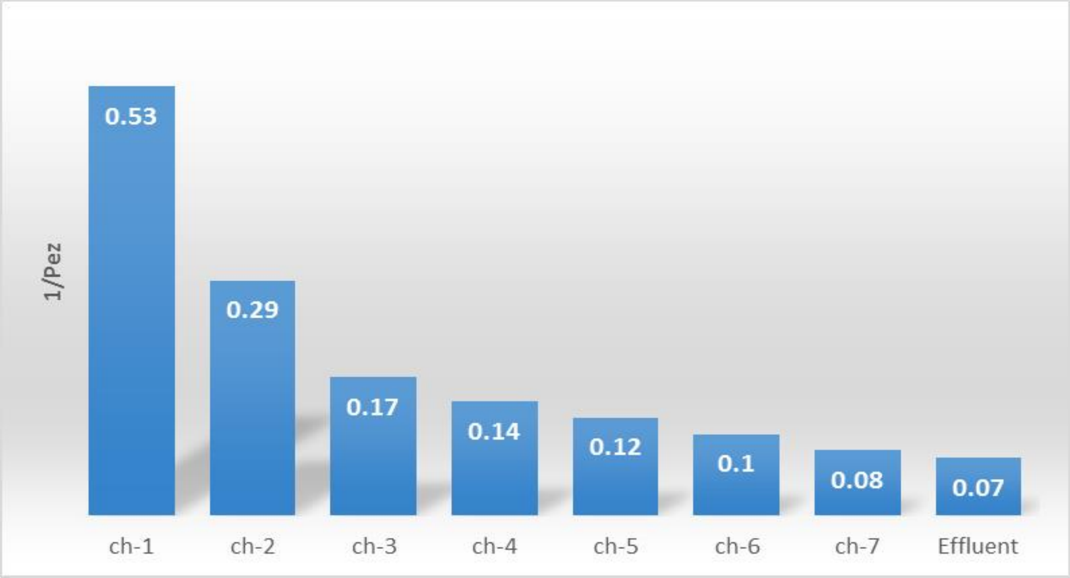

Figure 7. 1/Pez of 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber and effluent of the ABR.

Therefore, the plug flow pattern could be obtained in the reactor by increasing the number of chambers. Tomlinson and Chambers found that when 1/Pez > 0.2, the degree of dispersion in the reactor was kept high. Likely, in this study, as the 1/Pez values of the ABR turned from 0.53 to 0.070, that the 1-, 2-chamber of the ABR were the highest. Therefore, the fluid in the 1-, 2-chamber tended to be in the form of complete mixed flow while that the 3-, 4-, 5-, 6-, and 7-chamber tended to be in the form of plug flow. As the 1/Pez value decreased, the fluid in the reactor gradually approached to the plug flow. That is to say, with the chambers increased from one to seven, the fluid in the reactor increasingly took the form of plug flow.

3.4 Dead Space

Dead space in the reactor can be generally divided into hydraulic dead space and biomass dead space. But in this study, tap water was used to analyse the hydrodynamic characteristics. So only hydraulic dead space was calculated in this experiment. As shown in Fig 8. The increase in the chambers lead to the decrease in the percentage of hydraulic dead space. The dead spaces that caused by hydraulic behaviour, in 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber of the ABR were 54.01, 36.56, 21.75, 11.42, 9.57, 6.27 and 0%, respectively (Fig 8). The dead space of chamber 6 and 7 is less than the other chambers due to the effect of fluidized bed reactor. As the dead space was zero at chamber 7. Therefore, the optimal number of chamber of the reactor shall be 6.

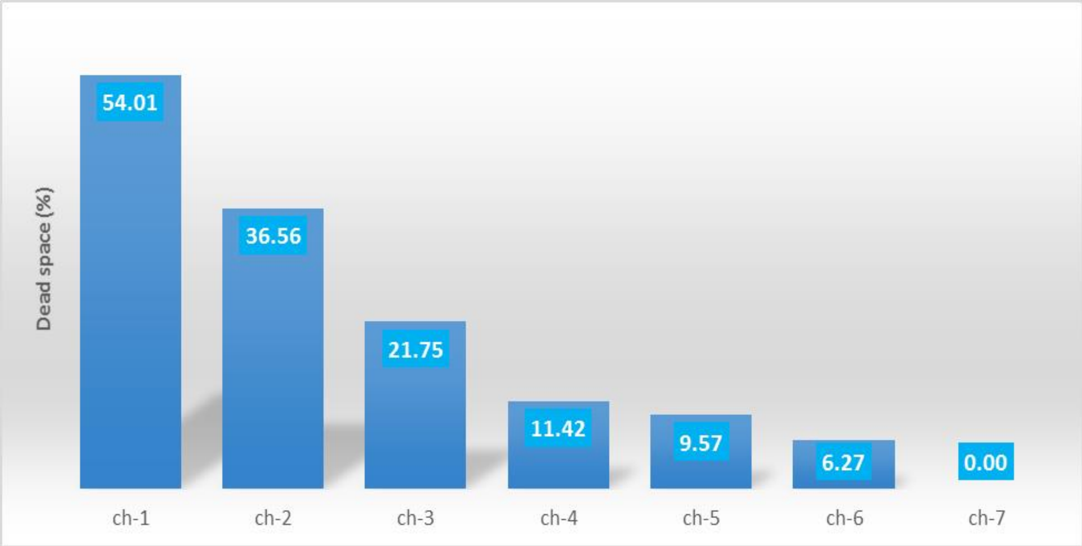

Figure 8. Percentages of dead space in 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber and effluent

The hydraulic dead space in the ABR occurs mainly at the baffle corners and the bottom free space of the inclined baffle. The existence of vortex of various degrees at the baffle corners affects diffusion of the tracer, and consequently results in slow release of the tracer; the dead space is therefore formed.

3.5 Hydraulic Efficiency

Hydraulic efficiency reflects two basic features, which are: (1) the ability to distribute the inflow evenly across the system and (2) the amount of mixing. Obviously, the satisfactory hydraulic efficiency of the ABR varies from 0.08 to 0.80 (Fig 9). However, it tended to higher when the number of chamber was increased. The hydraulic efficiency of first two chamber were 0.08 and 0.30, which is less than 0.50 that means poor hydraulic efficiency. The hydraulic efficiency of 3-, 4-, 5-, 6-chamber were 0.56, 0.75, 0.75 and 0.75, respectively. As those values is within the limit $0.5 < \lambda \leq 0.75$, so the flow in those chambers was satisfactory hydraulic efficiency. The values of 7-chamber and effluent were 0.77 and 0.80, which is greater than 0.75. So the hydraulic efficiency was very good.

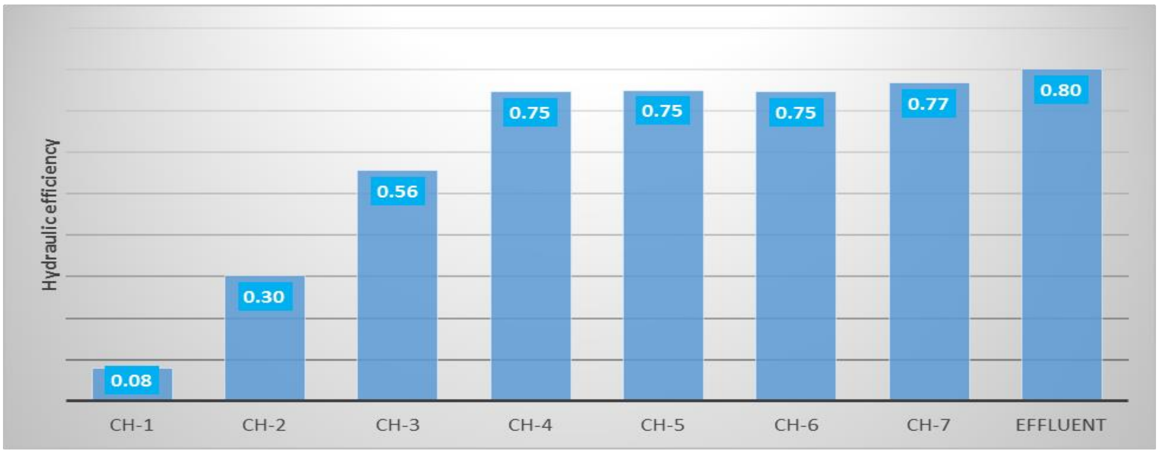

Figure 9. Hydraulic efficiency of various chambers

4. CONCLUSIONS

In conclusion, it is apparent from these studies that the ABR may be characterized as a series of well-mixed CSTRs, with low dead space. There is very little mixing between one compartment and the next, due to the baffle arrangement. Hence the ABR may be represented for the purposes of modelling as a series of ideal stirred tanks, corresponding to the number of actual compartments. With the increase in the ABR chambers, the mean residence time also increase. The greater the number of compartments, the closer the reactor will approach plug flow. Dead space may be divided into two categories, hydraulic and biological. Hydraulic dead space, which is a function of flow rate and the number of baffles, may broadly be said to increase with decreasing HRT. The dead spaces that caused by hydraulic behaviour, in 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber of the ABR are 54.01, 36.56, 21.75, 11.42, 9.57, 6.27 and 0%, respectively. The dead space in this study was very high due to low HRT, though the dead space decrease with increase the number of chamber. In the last two chambers, the dead space was reduced at a significant amount due to the effect of filter media. The hydraulic efficiency of 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber of the baffle reactor are 0.08, 0.30, 0.56, 0.75, 0.75, 0.75 and 0.77, respectively. That means hydraulic efficiency is also increase with the increase of ABR compartments. Taking the operating performance and economic factors of the reactor into full consideration, the present study recommends that the series number (N) of ABR compartments shall be kept at least 6.

ACKNOWLEDGEMENTS

I would like to express my gratitude and heartiest thanks to my honourable teacher Md. Khalekuzzaman, Assistant Professor, Department of Civil Engineering, KUET for his invaluable guidance, suggestion, co-operation and encouragement at every stage of work through his most busy occupied days. His active interest and supervision in this topic and advice were the source of my inspiration and help me enormously to carry out this work.
I also must acknowledge the help of Dr. Muhammed Alamgir, Professor, Department of Civil Engineering, KUET for his guidance, patient explanation, encouragement and support throughout the study.

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Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), 9~11 February 2018, KUET, Khulna, Bangladesh (ISBN-978-984-34-3502-6)

EVALUATION OF DUCKWEED BASED WASTE STABILIZATION POND SYSTEM FOR DOMESTIC WASTEWATER TREATMENT

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ABSTRACT

Natural systems of wastewater treatment are regarded as sustainable ecotechnologies specially for the developing countries. In this study performance of a natural treatment system, namely, duckweed (S. Polyrrhiza) based waste stabilization pond system for domestic wastewater treatment was investigated. The domestic wastewater was collected from an outlet of a residential building at Dhamondi area in Dhaka city, Bangladesh. The domestic wastewater was poured in a small-scale glass reactor that was subjected to atmospheric conditions with 5 days Hydraulic Retention Time (HRT). Once in a week 20 liters raw domestic wastewater was used as influent; the experiment was carried out for 8 consecutive weeks. Total 16 samples (08 for influent and 08 for effluent) were collected and analyzed to evaluate pollutant removal performances accross the experimental system. In domestic wastewater the average concentrations of P^H, DO, TDS, TSS, COD, PO_4-P, NO_3-N, NO_2-N and NH_3-N were found to be 7.4, 1.7 mg/L, 443.3 mg/L, 170.0 mg/L, 257.0 mg/L, 26.6 mg/L, 1.0 mg/L, 26.3 mg/L and 23.6 mg/L respectively. Whereas, in effluent the average concentrations of such parameters were found 8.34, 6.60 mg/L, 367.75 mg/L, 29.13 mg/L, 49.26 mg/L, 6.14 mg/L, 1.75 mg/L, 5.61 mg/L and 13.65 mg/L respectively. Consequently, the system achieved 17%, 82.9%, 80.8%, 76.9% and 42.0% removal efficiencies of TDS, TSS, COD, PO_4-P, and NH_3-N respectively. These results indicate that duckweed based wastewater stabilization pond system might be successfully employed for treating domestic wastewater in developing countries as a decentralized treatment unit.

Keywords: *Duckweed, waste stabilization pond, domestic wastewater, ecotechnology, developing countries*

1. INTRODUCTION

Besides to ensure safe water supply, the concept of wastewater treatment has also been widely recognised as an important issue in recent days due to global water shortage, even in developing countries (Ujang and Buckley, 2002; Verstraete et al., 2009).

Generally, the advanced wastewater treatment technologies have been designed and proposed so that the treated effluent can meet the highly restrictive guidelines for disposal and/or reuse. However, these technologies are still limited to developed countries only. Advanced treatment technologies have not expanded to developing countries due to the high cost, energy requirements, difficulties of installation, operation and maintenance as well as large solids or sludge production (Mara, 2004). In addition, the guidelines of environmental protection are being stringent in developing countries day by day in recent time. To overcome these challenges, interest in natural systems for wastewater treatment is increasing day by day not only for wastewater treatment but also for conserving biological communities in developing countries (Kocaman et al., 2007).

Literature stated that natural systems for effective wastewater treatment are available in three major categories: aquatic pond (e.g., algae based waste stabilization pond, duckweed based waste stabilization pond, hyacinth pond) terrestrial (e.g., soil aquifer treatment, overland flow), and wetland (e.g., natural marshes, free water surface constructed wetland, subsurface flow wetland) (Crites et al., 2006). The major natural processes occurring in natural systems during wastewater treatment include sedimentation (settling of solids), plant uptake, bacterial degradation, and chemical adsorption (fixation).

The natural system of wastewater treatment using aquatic macrophytes such as duckweed has already gain attention and has been widely discussed in literature for nearly 40 years (Culley and Epps, 1973; Hillman and Culley, 1978; Oron et al., 1984; Landolt and Kandeler, 1987; Alaerts et al., 1996; Leng, 1999; Smith and Moelyowati, 2001; Nhapi et al., 2003; Willett, 2005; Ozengin and Elmaci, 2007; Xu and Shen, 2011; Verma and Suthar 2014; Allam et al., 2015; Gaur and Suthar, 2017). Duckweeds are green, small-sized (1-3 mm), fast-growth, free floating aquatic macro-phytes having short but dense roots (1-3 cm) that belongs to *Lemnaceae* family (which is derived from the Greek word 'Limne', meaning pond) (Cheng et al., 2002; Cheng and Stomp, 2009; Ozengin and Elmaci 2007). The *Lemnaceae* family consist of five genera, Lemna, Landoltia, Spirodela, Wolffia and Wolffiella, among which about 40 species have been identified wide-reaching (Les et al., 2002; Willett, 2005). Duckweed is well known for its high productivity and high protein content in temperate climates and easy handling, harvesting and processing (Oron et al., 1984; Oron et al., 1986; Hammouda et al., 1995). Duckweed fronds grow in colonies that, in particular growing conditions, form a dense and uniform surface mat having low fibre content and reduces mosquito development (Altay et al., 1996). Duckweed is applied on the surface of stabilization ponds, and as it has great ability to reduce the BOD, COD, suspended solids, bacterial and other pathogens from wastewater.

One of the major problems with conventional wastewater treatment methods is that none of the available technologies has a direct economic return. Therefore, with no economic return, local authorities are generally not interested in taking up treatment of wastewater in developing countries, thereby causing severe health hazards and environmental pollution (Von Sparling, 1996; Mahmood et al., 2013). In contrast duckweed-based waste stabilization pond system for wastewater treatment showed its potential for its nutrient value and direct economic returns from pisciculture. The objective of this study is to evaluate the pollutant removal performance of a duckweed based waste stabilization pond system while treating domestic wastewater.

2. METHODOLOGYV

2.1 Duckweed collection and culture

The duckweed (*Spairodela polyrhiza*) used in this study was collected from a ditch near Dhanmondi lake, Dhaka. The collected duckweed then cultured in a separate reactor with atmospheric condition using same domestic wastewater that was subjected to treat. During the experiment the cultured duckweed was used periodically.

2.2 Domestic wastewater collection

Domestic wastewater was collected from an outlet (just before fall onto adjacent municipal drain) of a six-storied residential building in Dhanmondi R/A, Dhaka. Figure 1 shows the photograph of sampling point. Once in a week 20 litre wastewater was collected for the experiment and for analyse its characteristics' as well.

2.3 Experimental Setup and operational conditions

In this study a small-scale glass made tank was used as reactor which was placed at the roof-top of University of Asia Pacific, Dhaka to maintain atmospheric condition. The experiment was conducted during November 2016 to February 2017. Figure 1 shows the schematic view of experimental set up. The size of the reactor was 45 cm x 33 cm x 24 cm. Therefore, the surface area is 1485 cm^2. Duckweed-covered wastewater has depth of 15 cm. Once in a week 20 litre domestic wastewater was poured into the reactor. Effluents were taken once after 5 days (at 1:20 pm-1:35 pm). The experiment was repeated for eight consecutive weeks. Loss of water by evaporation and evapotranspiration from the reactor during the experiment was neglected.

The experiment commenced with a duckweed density of 0.07 g/cm^2 (wet weight) duckweed. Everyday duckweed was grown up and every week the duckweeds were eliminating to keep initial density constant. The reactor was washed before pouring initial wastewater every time. Figure 3 represents the diagram of the experiment.

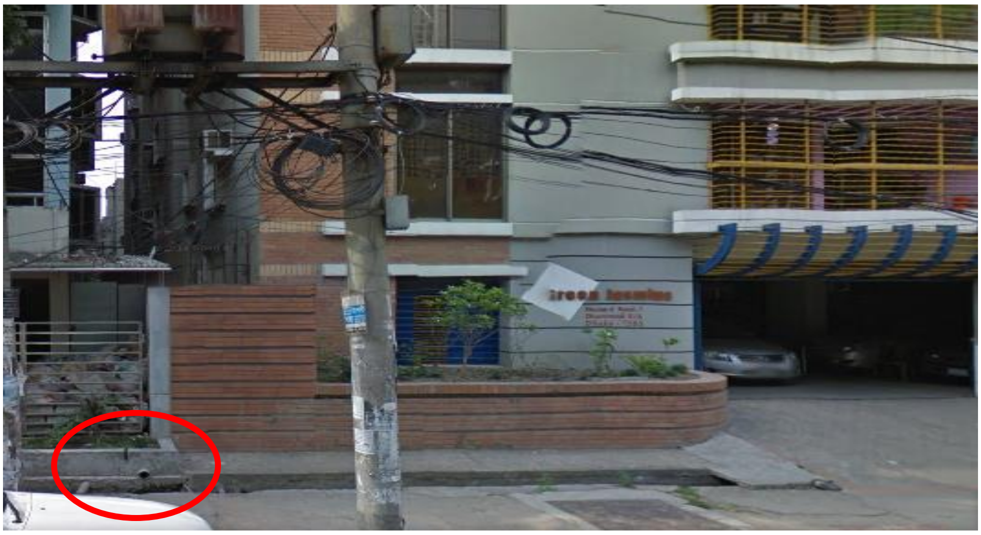

Figure 1 : Outlet from where domestic wastewater was collected (red circle).

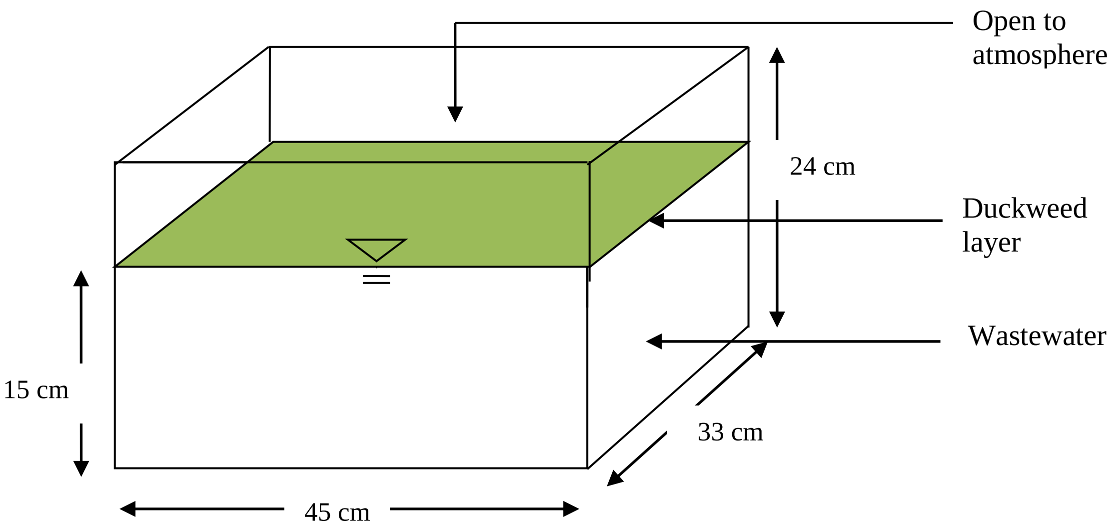

Figure 2: Sketch diagram of the reactor.

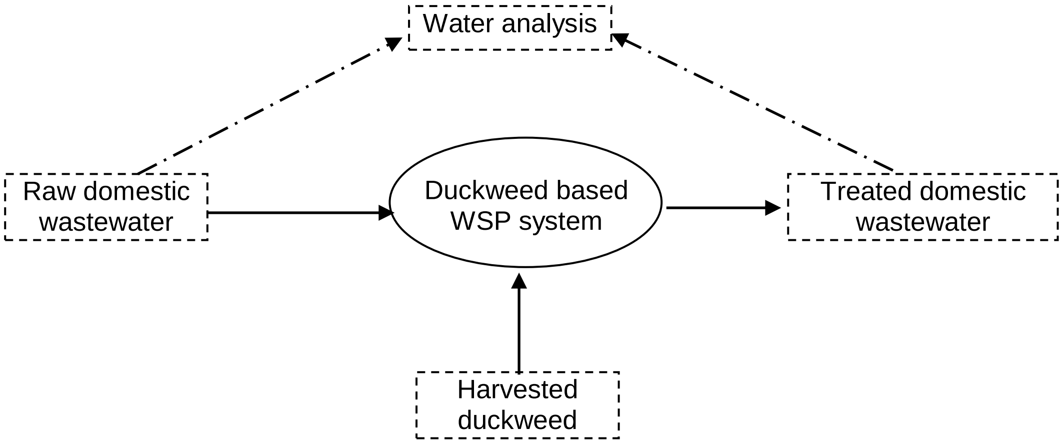

Figure 3: Diagram of the experiment.

2.4 Analytical methods

The collected samples (08 samples of raw domestic wastewater as influent and 08 samples of treated wastewater as effluent) were analysed using standard methods at Environmental and Chemistry Laboratory, University of Asia Pacific, Dhaka.

The samples were tested for total 10 parameters: pH, DO, Temperature, COD, PO_4-P, NO_2-N, NO_3-N, NH_3-N, TSS, TDS. All the samples were taken between 1:00 to 1:30 pm and analysed immediately. The pH and dissolved oxygen (DO) were measured using pH metre (HORIBA F-21) and DO metre (HACH HQ30d), respectively. HITACHI U-2800 spectrophotometer was used for COD, PO_4-P, NO_2-N, NO_3-N, NH_3-N, TSS, TDS measurement following standard methods. All tests were carried out with appropriate reagents and blanks.

3. RESULTS AND DISCUSSION

3.1 Characteristics of domestic wastewater

Table 1 shows the concentrations of different parameters of domestic wastewater that represents it characteristics. Based on literature it could be characterized as medium strength domestic wastewater (Metcalf and Eddy, 1991; Muttamara, 1996).

3.2 pH, DO and temperature

Figure 4 shows pH and DO concentrations and temperature in influent and effluent. pH value was found high after the treatment: average value in influent was 7.4 whereas in effluent it was 8.34. The maximum 30.7% increase in pH was found during this experiment (sample 4 in figure 4) and the increase in pH value in duckweed based system is already reported (Bal Krishna and Polprasert, 2008; Ozengin and Elmaci, 2007; Selvarani et al., 2015). The reasons of pH increase might be due to the photosynthetic activity in the reactor that utilized CO_2 and produced less amount of carbonic acid (Selvarani et al., 2015).

DO concentrations were found four times higher in effluent (6.60 mg/L) and maximum 587% increase in DO level was observed (sample 4 in figure 4). The increase in DO level during duckweed based treatment system also matched with literature and the reason might be the production of gaseous oxygen due to photosynthetic activity (EL-Kheir et al., 2007).

Temperature was dependent on the local atmospheric condition as the experiment was conducted at roof-top area. In effluent it was found higher around 1°C than influent as the reactor was made of glass which might absorb the heat. Literature shows that duckweed will decrease while temperature below 17 °C or above 34-35 °C (Smith and Maolyawat, 1998; Azeez and Sabbar, 2012). In this experiment, both cases (influent and effluent) the temperature was within 17.1 °C to 25 °C (figure 4) which was within the tolerable limit for *Lemnaceae* family (Culley et al., 1981) and was suitable for the experiment.

Table 1: Characteristics of domestic wastewater

Parameters	**Concentrations**		
	Minimum	**Maximum**	**Mean ± SD**
pH	7.12	7.61	7.4 ± 0.2
DO (mg/L)	0.54	4.55	1.7 ± 1.2
Temp (^{o}C)	17.1	24.5	21.7 ± 2.3
TDS (mg/L)	332	500	443.3 ± 51.8
TSS (mg/L)	64	272	170.0 ± 89.8
COD (mg/L)	105	434	257.0 ± 91.2
PO_4-P (mg/L)	19	35	26.6± 5.0
NO_3-N (mg/L)	0.2	2.4	1.0 ± 0.6
NO_2-N (mg/L)	9	76	26.3 ± 26.5
NH_3-N (mg/L)	15.5	32.4	23.6 ± 5.4

3.3 Organic removal

Maximum rate of COD removal was found 94.2% (sample 7 in figure 5) with an average removal rate of 80.8% in this system. Figure 5 shows the COD concentration in influent and effluent. Literature reported that significant enhancement of COD removal in duckweed treatment system and the removal rate was within the range of 70% to 80% (Korner et al., 2003; Pandey, 2001) or 50% to 95% (Alaerts al., 1996; Boniard et al., 1994; Oron et al., 1987), The result of organic removal indicated that duckweed provided additional surfaces for bacterial growth, additional oxygen supply and 5 days HRT period was sufficient to biodegrade the organic content.

3.4 Nutrient removal

Figure 6 shows the concentrations of N and P in influent and effluent. Ammonia-nitrogen was reduced maximum of 76% with an average value of 59% except sample no. 6 (figure 6) where the effluent concentration was found higher than influent. NO3-N reduction was observed in most samples. Average 76.9% removal of phosphorus was observed during this experiment though literature stated that lemnacae family are generally able to absorb 30-50% dissolved phosphorus (Goopy and Murray, 2003). Therefore, the reason of higher absorption of nutrient by duckweed in this study might be the HRT value of 5 days.

The mechanism of nutrient (N and P) removal might be plant uptake by the attached biofilm on duckweed and the walls of the reactor, absorption into clay particles and organic matter, ammonia volatilization, ammonia assimilation into algal biomass, and biological nitrification coupled with denitrification, microbial immobilization into detritus plant tissue, chemical precipitation and sludge removal (Fanta et al. 2016; Iqbal, 1999; Smith & Moelyowati, 2001; Zimmo et al. 2005).

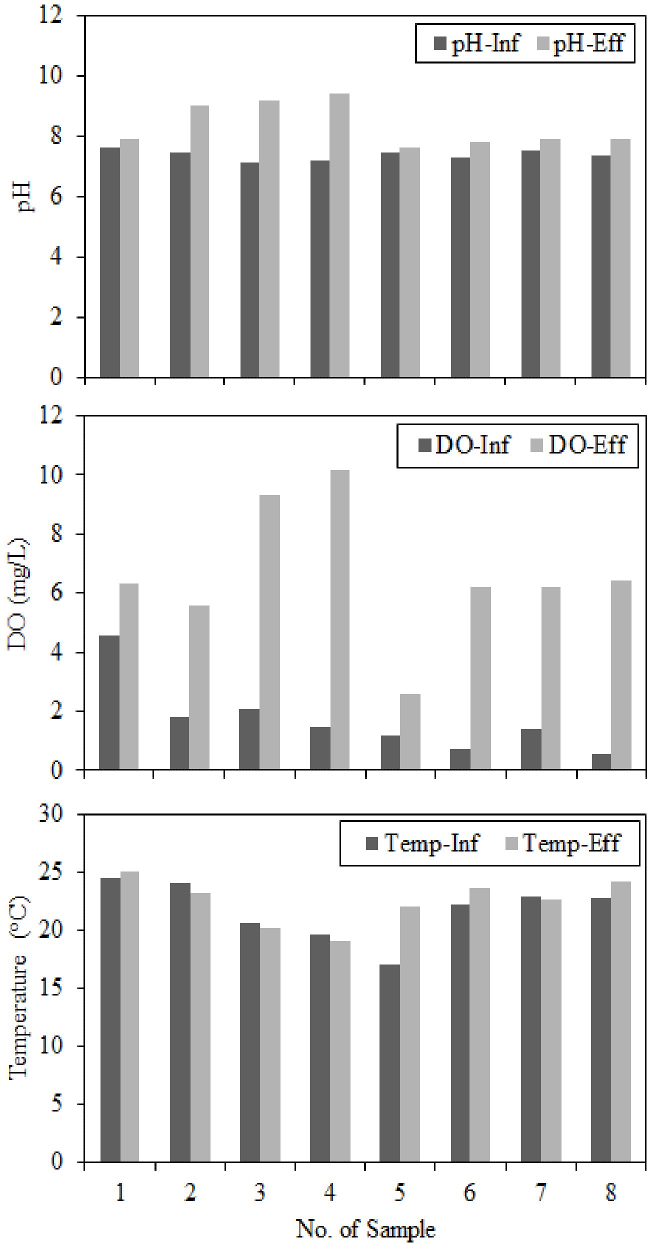

Figure 4: pH, DO and Temperature in influents and effluents.

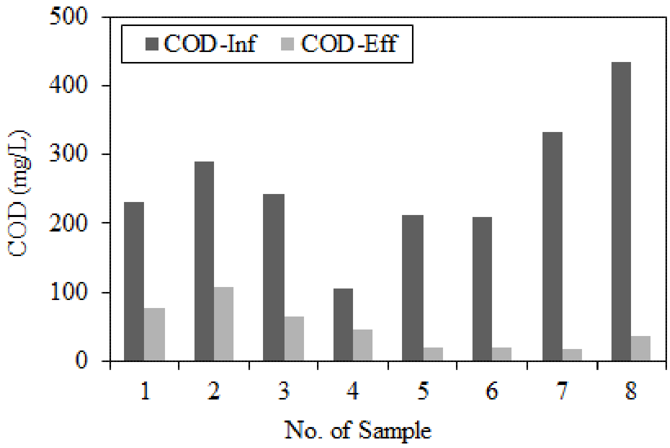

Figure 5: COD concentration in influents and effluents.

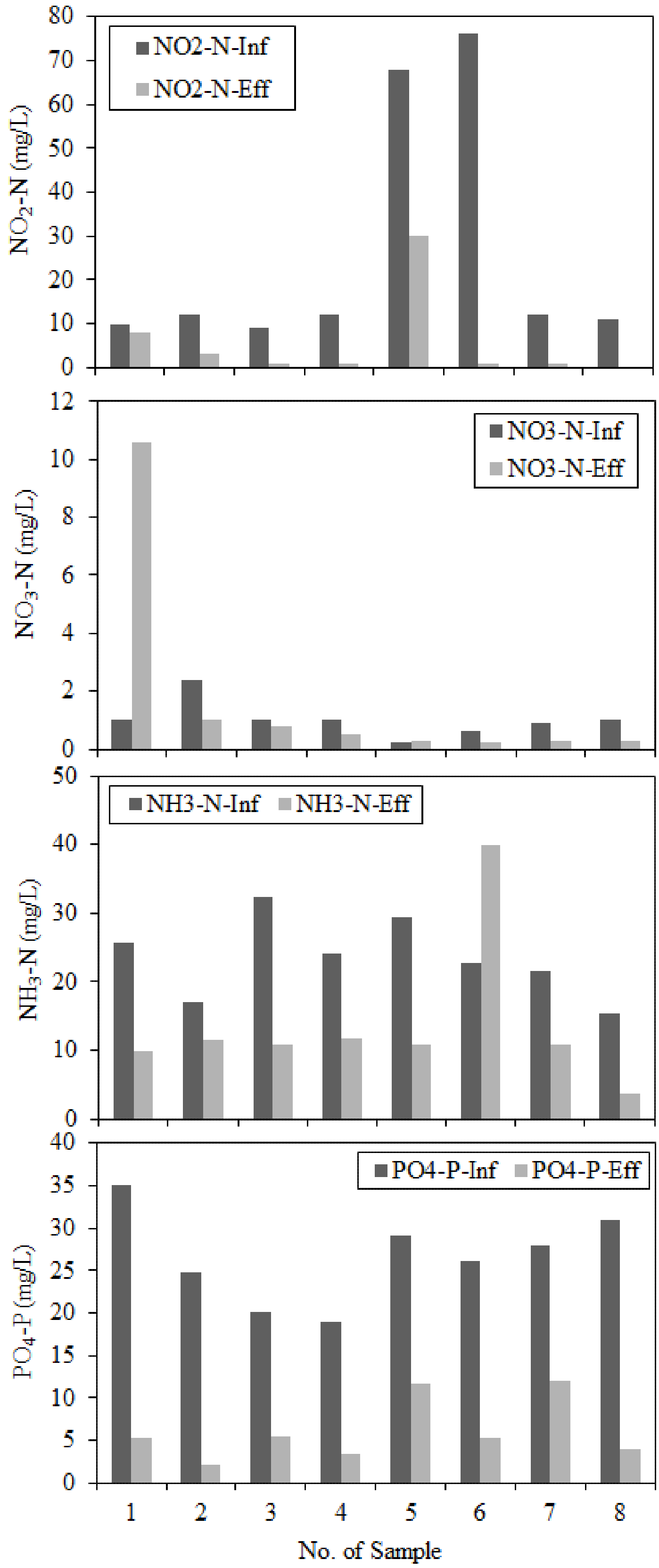

Figure 6: Nitrogen and Phosphorus concentrations in influents and effluents.

3.5 Solids removal

Figure 7 shows the concentrations of Total suspended solids (TSS) and Total dissolved solids (TDS) in influent and effluent. The maximum removal of TSS in this experiment was found 93.8% (sample 3 in figure 7) with an average value of 82.9%. TSS are mainly reduced by: (1) the process of sedimentation; (2) biodegradation of organic matters; (3) absorption of a minor fraction by duckweed roots and (4) inhibition of algal growth due to covering of surface by duckweed mat (Iqbal, 1999). TDS was removed maximum 40.9% (sample 1 in figure 7) with an average removal rate of 17% in this experiment.

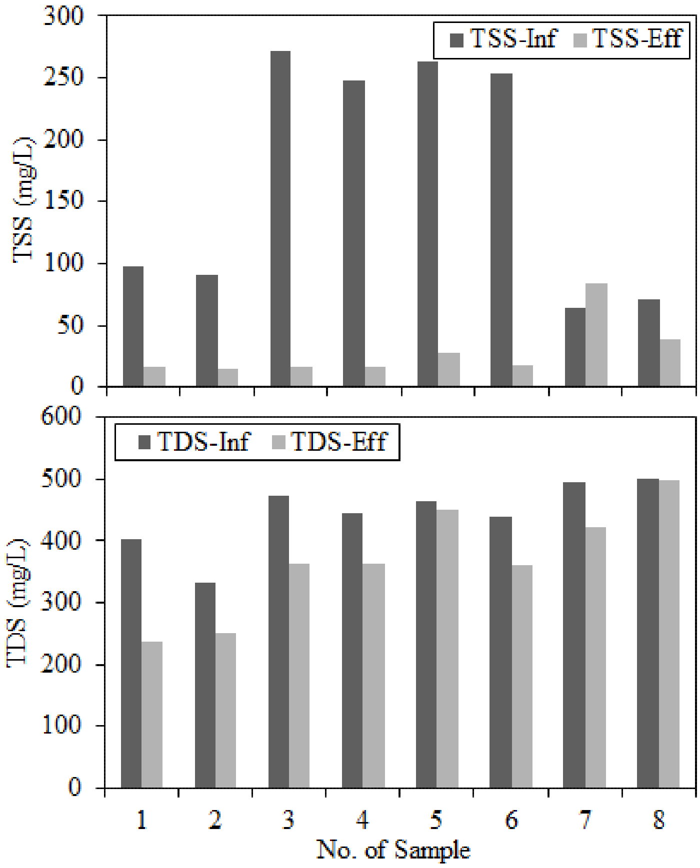

Figure 7: Solids concentration in influents and effluents.

3.6 Fate of used duckweed

Although the fate of duckweed that used in such treatment systems is crucial as it may create further hazards for environment, but in literature several ways of dispose as well as reuse of the duckweed has been stated such as: animal fodder, green fertilizer, source of protein for poultry/fish feeds etc. (Bonomo et al., 1997; Moss, 1999). During this lab-scale study the used duckweed was disposed normally in environment but for pilot scale or full-scale systems the literature stated disposal or reuse processes could be followed.

4. CONCLUSIONS

The present study demonstrated the performance of duckweed based treatment system in removing pollutant from domestic wastewater. In domestic wastewater the average concentrations of pH, DO, TDS, TSS, COD, PO_4-P, NO_3-N, NO_2-N and NH_3-N were found to be 7.4, 1.7 mg/L, 443.3 mg/L, 170.0 mg/L, 257.0 mg/L, 26.6 mg/L, 1.0 mg/L, 26.3 mg/L and 23.6 mg/L respectively. Whereas, in effluent the average concentrations of such parameters were found 8.34, 6.60 mg/L, 367.75 mg/L, 29.13 mg/L, 49.26 mg/L, 6.14 mg/L, 1.75 mg/L, 5.61 mg/L and 13.65 mg/L respectively. Consequently, the system achieved 17%, 82.9%, 80.8%, 76.9% and 42.0% removal efficiencies of TDS, TSS, COD, PO_4-P, and NH_3-N respectively. These results indicate that duckweed based waste stabilization pond system might be cost-effective, energy efficient and environmentally sound technology to treat domestic wastewater in developing countries as decentralized treatment unit.

ACKNOWLEDGEMENTS

This research is conducted in University of Asia Pacific, Dhaka, Bangladesh, with full support of laboratory and finance.

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HEAVY METALS PHYTOREMIDIATION POTENTIAL OF NAPIER GRASS CULTIVATED IN TANNERY SLUDGE

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ABSTRACT

Phytoremediationis a cost effectiveand eco-friendly method for cleanup of contaminated soil. This study focused on the assessment of phytoremediation potential of Napier grass (Pennisetumpurpureum) and Indian mastered (Brassica juncea) yielding in tannery sludge. Initial characterization of tannery sludge showed a high concentration of chromium, lead, copper and zinc which were 6845.5±50.2 mg/kg, 73±2.5 mg/kg, 93±1.5 mg/kg, and 29±2.5 mg/kg, respectively. Both seeds of these plants were sown on tannery sludge kept in baskets and harvested after 8 and 12 weeks of plantation.The study indicated that both Napier grass and Indian mustard accumulatedheavy metals in the order of Cr>Zn>Cu>Pb at different parts of these plants. Indian mustard accumulated highest concentration of Cr, Cu, and Pb whereas Napier grass showed highest Zn uptake and good Cr accumulating capacity.The uptake rate of Cr increased in Napier grass with the increase of plant age. Moreover, Napier grass is one of the rapid yielding tropical grasses and can retain for a longer period than Indian mustard. For that attribute, it may accumulate more heavy metals than Indian mustard within its life span. Both of these plants can be used for remediating heavy metals from contaminated tannery sludge.

Keywords:*Napier grass, Indian mustard,phytoremediation, heavy metals, tannery sludge*

1. INTRODUCTION

Tannery sludge contains elevated concentration of heavy metals like Cr, As,Pb, Ni, Cu, Zn and Cd due to the use of basic chromium salt, different syntans, dyes, pigments, retanning agents during the leather production(Juel, Mizan, & Ahmed, 2017). These kinds of heavy metals are non-biodegradable andaccumulated in soils, waters andcontaminate the food chain at later(Ali, Khan, & Sajad, 2013).In recent years, although there are some methods available for reuse or recyclingof tannery sludge, most of the tannery sludge is disposed of as landfilling without any treatment. But this can alter the physicochemical properties and fertility of the soil.When crops are grown on such kind of contaminated soil, the heavy metal can be accumulatedin its vegetative parts with incorporationinto the food chain and leading to bio-amplification(Pergent & Martini, 1999).These metals are toxic and can form irreversible effects even at low concentration (Kara, 2005). Moreover, Heavy metals can cause oxidative stress by the generation of free radicals which can disrupt cell’s inherent antioxidant defenses and can cause cell damage(Das, Das, & Dhundasi, 2008; Mudipalli, 2008).It’s imperative to recover metals from the soli in order to mitigate the contamination of ecosystem as well as environment. But it’s not a facile task with respect to cost and technical complexity (Barceló & Poschenrieder, 2003).

Different kinds of physical, chemical and biological techniques are used for this purpose.The traditional processes are soil incineration, excavation, soil washing, soil flushing, solidification, and stabilization of electro-kinetic systems (Sheoran, Sheoran, & Poonia, 2011). But these physical and chemical methods have some basic limitations like high cost, intensive labor, irreversible changes in soil properties and disturbance of native soil microflora(Ali, Khan, & Sajad, 2013). As a result it's inevitable to find out cost effective, efficient and environment friendly remediation methods for the decontamination of heavy metal-polluted soils.In that scenario, Phytoremediation is a cost effective and eco-friendly technique which can be a good alternative to treat or stabilize hazardous wastes.Plants are supplied with the ability to corrupt the toxinsin their vegetative parts and by this way it's possible to expel, exchange and stabilize heavy metals from the contaminated soil (Salt, Smith, & Raskin, 1998). This process of heavy metal extraction, utilizes a particular group of plants known as hyper-accumulators. The hyper-accumulator plant species have 100 times higher capability to accumulate metals than those typically found in common plants(Choudhury, Islam, Ahmed, & Nayar, 2015). In this study, Indian mustard (Brassica Juncea) and Napier grass (PennisetumPurpureum) were employed to investigate their phytoremediation potential cultivated on tannery sludge. Both plant species are widely available in Bangladesh. Indian mustard is a well-known hyper-accumulator plant for its abnormal heavy metals extraction capacity form the soil (Choudhury, Islam, Ahmed, & Nayar, 2015). In recent,Napier grass (PennisetumPurpureum) has drawn attention in phytoremediation due to its long, deep root system and resistance to an extensive variety of unfavorable climatic and edaphic conditions. Very few researcher investigated Napier grass in phytoremediation of heavy metals cultivated in contaminated sites. Ishii, Hamano, Kang, Idota, &Nishiwaki, 2015 investigated Cadmium phytoremediation capacity of Napier grass cultivated in Japan. Moreover, both Indian mustard and Napier grass were not studied to investigate their performance cultivated in high concentration of chromium contaminated site like tannery sludge.

2. METHODOLOGY

2.1 Collection and preparation samples

Tannery sludge was collected from sludge dumping site of Apex Tannery Ltd, unit-2, Gazipur, Bangladesh. After collection, the sludge was dried to drive out extramoisture and the sample was prepared for seedling.Seeds of Indian mustard & Napier grass were collected from local market. Then the seed samples were sown in two different pots containing sludge sample (Figure 1 and Figure 2). The seeds were grown through proper care and the plant sampleswereharvested after 8^{th} and 12^{th} weeks of plantation. The samples were then washed with distilled water and then sorted into three parts: roots, shoots, and leaves. After grinding and homogenization the samples stored in refrigerated condition (4ºc) in sealed container until the next analysis.

Figure 1: Growth of Napier grass after 8th and 12th weeks

Figure 2: Growth of Indian mustard after 8th and 12th weeks

2.4 Heavy metal analysis

2.4.1Digestion for plant analysis

0.5 g of pulverized sample was taken in a 200 ml beaker and 5 mL of concentrated Nitric acid (HNO_3) was added. The beaker was covered with watch glass and allowed to stand for overnight. After that, the covered beaker was placed on hot plate and heated at 125ºC for one hour and then cooled. The digestion was continued at same temperature with the presence of 1-2 mL of 30% H_2O_2 until the digest was clear. When the digested sample was clear, temperatures was reduced to 80ºC and continue heating until dryness. Then diluted nitric acid and deionized water were added as a ratio of 1:2 to dissolve digest residue and bring sample to final volume of 50 ml. Finally, the sample was filtered through a 0.45 µm filter paper and preserved for the analysis of Cr, Cu, Zn, and Pb by Atomic Absorption Spectrophotometer (AAS) (Shimadzu AA 6800).

2.4.2Digestion for sludge analysis

At first,1g ofpulverized sample (dry weight) was taken to a beaker.10 mL nitricacid was mixed with the slurry and covered with a watch glass. The samples were then heating at 95± 5°C and refluxed for 15 minutes without boiling. Next, the sample was allowed to cool. Then 5mL concentrated HNO_3 was added and refluxed for 30 minutes.HNO_3 was added repeatedly until no brown fumes were emitted that indicates the complete reaction with HNO_3. Sample wasthen allowed to evaporate approximately 5 mL solution without boiling. After cooling the sample, 2 mL of water and 3 mL of 30% H_2O_2 were added and warmed to initiate the peroxide reaction. The addition of 30% H_2O_2 was continued with warming until the effervescence was minimal or until the general sample appearance was unchanged. After the completion of peroxide reaction, the sample volume was reduced to approximately 5 mL. Finally, the sample was cooled, diluted to 15 mL with water and filtered through a 0.45 µm filter paper.Analysis of Cr, Cu, Zn, and Pb was carried out by Atomic Absorption Spectrophotometer (AAS) (Shimadzu AA 6800).

3. RESULTS AND DISCUSSION

3.1 Heavy metal contents in tannery sludge:

Heavy metal concentrations of sludge sample were shown in the Table1. The concentration of metalswas 6881.55 mg/kg, 73.515 mg/kg, 93.6mg/kg and 29.73mg/kg for the Cr, Cu, Zn, and Pb, respectively. Metal concentration order from higher to lower in the sludge is Cr>Zn>Cu>Pb. Relatively higher metal contents were found in other papers for tannery sludge of Bangladesh(Juel, Mizan, & Ahmed, 2017; Juel, Chowdhury, Mizan, & Alam, 2016). This variation may be due to the variation in the tanning process. These metal concentrations of sludge were compared with several international regulatory limits for utilization.

Table 1: Heavy metals concentration in tannery sludge and their permissible limits for utilization

Parameter	**Heavy metal concentration of tannery sludge (mg/kg dry wt.)**			
	Cr	**Cu**	**Zn**	**Pb**
Sludge sample	6845.5±50.2	73±2.5	93±1.5	29±2.5
Permissible limit in Bangladesh [a]	900	800	2500	900
USEPA limit[b]	3000	4300	7500	840

[a]Bangladesh standards and guidelines for sludge management (2015)
[b]USEPA, Land Application of Sewage Sludge. Web link:http//www3.epa.gov/npdes/pubs/sludge.pdf

The present studyshowed that the average concentrations of Copper, Zinc and Lead in tannery sludge were lower than permissible limit where the concentration of chromium exceedsboth Bangladesh and USEPA sludge application limit. Cr concentration was about 8 fold higher than Bangladesh limit and about 3 fold higher than USEPA limit.

3.2 Accumulation of Heavy Metals in Napier and Indianmustard:

Figure 3 showed the accumulation of Cr, Cu, Zn, and Pb per unit dry massof root, shoot, and leaf of Napier grass. The figure also indicates the heavy metal uptake data of 8 and 12 weeks of harvesting. It revealed that all metal extraction except lead by different parts of Napier grass increased from 8 weeks to 12 weeks though the accumulation pattern was not same for these metals. After 8 weeks of harvesting, the concentration of chromium in root portion was 452.1 mg/kg which increased to 1623.1 mg/kg after 12 weeks of plantation, i.e., about a 4 fold higher uptake rate accounted during the last 4 weeks of its growth (Table 2). But, the uptake rate of copper in root was comparatively lower in last 4 weeks than that of chromium. In case of zinc and lead, accumulation rate in all portion of the plant was better within early 8 weeks of growth compared to 12 weeks. This may be happened due to high bioavailable nature of zinc(Juel, Chowdhury, Mizan, & Alam, 2016;Rahman et al., 2012)

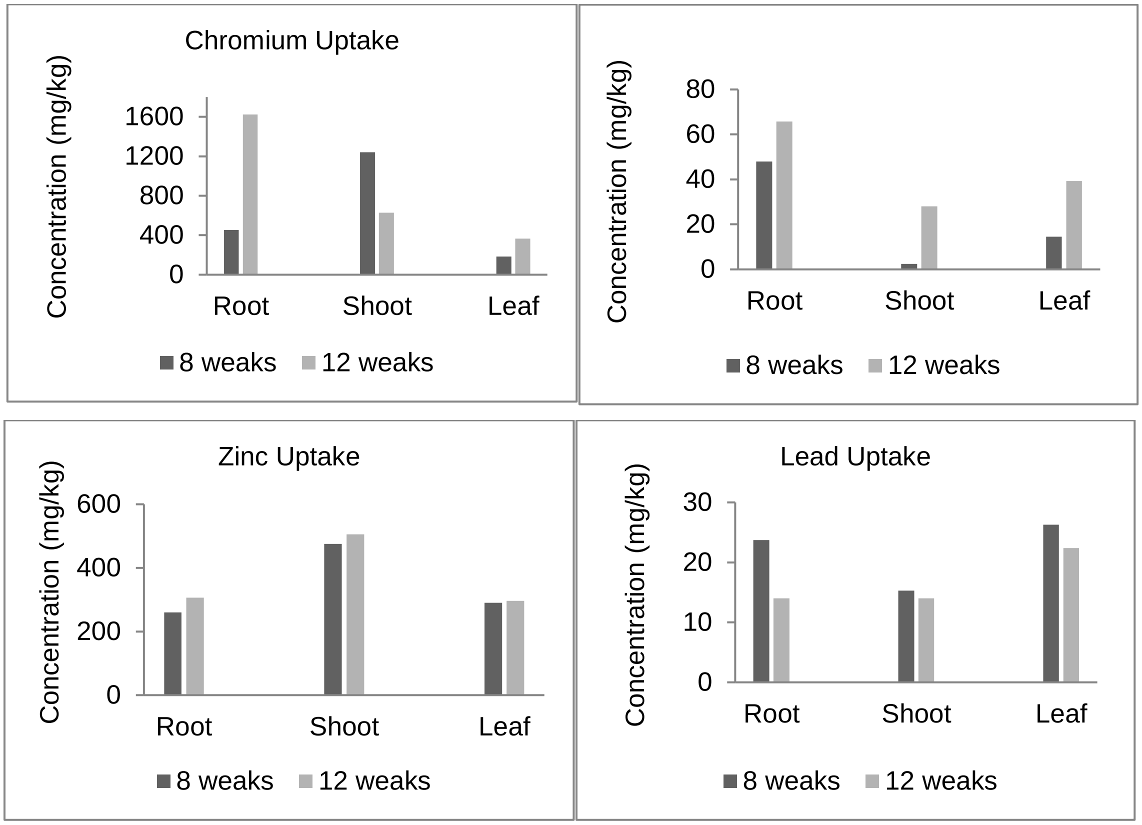

Figure 3:Uptake of different metals after 8 and 12 weeks in various parts of Napier grass

Table 2: Accumulation of heavy metals (mg/kg) in different parts of theNapier grass and Indian mustard after 8 weeks and 12 weeks of plantation.

Parameter		**Heavy metals in the sample (mg/kg)**			
		Chromium (Cr)	**Copper (Cu)**	**Zinc (Zn)**	**Lead (Pb)**
Napier grass (8 weeks)	Root	452.1	48	260	23.7
	Shoot	1241.6	2.4	306.1	15.3
	Leaf	185.6	14.5	290.5	26.3
Napier grass (12 weeks)	Root	1623.1	65.8	475	14
	Shoot	629.7	28	505.9	14
	Leaf	366.4	39.3	296.5	22.4
Indian mustard (12 weeks)	Root	278.5	284.6	235.6	34.8
	Shoot	1457	69.3	222.3	47.3
	Leaf	2169.7	58.1	403	80.3

Figure 4 indicates the difference of Cr, Cu, Zn, and Pb extraction capacity of Napier grass and Indian mustard after 12 weeks of plantation. It indicated that the magnitude and distribution of these metals were different. The total metal concentration order from higher to lower in both plants is Cr>Zn>Cu>Pb, which varied from one part to another. This order of metal uptake by plants was similar with the order of metal concentration found in sludge. Generally, the process of metal uptake and accumulation by plants depend on the available metal concentration in soil, solubility sequences and plant species growing on these soils (Gupta & Sinha, 2007). The transport of metals from roots to shoot, and leaf includes long distance affected by many factors. The accumulation of Cr was better in root of Napier plant whereas leaf of Indian mustard showed highest Cr accumulation. Cr uptake in different parts (root, shoot, leaf and fruit) varies plants to plants. (Gupta & Sinha, 2006) reported that the concentration of metals accumulated in root is higher than shoot of *Sesamumindicum*whereas same author found vice versa for other plants (Gupta & Sinha, 2007). Both plants showed similar pattern in case of Cu, and Pb accumulation, i.e., highest concentration accounted at lower part of plants. Zn was almost evenly distributed at lower and upper parts of both plants. (Choudhury, Islam, Ahmed & Nayar, 2015) also found similar type of pattern in case of Zn distribution in different parts of Indian mustard and Marigold grown at Buriganga river sediment.

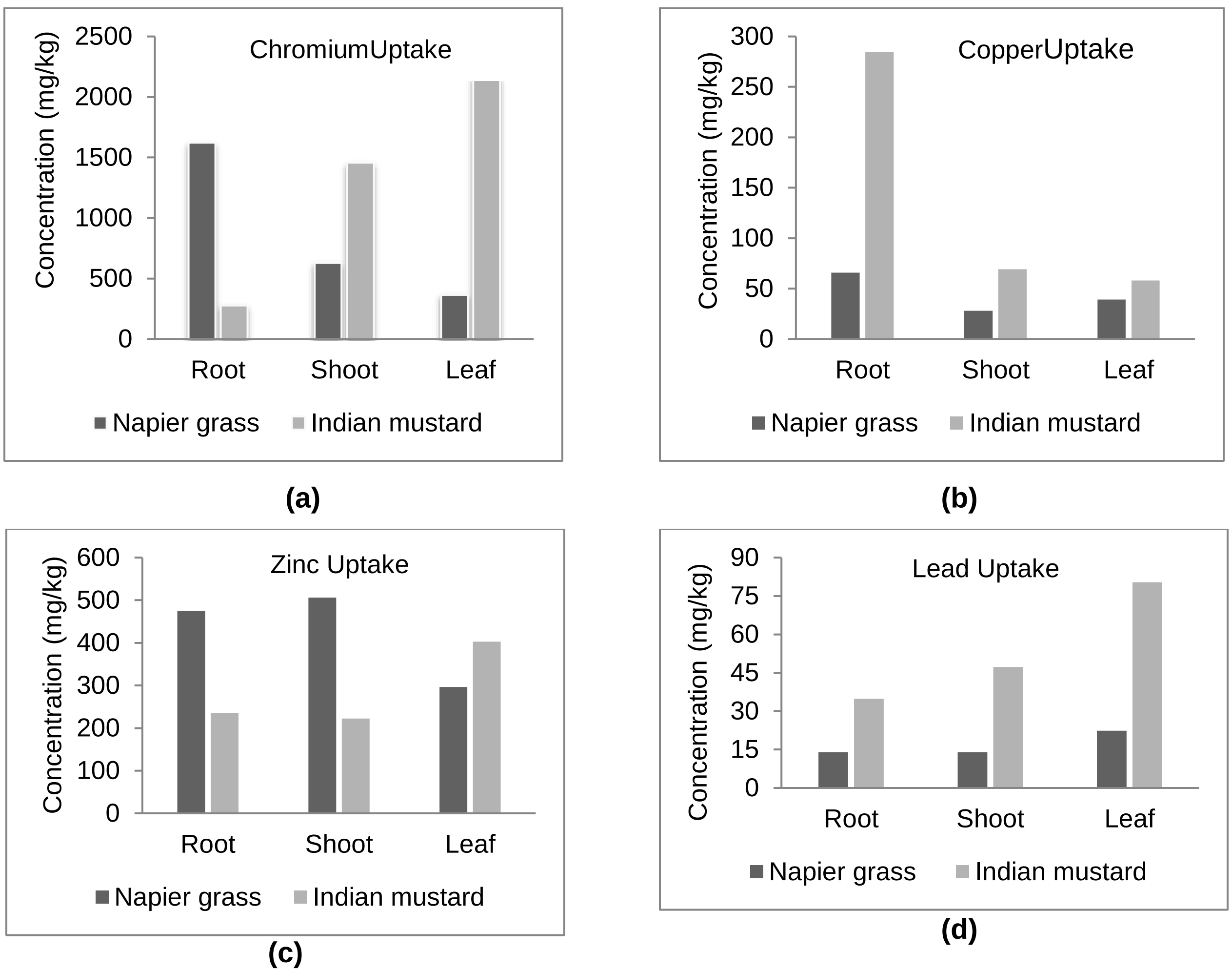

Figure 4: Comparison of heavy metals accumulation in different parts of Napier grass and Indian mustard after 12 weeks of plantation grown on tannery sludge.

The maximum concentration of chromium, copper and lead were accounted in Indian mustard whereas Napier grass showed highest Zn extraction ability.Moreover, Napier grass is one of the highest yielding tropical grass in Bangladesh and it can sustain for a longer periods than Indian mustards. Harvesting of that plant can continue at an interval of 6-8 weeks for 3-5 years[1]. For its longer life period than Indian mustard it may has more extraction capability of heavymetals.

4. CONCLUSIONS

The results of the present research works showed that both Napier grass (Pennisetumpurpureum) and Indian mustard (Brassica juncea) plants were grown well on tannery sludge and accumulatedhigh concentration of heavy metals in different parts of the plant grown ontannery sludge. Indian mustard showed good performance in Cr, Cu, and Pb accumulation whereas Napier grass was good at Cr, and Zn uptake. Chromium accumulated rapidly in Napier grass during last 4 weeks of growth. Although the Cr accumulation rate of Napier grass was comparatively lower than Indian mustard for first 12 weeks of plantation, the total life span of Napier grass was higher than Indian mustard and the metal accumulation rate of Napier grass was in increasing trend with time. Hence, itindicates the higher possibility of heavy metals accumulation than Indian mustard.During the study period, Indian mustard and Napier grass were harvested in the basket for a short period of time and the distribution of the roots of the plants were random within the sludge. Hence no attempt was made to measure the post-harvesting changes of heavy metals in soil. To have an idea about the average reduction of heavy metal concentration extensive sampling should have been required, which was not done in the present study. Assessment of heavy metal concentration in sludge sample and multiple plants sample could have given some information about the average lowering of heavy metal concentration in the sludge after application of phytoremediation.

ACKNOWLEDGEMENT

The authors are thankful to Mr. Mizan, scientific officer, Leather Research Institute for helping in data collection. The authors are highly grateful to Dr. Tanvir Ahmed, Associate Professor, BUET for giving opportunity to determine heavy metals at environmental engineering laboratory, BUET.

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RISK-BASED ASSESSMENT OF HEAVY METAL CONTAMINATED SITE AT KHULNA REGION OF BANGLADESH

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ABSTRACT

Waste disposal site produces leachate which contaminates underlying soil and possesses public health and environmental risk. The present study aimed to evaluate health and environmental risk associated with heavy metals release from soil and leachate of waste disposal site. To these attempts, fifteen soil and leachate samples were collected from distinct locations in and around the waste disposal site at Rajbandh, Khulna, Bangladesh. In the laboratory, concentration of heavy metals of As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Pb and Zn in soil and leachate samples were measured according to standard test methods. To evaluate health risk from soil exposure pathways of ingestion, dermal and inhalation while ingestion and dermal for leachate were considered according to US.EPA guideline (1989). The chronic daily index (CDI), hazard quotient (HQ) and hazard index (HI) were evaluated. Result reveals that the dermal and ingestion were more effective for contributing health risk for inhabitants for soil and leachate, respectively. Results also indicated that child's were more vulnerable than that of adults. Reasonable Maximum Exposure (RME) showed comparatively more risk values than that of Central Tendency Exposure (CTE). Results of Enrichment Factor (EF) for Pb, Zn, Cd, As and Hg indicated that soil was extremely severe enriched. In addition, Potential Ecological Risk Index (PERI) for entire soil samples indicated that the soil was extremely strong ecological risk of the disposal site. In this study, to check the distribution of CDI, HQ and HI in risk model, ArcGIS was performed. For uncertainty analysis of parameters in risk models and risk values, Monte Carlo Simulation (MCS) was performed. Finally, it can be concluded that this study will help in making precise management strategies to avoid or decline of heavy-metal contamination as well as finally environmental and health risk of inhabitants in and around of disposal site.

Keywords: *Disposal site, hazard quotient, hazard index, health risk, enrichment factor, potential ecological risk index, Monte Carlo simulation, spatial distribution.*

1. INTRODUCTION

Contamination problem have been started in the 19th century with the production of dyes and other organic chemicals developed from coal tar industry in Germany. During the 20th century the contamination problem increased drastically with production of steel and iron, lead batteries, petroleum refining and other industrial practices. The period of World War II leads in massive production of wartime products which needed a use of chlorinated solvents, polymers, plastics, paints, metal finishing and wood preservatives. Very little was known about the environmental impact of many of these chemicals wastes until much later (Bedient, 1997). Nowadays around 100000 of chemicals are registered at EU market and more than 1000 of new chemicals are introduced annually. Municipals solid waste (MSW) generation in Khulna city, Bangladesh is estimated to roughly 450 t/d in 2016 (Alam and Hassan, 2013). These MSW are dumped in waste disposals site as the cheapest means of MSW management system. The waste dumped in this process causes various aesthetic and public health problems and also attracts insects, rodents and various disease vectors (Aderemi et al., 2011; Sizirici and Tansel, 2010). The MSW in dumping process, undergoes slow, anaerobic decomposition over a period of 30-50 years and generate substantial amount of leachate with decomposition products, heavy metals and a variety of carcinogens and non-carcinogens chemicals which may seep from the disposal site into underground aquifers and thus polluting water resources (Shenbagarani, 2013). There are also possibilities of surface runoff and/or overflow of leachate to the surrounding lands, ponds, canals and rivers causing surface water quality deterioration (Lee and Jones-Lee, 1994). However, due to the generating huge amount of MSW, most of the developing countries have dumped MSW in the open disposal sites which possess serious impacts to the surrounding area. In addition, contamination of underlying groundwater is one of the major problems regarding open dumping sites (Butt and Oduyemi, 2003; Butt et al., 2008). Evaluating the environmental impact of contaminants in soils must start with a robust determination of their concentration and spatial distribution. GIS based spatial distribution map is generally used to display the distribution of metal contamination has been widely used to assist the interpretation of environmental data and to distinguish between natural and anthropogenic inputs (Manta, 2002).

To date, in the developing countries due to lack of proper design of waste disposal site, leachate is runoff into the surface bodies as well as infiltrated easily through the underlying soil layer and hence pollutant the groundwater which is the most important concern of the human being. To these attempts, it is essential to examine the contamination level of waste disposal site via (soil, leachate, surface and groundwater). The main focused of this study, to evaluate human health and environmental risk from soil and leachate from a selected waste disposal site. For the fulfilment of desired objectives, fifteen soil and leachate samples were collected from distinct locations within a waste disposal site at Rajbandh, Khulna, Bangladesh. The latitude and departure of all the sampling locations was recorded using GPS device. To evaluate health risk assessment from contaminated soil; ingestion, dermal and inhalation pathway, while, for leachate, ingestion and dermal contact were considered according to US.EPA guideline (1989). Then chronic daily index (CDI), Hazard Quotient (HQ) and Hazard Index (HI) via ingestion, dermal contact and inhalation route were evaluated. Health risk assessment procedure provides a clear and systematic form of quantitative (or semi-quantitative) description of health and environmental risk. It is well known that this approach is burdened with various types of uncertainties of different origin and nature. Therefore, the results of risk assessments should always contain both the “number” and the “measure of uncertainty”. The problem is that even if one does attempt to take account of the uncertainty, one does not know a priori what is the probability of getting a given risk value within the specified range of uncertainty. A promising tool for the assessment of risk which provides a means of describing the sensitivity with respect to different exposure factors and evaluating different intervention scenarios is the technique of Monte Carlo simulation (MCS). In this study, to check uncertainty of exposure parameters and risk values, MCS was used. In addition, ordinary kriging (OK) through ArcGIS was performed to distribute CDI, HQ and HI spatially. Here, it can be noted that this study will help in making precise management strategies to avoid or decline of heavy-metal contamination as well as finally environmental and health risk of inhabitants in and around of the selected waste disposal site.

2. METHODOLOGY

The materials and adopted methods of this study are described in the following articles.

2.1 Sampling of Soil and Leachate

Before collecting leachate samples the bottle was washed by distilled water several times. Then the bottles were air or sun dried. Then 2-3 mL a solution was used as preservative. The preservative was prepared by mixing concentrated nitric acid and distilled water at a ratio of 1:1. Then the bottle was kept for 24 hours at room temperature. After that the bottles were prepared for collecting water sample. In this study, fifteen soil and fifteen leachate samples were collected from distinct sampling locations in and around waste disposal site shown in Figure 1. The latitude and departure of each sampling point was recorded GPS device.

2.2 Laboratory Investigations

The collected soil and leachate samples were brought to the laboratory to measure the concentration of heavy metals of Al, Fe, Mn, Cr, Cu, Pb, Zn, Ni, Cd, As, Co and Hg. In order to measure concentration in soil samples it was digested with the help of HNO_3 and H_2O_2. After performing the digestion procedure for soil samples, heavy metals of soil and leachate samples were determined using atomic absorption spectrophotometer (AAS) and the amount of each heavy metal was deduced from calibration graph.

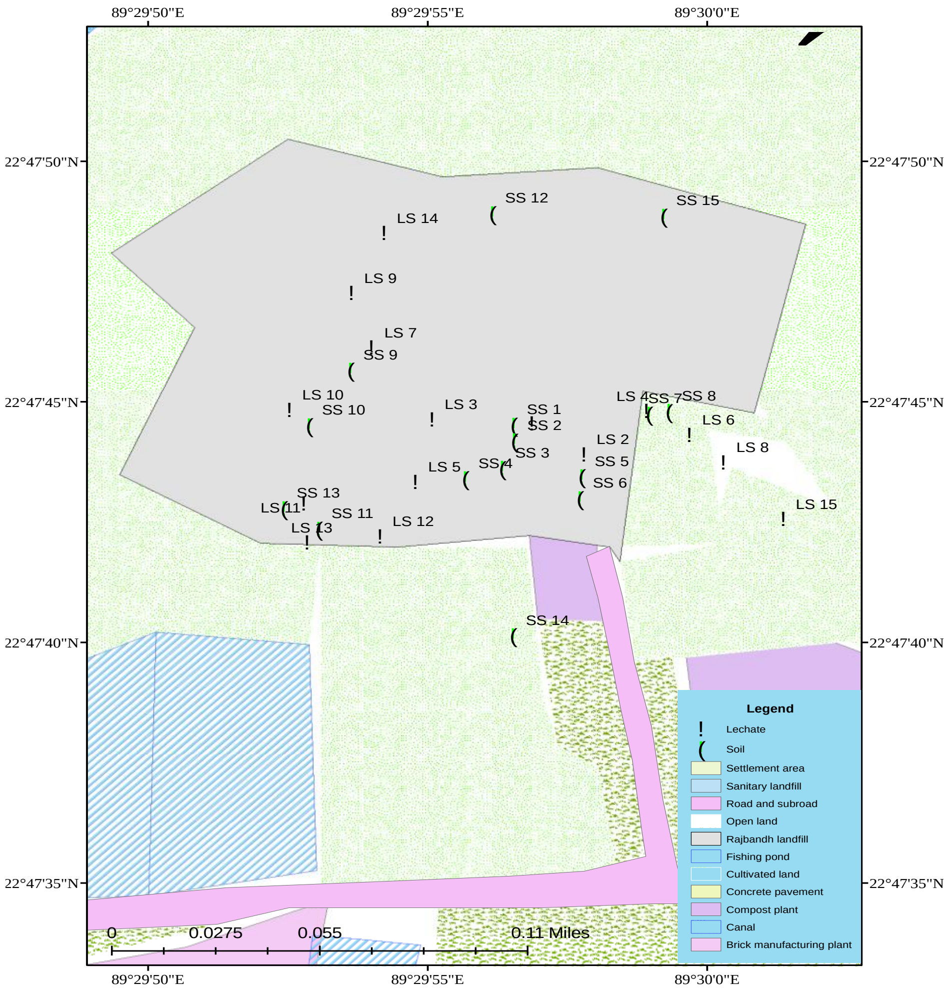

Figure 1: Soil and leachate sampling locations of waste disposal site at Rajbandh, Khulna.

3. RISK ASSESSMENT METHODOLOGY

The health and environmental risks associated from heavy metal contaminated site are presented and hence discussed in the following articles.

3.1 Health Risk Assessment

The health risk assessment comprises of problem identification (contaminated site), exposure assessment (exposure pathways) toxicity assessment (reference doses, potency factor) and risk assessment (cancer and non-cancer risks) and hence discussed in the following articles.

3.1.1 Exposure Assessment

Exposure assessment for human health risk of waste disposal sites has become progressively more important due to the emission of toxicological heavy metals from contaminated soil and leachate. According to US.EPA (1989) guidelines human can be contaminated through three pathways including direct ingestion, dermal contact and inhalation through nose. Among them dermal contact and ingestion are vital in health risk for leachate (US.EPA, 1989; US.EPA, 2004; Wu et al., 2009). In this study, all three pathways were considered for soil samples and ingestion and dermal contact were considered for leachate. In addition, chronic daily intake (CDI) (mg/kg/day) in case of non-carcinogen risk for ingestion, dermal and inhalation for soil were computed using Equation 1, 2 and 3, respectively, was taken from exhibit 6-18 in the Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part A): Interim Final (RAGS) (US.EPA, 1989). In this study, the values of individual factors (ingestion rate, body weight, body surface area, etc.), or parameters (time weighted factors such as contact frequency, contact duration or lifetime exposure) for different groups of inhabitants with various exposure pathways for central tendanct exposure (CTE) and resonable maximum exposure (RME) were followed from RAGS (US.EPA, 1989).

$$CDI_{ing} = \frac{C_s * IR * CF * FI * ABS * EF * ED}{BW * AT} \quad (1)$$

$$CDI_{der} = \frac{C_S * SA * CF * AF * ABS * SM * EF * ED}{BW * AT} \quad (2)$$

$$CDI_{inh} = \frac{C_S * IR * ET * EF * ED}{PEF * BW * AT} \quad (3)$$

Where, CDIing/der/inh = chronic dialy intake through ingestion/dermal contact/inhalation with heavy metals in soil, Cs = heavy metal concentration in soil.

In addition, according to RAGS (US.EPA, 1989), the following exposure models (Equation 4 for ingestion and Equation 5 for dermal) for leachate for the evaluation of non-carcinogen risk were considered.

$$CDI_{ing} = \frac{C_W * CR * ABS_S * ET * EF * ED}{BW * AT} \quad (4)$$

$$CDI_{derm} = \frac{C_W * SA * CF * PC * ABS_S * ET * EF * ED}{BW * AT} \quad (5)$$

Where CDIing/der = chronic dialy intake through ingestion/dermal contact with heavy metal concentration (Cw) in leachate.

In the above exposure models, the exposure paramers stands the meaning of IR= average soil ingestion rate (mg soil/day), CF = conversion factor (10^{-6} kg/mg), FI= fraction ingested from contaminated source (unitless), ABSs=absorption factor (%), SA=skin surface area avialable for contact (cm^2), AF= solid material to skin adherance factor (mg/cm^2), SM= factor for solid materials matrix (%), PEF=particales emition factor (m3/kg), ET= exposure time (hrs/event), EF=exposure frequency (days/year), ED=exposure duration (years), BW=body weight (kg), AT=averaging time (period over which exposure is averaged-days). AT=EDx365 days/year, for non-carcinogens effects of human exposure and LTx365 days/year for carcinogens effects of human exposure, considring an average lifetime, LT of 70 years.

3.1.2 Toxicity Assessment

The risk is divided into two parts from toxicity point of view: cancer risk and non-cancer risk. Essentially all chemicals can cause non-cancer adverse health effects if given at a high enough doses. However, when the dose is sufficiently low, typically no adverse effect is observed. The reference dose (RfD) and potency factor (PF) are considered for non-cancer and cancer risks, respectively and were followed from RAGS (US.EPA, 1989). The first is a qualitative evaluation of the weight of evidence that chemical does or does not cause cancer in humans. Therefore the carcinogen and non-carcinogen thresholds are assigned from the historical database and numerous experiments.

3.1.3 Health Risk Assessment

According to RAGS (US.EPA, 1989), risk models (Equation 6) for evaluating non-cancer risk of soil and leachate were considered. Potential non-carcinogenic risks for exposure to contaminants were assessed by comparison of the calculated contaminant exposures from each exposure route with the reference dose (RfD) (Table 6) in order to produce the hazard quotient (HQ), defined as follows

$$HQ_{ing/derm/inh} = \frac{CDI_{ing/derm/inh}}{RfD_{ing/derm/inh}} \quad (6)$$

Where HQing/derm/inh is hazard quotient via ingestion, dermal contact and inhalation (unitless) and Rf*D*ing/derm/inh is oral/dermal/inhalation reference dose (mg/kg-day). The Rf*D*ing, Rf*D*derm and Rf*D*inh values were obtained from the literature elsewhere (Li and Zhang, 2010; US.EPA, 1989; Wu et al., 2009; Liang et al., 2011).

The HQ is a numeric estimate of the systemic toxicity potential posed by a single heavy metal within a single route of exposure. To evaluate the overall potential for non-carcinogenic effects posed by more than one heavy metal, the computed HQs for each heavy metal are integrated and expressed as a hazard index (HI) by Equation 7 (US.EPA, 1989)

$$HI_{ing/derm/inh} = \sum_{i=1}^{n} HQ_{ing/derm/inh} \quad (7)$$

Where HIing/derm/inh is hazard index via ingestion, dermal or inhalation (unitless).

3.2 Environmental Risk

3.2.1 Enrichment Factor

Enrichment factor (EF) is used to determine the level of contamination by anthropogenic actions based on heavy metal accumulation by soil (Sakan et al., 2009). The EF is calculated consuming the following Equation 8.

$$EF = \left(\frac{C_x}{C_{ref}}\right)_{sediment} \Big/ \left(\frac{C_x}{C_{ref}}\right)_{background} \quad (8)$$

Where, Cx is the concentration of element x, and Cref is the concentration of reference element in soil and the earth's crust, respectively (Kalender and Ucar, 2013). In the assessment of EF, Al was used as the reference heavy metal because this normalizing element assumed less contamination with respect to the other study heavy metals in soil of the selected disposal site. The interest of using Al content is its relationship to the abundance of clay and other aluminium silicates in the sediment. Al contents are influenced by natural sedimentation and the effects of enhanced erosion, but not by pollution (Li and Schoonmaker, 2003; Luoma and Rainbow, 2008). As, Al was selected as reference element hence EF of Al was found to be 1.

3.2.2 Potential Ecological Risk Index

The potential ecological risk factor (PERI) was used as an indicator to check the ecological risk in soil (Hakanson, 1980). This strategy for assessing natural hazard extensively considers the cooperative energy, concentration of heavy metals and biological affectability of those heavy metals (Nabholz, 1991; Singh et al., 2010; Douay et al., 2013). PERI is formed by three basic parts: contamination factor (CF), toxic-response factor (TR) and potential ecological risk factor (ER). In this study, the ER and PERI were calculated using the following Equation 9 and Equation 10, respectively.

$$ER = TR \times CF \quad (9)$$

$$PERI = \sum ER \quad (10)$$

Where, CF of a particular heavy metal is the ratio of heavy metal concentration in soil and the background value of same metal, computed by Equation 11.

$$CF = \frac{C_{Metal}}{C_{Background}} \quad (11)$$

4. RESULT AND DISCUSSION

In this study, the risk-based assessment were performed in terms of health and environmental risks for exposure media of soil and leachate and discussed in followings.

4.1 Health Risk

The health risk were assessed for different exposure pathways of dermal contact, ingestion and inhalation and discussed in followings.

4.1.1 Risk Assessment Observations for Soil

Non-carcinogenic health risk assessment for the selected heavy metals in soil of sampling point 1 (SS1) for children's and adults via the exposure routes of ingestion, dermal and inhalation is summarized in Table 3. Table 3 shows that the CDI for non-cancer risk for child via ingestion was maximum for Pb and sequence of CDI through ingestion was found to be Pb> Zn> Mn> Cu> Co> Cr> As> Ni> Cd. Moreover, for child via exposure route ingestion the HQ were found in the sequence of Pb > Hg > As > Cd > Mn > Cr > Cu >Zn> Co > Ni shown in Figure 2. Figure 2 indicated that Pb, Hg, As and Cd was the main contributor to non-carcinogenic risk for child, whereas, Zn, Ni and Co in soil was the least contributed for non-carcinogenic risk. Result reveals that exposure pathway of dermal for SS1 showed comparatively the higher values of HQ in soil for child in CTE condition than that of other exposure pathways (Figure 2). In addition, result reveals that Pb possess adverse health effect on child in both the CTE and RME condition for entire soil samples. In all soil samples, HI for Pb was found to be greater than 1 where the acceptable limit of HI is 1 for non-carcinogenic health effect. In addition, the HI for the exposure pathway of dermal for soil of child and at CTE and RME condition is shown in Figure 3. Figure 3 depicts RME showed comparatively the higher values of HI than that of CTE in case of child for soil exposures. Moreover, the same results were also found for adult.

The values of non-cancer risk with various exposure pathways for different environmental media are shown in Figure 4. Figure 4 reveals that the exposure pathway of dermal for entire soil (SS1 to SS15) contributed most of the non-cancer risk for child, In addition, the pathway of ingestion for entire leachate (LS1 to LS15) showed comparatively the higher contribution for non-cancer risk of child than that of dermal contact pathway (Figure 4).

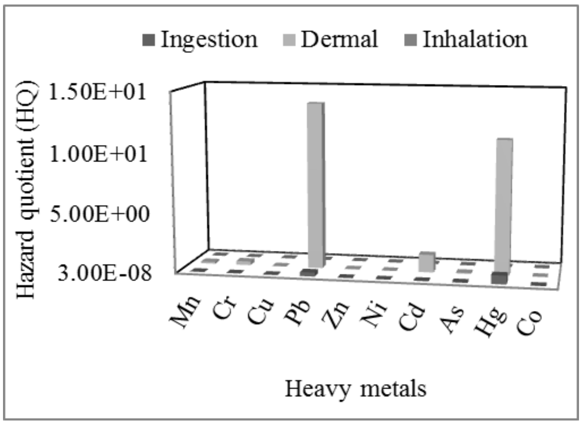

Figure 2: Hazard quotient (HQ) of child for soil of SS1 of CTE condition.

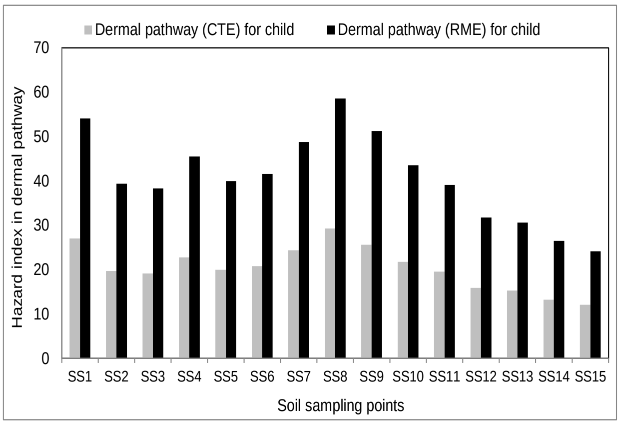

Figure 3: HI for dermal pathway in soil of child in CTE and RME condition.

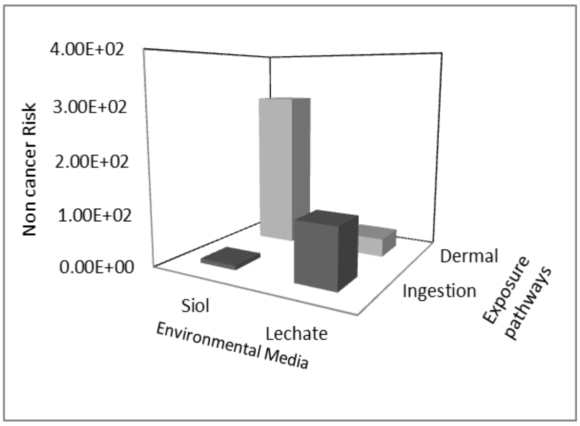

Figure 4: Vertical bar chart illustration of risk summary results for child at CTE condition.

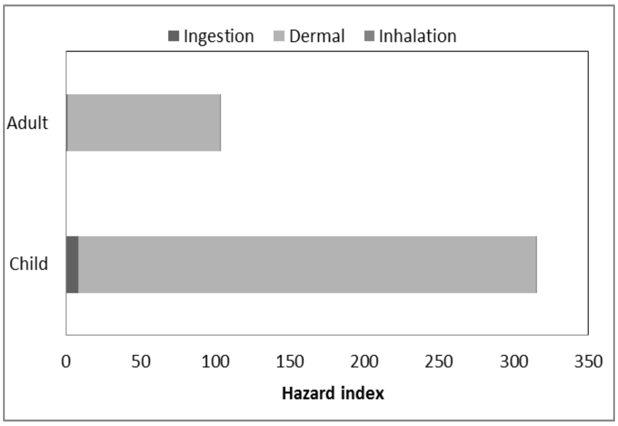

Figure 5: Risk summary results of inhabitants for soil in CTE condition.

The variation of HI for child and adult for entire soil in CTE condition for various pathways is shown in Figure 5. Figure 5 depicts that for both the child and adult, the exposure pathway of dermal was the main dominant pathway for contributing non-cancer risk for inhabitants. Moreover, it was clear from Figure 5 that the HI value for child was comparatively higher than that of adult for all exposure pathways considered in this study. It indicated that the Childs were more vulnerable to health risk than that of adults of the selected disposal site.

4.1.2 Risk Assessment Observations for Leachate Samples

The health risk for heavy metals in LS1 for inhabitants for various pathways is summarized in Table 4. The CDI for child via dermal was maximum for Fe (Table 4). In addition, HQ via dermal indicated that Mn, Pb, As, Cd and Cr in leachate was the main contributor to risk for child. Result reveals that Fe has a major contribution in possessing adverse health risk for child alongside with other contributor of As, Ad and Mn. Figure 6 depicts variation of HI of child and adult of LS2 at CTE condition. Figure 6 displays the greater value of Fe than other heavy metals. Figure 6 showed higher values of HI for child than that of adult in all heavy metals indicated child was suffered more than adult due to the adverse effect of heavy metals in leachate.

Table 3: Summary of health risk assessment for selected heavy metals in soil of BH2 for CTE condition during dry season

Heavy metals	Child(CDI)			Adult(CDI)			HQ Child			Total (HI)	HQ Adult			Total (HI)
	Ingestion	Dermal	Inhalation	Ingestion	Dermal	Inhalation	Ingestion	Dermal	Inhalation		Ingestion	Dermal	Inhalation	
Mn	1.72E-04	2.65E-04	2.02E-08	1.62E-05	8.85E-05	3.82E-09	3.74E-03	1.44E-01	1.41E-03	1.49E-01	3.53E-04	4.81E-02	2.67E-04	4.87E-02
Cr	1.04E-05	1.61E-05	1.23E-09	9.85E-07	5.38E-06	2.32E-10	3.48E-03	2.68E-01	4.30E-05	2.72E-01	3.28E-04	8.96E-02	8.10E-06	9.00E-02
Cu	1.20E-04	1.85E-04	1.41E-08	1.13E-05	6.19E-05	2.67E-09	3.01E-03	1.55E-02	3.52E-07	1.85E-02	2.83E-04	5.16E-03	6.64E-08	5.44E-03
Pb	5.01E-04	7.72E-04	5.89E-08	4.72E-05	2.58E-04	1.11E-08	3.58E-01	1.47E+01	1.67E-05	1.51E+01	3.37E-02	4.91E+00	3.16E-06	4.94E+00
Zn	2.60E-04	4.01E-04	3.06E-08	2.45E-05	1.34E-04	5.77E-09	8.66E-04	6.68E-03	1.02E-07	7.55E-03	8.17E-05	2.23E-03	1.92E-08	2.31E-03
Ni	7.03E-06	1.08E-05	8.27E-10	6.63E-07	3.62E-06	1.56E-10	3.51E-04	2.01E-03	4.01E-08	2.36E-03	3.31E-05	6.70E-04	7.57E-09	7.03E-04
Cd	6.56E-06	1.01E-05	7.72E-10	6.18E-07	3.38E-06	1.46E-10	6.56E-03	1.01E+00	1.35E-05	1.02E+00	6.18E-04	3.38E-01	2.55E-06	3.38E-01
As	8.90E-06	1.37E-05	1.05E-09	8.40E-07	4.58E-06	1.98E-10	2.97E-02	1.12E-01	3.49E-06	1.41E-01	2.80E-03	3.73E-02	6.58E-07	4.01E-02
Hg	6.62E-05	1.02E-04	7.79E-09	6.24E-06	3.41E-05	1.47E-09	2.21E-01	3.40E+00	9.08E-05	3.62E+00	2.08E-02	1.14E+00	1.71E-05	1.16E+00
Co	1.25E-05	1.93E-05	1.47E-09	1.18E-06	6.45E-06	2.78E-10	6.27E-04	1.21E-03	2.58E-04	2.09E-03	5.91E-05	4.03E-04	4.87E-05	5.11E-04

Table 4: Summary of health risk assessment for selected heavy metals in LS2 for CTE condition during dry season

Heavy metals	Child(CDI)		Adult(CDI)		HQ Child		Total (HI)	HQ Adult		Total (HI)
	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal		Ingestion	Dermal	
Mn	8.84E-03	9.08E-04	1.67E-03	3.03E-04	1.92E-01	4.94E-01	6.86E-01	3.62E-02	1.65E-01	2.01E-01
Cr	5.73E-05	1.18E-05	1.08E-05	3.93E-06	1.91E-02	1.96E-01	2.16E-01	3.60E-03	6.56E-02	6.92E-02
Cu	1.31E-03	1.35E-04	2.48E-04	4.51E-05	3.29E-02	1.13E-02	4.41E-02	6.20E-03	3.76E-03	9.96E-03
Pb	9.51E-04	9.78E-06	1.79E-04	3.26E-06	6.79E-01	1.86E-01	8.66E-01	1.28E-01	6.22E-02	1.90E-01
Zn	1.36E-03	8.36E-05	2.56E-04	2.79E-05	4.52E-03	1.39E-03	5.91E-03	8.52E-04	4.65E-04	1.32E-03
Ni	6.13E-05	1.26E-06	1.16E-05	4.21E-07	3.06E-03	2.33E-04	3.30E-03	5.78E-04	7.79E-05	6.56E-04
Cd	1.60E-04	1.64E-05	3.01E-05	5.48E-06	1.60E-01	1.64E+00	1.80E+00	3.01E-02	5.48E-01	5.78E-01
As	2.13E-04	2.19E-05	4.03E-05	7.33E-06	7.12E-01	1.78E-01	8.90E-01	1.34E-01	5.96E-02	1.94E-01
Fe	4.63E-02	4.76E-03	8.72E-03	1.59E-03	5.14E+00	6.79E-03	5.15E+00	9.69E-01	2.27E-03	9.71E-01

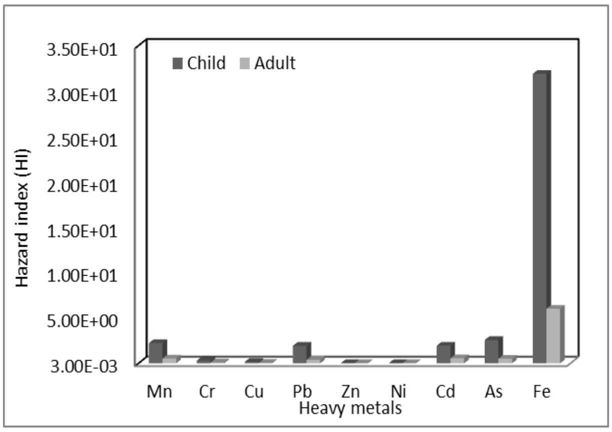

Figure 6: Hazard index of child and adult of LS7 of RME condition.

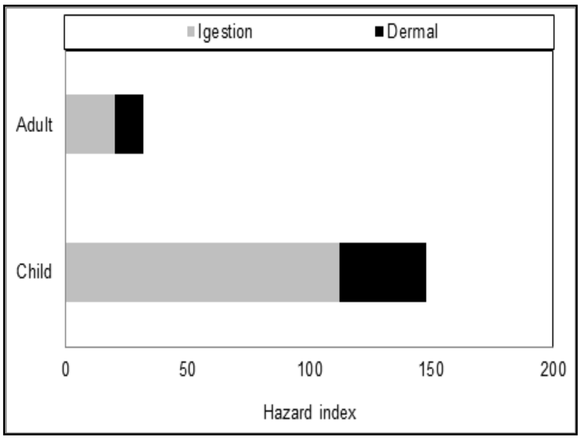

Figure 7: HI for inhabitants in different pathways for leachate in CTE condition

The variation of HI for child and adult for entire leachate samples in CTE condition for various pathways is shown in Figure 7. Figure 7 depicts that for both the child and adult, the exposure pathway of ingestion was the main dominant pathway for contributing non-cancer risk for inhabitants. Moreover, Figure 5 also depicts that the HI value for child was comparatively higher than that of adult for all exposure pathways considered in this study. It indicated that the child's were more vulnerable to health risk than that of adults of the selected disposal site. The health risk summary of entire soil and leachate for child at CTE condition are presented in Figure 8. Figure 8 depicts that soil was the main contributor (about 68%) for human health risk especially for child in CTE condition. In addition, for adult, soil contributed around 76 % of health risk.

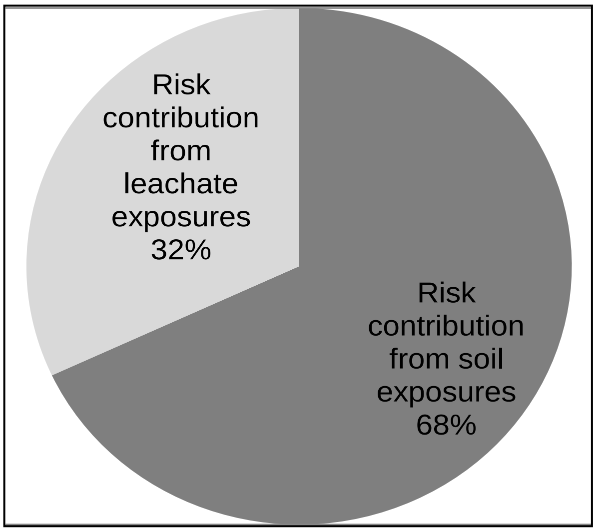

Figure 8: Pie chart illustration of risk summary results of different environmental media for child (CTE).

4.2 Environmental Risk

In this study, environmental risk was assessed interms of enrichment factor and analysis of potential ecological risk assessment and hence discussed in the following articles.

4.2.1 Enrichment Factor

The results of EF values in soil of all heavy metals considered in this study are represented in Figure 9. Figure 9 reveals that the values of EF for the heavy metals of Pb, Zn, Cd, As and Hg in soil were greater than 50 and lies in the class of extremely severe enriched. The value of Co indicates very severe enrichment where the EF value of Fe lies in the class of minor. In addition, the value of EF for Cu indicated the severe enrichment. The value of Cr and Ni indicated moderate enrichment. While the EF value Na shows no enrichment.

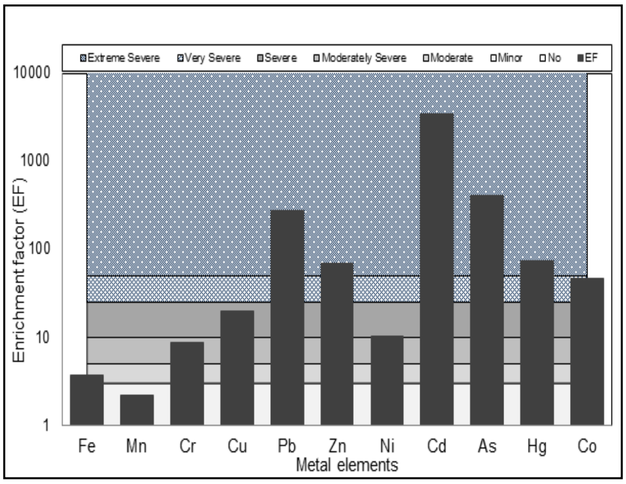

Figure 9: Classification of the level of contamination of soil based on EF in soil.

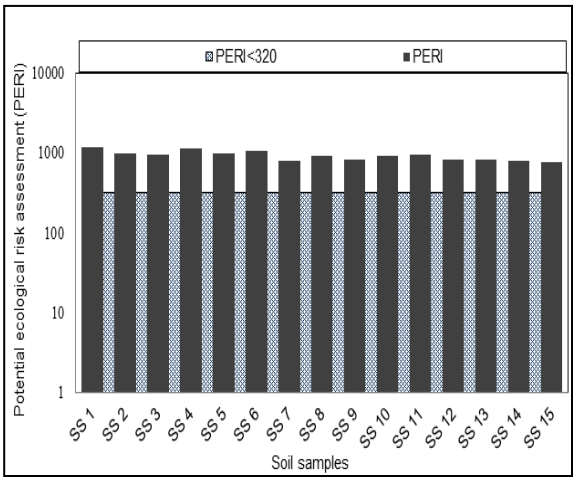

Figure 10: Variation of computed PERI in soil of boreholes of waste disposal

4.2.2 Potential Ecological Risk Index

With regard to the assessment method proposed by Hakanson (1980), ecological risk index (ER) of a single heavy metal as well as potential ecological risk index (PERI) was computed by adding ER for each heavy metal. In addition, ER is computed from contamination factor (CF) and toxic-response factor (TR) for each heavy metal. In addition, Figure 10 represents the variation of computed PERI for all soil sampling points. Hakanson (1980) stated that soil sample having the value of PERI less than 40, 40 to 80, 80 to 160, 160 to 320 and greater 320 indicated the ecological risk is slight, medium, strong, very strong and extremely strong, respectively. Figure 10 depicts that the magnitude of PERI for entire soil samples were found above 320 indicated extremely strong ecological risk by the heavy metals presence in soil for all the soil sampling points (boreholes) of the selected waste disposal site.

4.3 Uncertainty analysis (1-D Monte Carlo Simulation)

In Monte Carlo simulation (MCS), random values are selected for each of the tasks, based on the range of estimates. The model is calculated based on these random values. The result of the model is recorded, and the process is repeated. A typical MCS calculates the model hundreds or thousands of times, each time using different randomly-selected values. When the simulation is complete, we have a large number of results from the model, each based on random input values. These results are used to describe the likelihood, or probability, of reaching various results in the model. The analysis of uncertainty of exposure parameters (ED) and risk outputs (HI) were performed using 1-D MCS @RISK 7.5 with 10000 iterations. Figure 11 shows an input distribution for exposure duration (ED) for soil dermal contact (years).

In Figure 11, the height of the bars (the y-axis) represents the relative frequency of eposure durationof the eposed population and the spread of the bars (the x-axis) is the varying amounts of eposure duration (years). The y-axis for a PDF is referred to as the probability density, where the density at a point on the x-axis represents the probability that a variable will have a value within a narrow range about the point. This type of graph shows, for example, that there is a greater area under the curve (greater probability density) in the 4.5815-5.6820 years range than 3.3036-4.5815 or 5.6820-6.6839 years. That is, most inhabitants reported to be exposed near the disposal site. Graphical representation of risk parameter (HI) is shown in Figure 12. The probabilistic calculation of risk involves random sampling from each of exposure variable distributions.

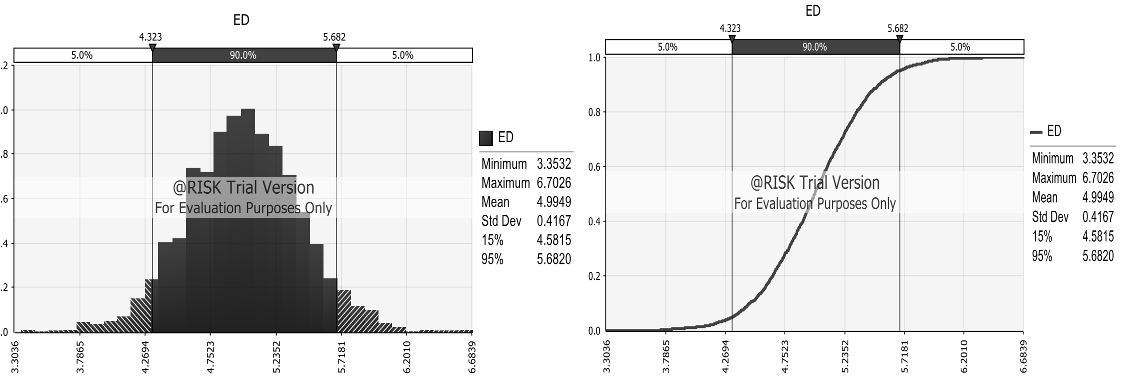

Figure 11: Normal distribution of ED of (a) Bell-shaped curve represents the PDF and (b) S-shaped curve represents the CDF.

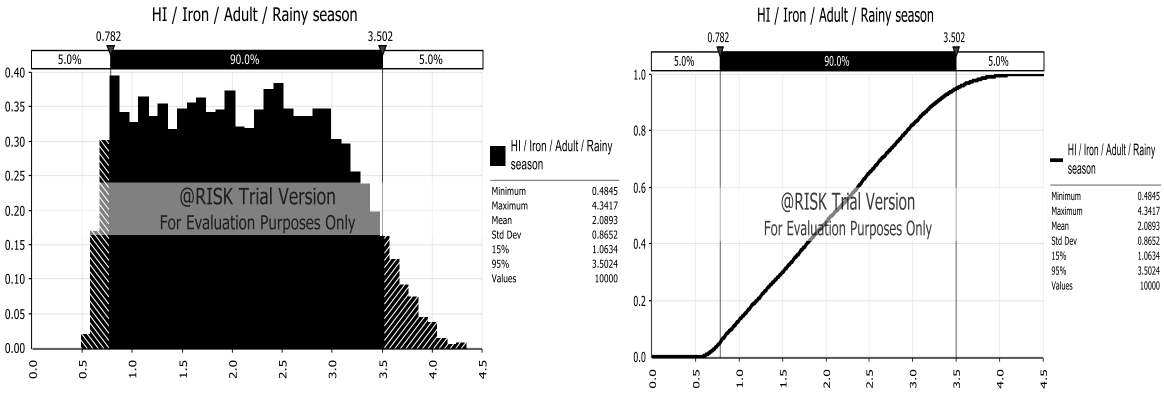

Figure 12: Normal distribution of HI of Iron in LS 2 for Adult as (a) Bell-shaped curve represents the PDF and (b) S-shaped curve represents the CDF.

4.4 Spatial Distribution of Hazard Index

Figure 13 illustrates the spatial distribution of HI of Pb for child and adult in RME condition. Figure 13 reveals that not a single collection point having HI value less than one. The deep black area indicated the possible maximum distribution of HI values for child in RME condition while the white one indicated less distribution of HI. Whatever for adult the distribution pattern was found similar to the child one but the HI value was found less than unity in all points for Pb. It can be summarised that the child near the disposal site possess to extreme health risk.

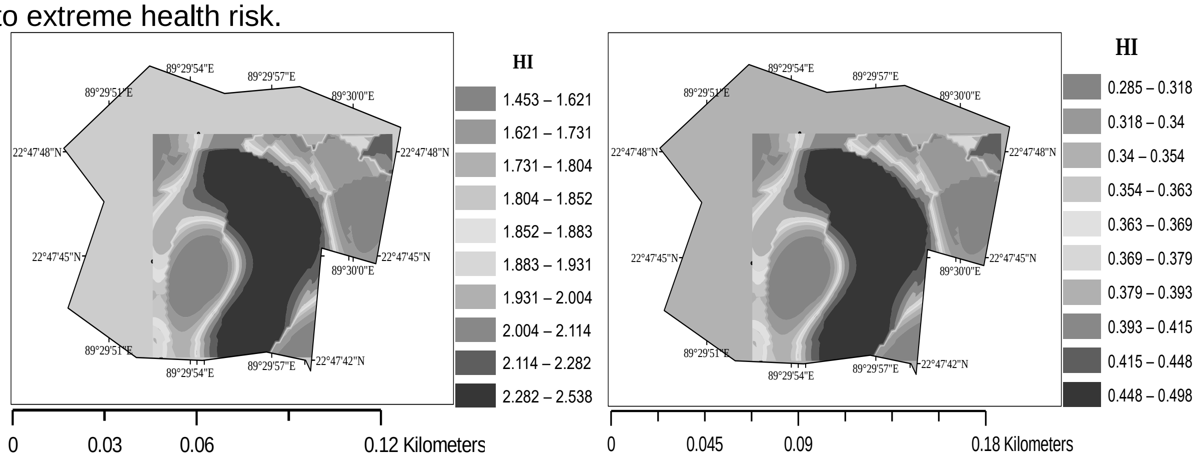

Figure 13: Spatial distribution of HI for leachate samples.

5. CONCLUSIONS

Result reveals that the heavy metals of Pb, Hg, As and Cd in soil and leachate were the mainly contributed for non- carcinogenic risk for child's and adults. In addition, result reveals that Pb possess adverse health effect on child in both the CTE and RME condition for entire soil samples. In all soil samples, HI for Pb was found to be greater than 1 where the acceptable limit of HI is 1 for non- carcinogenic health effect. In addition, the HI for exposure pathway of dermal for soil of child at CTE and RME condition showed comparatively the higher values. Result reveals that the dermal and ingestion were more effective for contributing health risk for inhabitants for soil and leachate, respectively. Results also represents that Childs were more vulnerable than that of adults. Results of EF for Pb, Zn, Cd, As and Hg indicated that soil was extremely severe enriched. In addition, PERI for entire soil samples indicated that the soil was extremely strong ecological risk of the disposal site. Based on spatial distribution, it can be summarised that the child's near the disposal site possess extreme health risk. The result of MCS was given in the form of a probability distribution of risk. The idea of MCS in health risk assessment concerning the exposure to heavy metals in soil and leachate was illustrated in the population living in the vicinity of the selected waste disposal site, taken as an example.

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APPLICATION OF MULTIVARIATE AND GEOSTATISTICAL APPROACHES IN ANALYSIS AND ASSESSMENT OF HEAVY METAL SOURCES IN SOIL OF WASTE DISPOSAL SITE AT KHULNA

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ABSTRACT

The main focused of the study was to identify the possible sources of contamination of metal elements in soil of waste disposal site. To theses endeavor, sixty soil samples were collected at a depth of 0-30 cm from the existing ground surface from a selected waste disposal site at Rajbandh, Khulna, Bangladesh. In the laboratory, the concentrations of metal elements of Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mn, Na, Ni, Pb, Sb, Sc, Sr, Ti, V and Zn in soil were measured. Descriptive and multivariate statistics including Pearson's correlation, principal component analysis (PCA) and agglomerative hierarchical clustering (AHC) were used. In addition, Inverse distance weighting (IDW) with power of 1-5 through ArcGIS were performed. Results of descriptive statistics reveals that concentrations of metal elements followed almost same pattern during both the dry and rainy seasons. Results of Pearson's correlation depicts that the sources of metal elements were almost the same and these metal elements might be derived from the waste accumulation activity. In addition, PCA reported that generation of Al, As, Ba, Ca, Cd, Co, Fe, K, Na, Ni, Sb, Sc, Sr, Ti and V from anthropogenic activities, while, Cu, Hg, Mn, Pb, and Zn from natural sources and Cr from both sources in dry season. In rainy season, Al, Ba, Ca, Co, Cu, Fe, Ni, Sb, Sc, Sr, Ti and V generated from anthropogenic activities whereas As, Cr, Hg, Mn, K and Na from natural sources and Cd, Pb and Zn from both sources.These results is in agreement with output obtained from AHC. In addition, patial distribution of waste disposal site epitomized most contaminated hotspots were found to be the nearest soil sampling point with respect to the central point of the selected disposal site.

Keywords: *Disposal site, Multivariate analysis, spatial distribution, Inverse Distance Weighting, Khulna*

1. INTRODUCTION

In recent periods, existence of metal elements in soil has become a foremost concern that arise necessities of monitoring the endangerment of soil by contamination of metal elements. Non-biodegradability characteristics and elongated biological half-lives of metal elements for abolition, their accretion in nutrition chain will obligate a substantial effect on all living element. The huge quantities of municipal solid waste (MSW) in waste disposal site going through distinct biological, physical and chemical processes for decomposition, produced leachate and contaminated soil which creates vulnerable to the environmental components and nearby inhabitants (Nriagu and Pacyna, 1988). The metal elements in soil are either derived from natural parent rock materials or anthropogenic activities such as urban-industrial development, landfill management, vehicular emissions, fossil fuel combustion and agricultural practices (Tahir et al., 2007). Contamination of soil occurs when the presence of toxic chemicals, pollutants or contaminants from fertilizers, organic wastes, organic pesticides, with high concentrations in soil (Jia et al., 2010). Ingestion of food grown in contaminated soil and intake of water from contaminated water bodies cause great risk to plants, wildlife, humans and of course for the soil itself. The application of multivariate statistical approaches such as principal component analysis (PCA), agglomerative hierarchical clustering (AHC) permit a better technique for classification, modeling and interpretation of soil monitoring data (Stanimirova et al., 2006). In addition, spatial distribution is essential for assessing the effect of metal elements in soil and to delineate contamination zones using geographic information system (GIS) techniques (Omran and Razek, 2012).

Khulna is one of the fast growing commercial cities in Bangladesh. Most of the MSW are disposed in waste disposal site at Rajbandh, the only authorized waste disposal site of Khulna city. Due to inadequate management practices and the low standard sanitary landfill, the leachate percolates into the groundwater and contaminates the groundwater source which is a potential threat to next generation. Thus, necessities arise to take steps for proper disposal of MSW as well as maintenance of MSW disposal site in Khulna. To theses endeavour, sixty soil samples were collected at a depth of 0-30 cm from the existing ground surface and the relevant metal elements of Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mn, Na, Ni, Pb, Sb, Sc, Sr, Ti, V and Zn were measured in the laboratory. Descriptive and multivariate statistics including Pearson's correlation, PCA and AHC were used to ascertain the possible pollutant sources of metal elements and their correlation. In addition, Inverse distance weighting (IDW) with power 1 to 5 were used to interpolate the concentrations of metal elements of unsampled locations and provide soil map to sensitize their spread over the study area using ArcGIS software. The purpose of the study are to (i) develop correlations of metal element and their possible sources of contamination in soil of waste disposal site (ii) visualize the level of contamination and distribution of metal element spatially in the soil of the waste disposal site.

2. METHODOLOGY

The sampling of soil samples, laboratory investigations and application of various multivariate and Geostatistical approaches are presented and hence discussed in the following articles.

2.1 Soil Sampling

In this study, sixty soil samples (forty for dry season and twenty for rainy season) were collected at a depth of 0-30 cm from the existing ground surface of the waste disposal site. Moreover, the sampling points were selected maintaining gradual addition of about 10 m distance from the first borehole (BH-1) located at the centre of the waste disposal site by the subsequent boreholes. In contrast, the first borehole of rainy season (BH-41) is about 30 m apart from BH-1 which is the centre of the site and maintains a gradual addition of about 15 m in selecting other following boreholes. Figure 1 depicted the soil sampling locations in waste disposal site at Rajbandh, red circles indicated sampling points in dry season and blue triangles indicated sampling points in rainy season.

2.2 Laboratory Investigations

10 g of each soil sample was taken into a 100 mL conical flask washed with deionized water prepared by adding 6 mL HNO3/HClO4 acid in ratio 2:1 and left overnight. Each sample was kept into the temperature of 150°C for about 90 minutes followed by 230°C for 30 minutes. Subsequently, HCl solution was added in ratio 1:1 to the digested sample and re-digested again for another 30 minutes. The digested sample was washed into 100 mL volumetric flask and mixture obtained was cooled down to room temperature. The concentrations of metal elements in this digested solution were determined using atomic absorption spectrophotometer (AAS) and the amount of each heavy metal was deduced from the calibration graph and the concentration of the metal elements were reported in mg/kg.

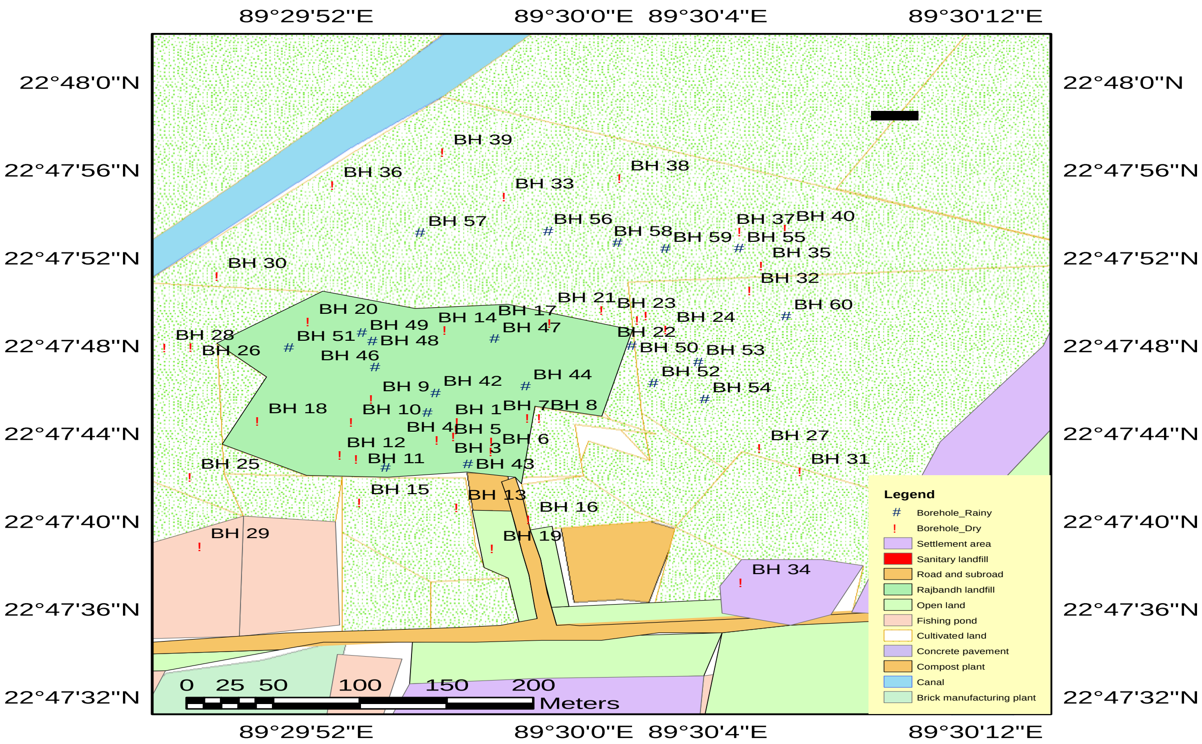


Figure 1: Map showing of soil sampling locations in waste disposal site

2.3 Descriptive Statistics

In this study, the descriptive statistics including normality test such as shapiro-wilk (S-W) test and kolmogorov–smirnov (K-S) test was performed using Statistical Package for the Social Sciences (SPSS) software. In addition, the normal quantile- quantile (QQ) plot was also schemed to check the distribution of data points more accurately. In this study, the conventional statistical parameters in terms of mean, maximum, minimum, median, SD, CV, skewness and kurtosis for two seasons (i.e. dry and rainy) was analysed to check the variability of metal elements due to anthropogenic activities as well as from natural parent materials as well as to show the seasonal variation of metal elements in soil.

2.4 Multivariate Statistics

In this study, the multivariate statistical analysis including Pearson's correlation, principal component analysis (PCA) and Agglomerative hierarchical clustering (AHC) were used and hence described in the following articles.

2.4.1 Pearson's correlation

In this study, Pearson's correlation was performed using XLSTAT to examine the association of metal elements in soil irrespective to their sources. In this study, the value of correlation coefficient, r, was computed using the following Equation 1 considering one dataset $\{x_1,\ldots,x_n\}$ containing n values and another dataset $\{y_1,\ldots,y_n\}$ containing n values.

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})\,(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}} \qquad (1)$$

In this study, the null hypothesis (H_0) and alternative hypothesis (H_1) of the significance test for correlation was expressed depending on a two-tailed test. Two-tailed significance test are as follows: H_0: r = 0 ("the correlation coefficient is 0, there is no association"); H_1: r > 0 ("the correlation coefficient is not 0, a nonzero correlation could exist").

2.4.2 Principal Component Analysis

PCA is probably the most popular multivariate technique that is used to analyse a dataset of inter-correlated quantitative dependent variables. The principal components (PCs) with variables, the high loadings (eigenvalues) depicted greater importance from the contamination sources, whereas, lower loadings (eigenvalues) point to lower importance with regards the sources of these contaminations (Lee et al., 2006; Zou et al., 2015). In this study, the PCA method was performed sequentially, first by information extraction in the input space (with n-dimensions) to determine the directions of which the input variables display the most substantial variability. The PC coefficients and the eigenvalues $(\lambda_i > 0, i = 1,2, \ldots..n)$ 0 for the correlation matrix $(C = E\{xx^T\})$ with respect to their eigenvectors $(e_i > 0, i = 1,2, \ldots..n)$ 0, is called the loadings were then calculated which gives a new set of variables that explains the variability in the original dataset; the first PCs retained a greater proportion of the total variance, consequently leading to effective and practical dimensionality reduction exercise. the following equation was used through XLSTAT to compute the variance.

$$\left.\begin{aligned} PC1 &= a_1x_1 + a_2x_2 + \cdots \ldots.. + a_nx_n \\ PCn &= \sum_{j=1}^{n} a_{1j}x_j \end{aligned}\right\} \qquad \ldots\ldots\ldots.. (2)$$

where; a_{1j} = eigenvectors obtained from the correlation matrix; x_j = input variables

2.4.3 Agglomerative Hierarchical Clustering

AHC accomplishes successive fusions of data into clusters where each object initially starts out as its own cluster. It also differs to the extent that different measures are employed to measure the distance between clusters. In this study, dendrograms were the output of AHC which display the cluster hierarchy and the distances at which the clusters were joined helpful to select an appropriate number of clusters for the dataset using XLSTAT. Cluster was selected by cutting the dendrogram where there is a significant jump in the distance of the cluster joins which is equivalent to selecting the knee point in a k-Means curve.

2.5 Spatial Distribution of Metal elements

The interpolated map using geostatistics provides the best and simpler way to comprehend spatial distribution of metal elements to recognize the risk of contamination zone depending on the concentrations plotted with the optimal interpolation model. Soil maps convey information about the soil to land users. In the present investigation, the selection of deterministic interpolation technique such as IDW was made based on the extent of similarity with a known scattered set of points. The assigned values to unknown points are calculated with a weighted average of the values available at the known points (Pebesma et al., 2007). With the increase in distance, the weight of interpolation decreases (Gotway et al., 1996) and weighting power that decides how the weight decreases as the distance increases. The value of the assigned power is one of the important factor of IDW interpolation method. In this study, the technique of IDW with integer power of 1 to 5 was performed to give more weight to the closest sampled points. Additionally, the size and number of neighborhood also affect the accuracy of the interpolation techniques (Isaake and Srivastava, 1989). The prediction of unsampled points was measured using the following Equation 3 by ArcGIS software.

$$Z_0 = \frac{\sum_{i=1}^{N} z_i d_i^{-n}}{\sum_{i=1}^{n} d_i^{-n}} \qquad (3)$$

Where, Z_0 is the estimation value of variable z in point i, Z_i is the sample value in point i, di is the distance of sample point to estimated point, N is the coefficient that determines weigh based on a distance., n is the total number of predictions for each validation case. In this study, estimations were made using different integer powers of 1 to 5.

3. RESULTS AND DISCUSSION

The findings of the study are illustrated in the following sections.

3.1 Analysis of Heavy Metal Concentration in Soil

For better result, it was found from normal QQ plot that almost all the metal elements in soil were distributed normally except As for both the dry and rainy seasons. Thus, log transformation was applied to As for normal distribution. The descriptive statistics of heavy metal concentrations in soil of waste disposal site in the dry season is provided in Table 1.

Table 1: Descriptive statistics of metal elements in soil in dry season (n=40)

Metal	Min	Max	Median	Mean	CV (%)	SD	Skewness	Kurtosis
Al	158.35	874.78	458.46	490.25	40.31	197.61	0.303	-0.727
Ca	100.20	318.00	173.19	183.80	33.55	61.67	0.577	-0.793
Cd	2.55	7.03	4.46	4.55	24.99	1.14	0.387	-0.530
Cu	2.92	16.45	4.82	6.20	59.41	3.68	1.541	1.110
Fe	733.19	1987.76	1386.50	1363.94	25.67	350.15	-0.081	-1.199
Hg	1.98	9.20	4.01	4.63	44.63	2.07	0.797	-0.460
K	104.88	460.33	316.37	292.00	35.98	105.06	-0.416	-0.937
Ni	2.56	8.06	4.71	4.83	33.02	1.60	0.409	-0.984
Pb	21.29	90.55	33.94	37.61	36.34	13.67	1.840	4.393
Ti	643.33	1937.3	1223.8	1221.2	33.27	406.26	0.160	-1.198
Zn	22.79	50.76	34.64	34.57	22.11	7.65	0.612	-0.116

Result from descriptive statistics reveals that the CV varies 22.11% of Zn to 59.41% of Cu in dry season as well as 18.25% of Zn to 77.25% of Mn in rainy season, respectively, which indicated a great degree of variability. The contours rising of CV values reflected the non-homogeneous distribution of concentrations of anthropogenically emitted metal elements (Li et al., 2012). The greatest and the smallest SD were detected for metal element of Ti (406.2571) and Cd (1.137265) in the dry season. Similarly, the greatest and the smallest SD were detected for metal element of Ti (297.8519) and Cd (0.736449) in the rainy season. Additionally for dry season, the metal elements of Al, Cd, Co, K, Na, Ni, Sc and Ti in soil were fairly symmetrical (skewness -0.5 to 0.5), whereas, As, Ba, Ca, Cr, Hg, Sb, Sr, V and Zn in soil indicated the data points were moderately skewed as the skewness value varies from -0.1 to -0.5 and 0.5 to 0.1. Moreover, metal elements of Cu, Fe, Mn and Pb in soil were highly skewed exhibited skewness value of <-1 and >1. In addition, the metal elements of Al, As, Ba, Ca, Cd, Co, Cr, Fe, Hg, K, Na, Ni, Sc, Ti and Zn exhibited platykurtic distribution (Kurtosis<0), whereas, Cu, Mn, Pb, Sb, Sr and V exhibited leptokurtic distribution (Kurtosis >0). Moreover in rainy season, the skewness of metal elements of Al, Ba, Co, Fe, Ni, Pb, Sb, V and Zn were fairly symmetrical; however the metal elements of Ca, K, Mn, Na, Sc, Sr and Ti indicated the data points were moderately and metal elements of As, Cd, Cr, Cu and Hg were highly skewed. Furthermore, the metal elements of Al, Ba, Ca, Co, Fe, K, Mn, Na, Ni, Pb, Sb, Sc, Sr, V and Zn exhibited platykurtic distribution, whereas the metal elements of As, Cd, Cr, Cu, Hg and Ti exhibited leptokurtic distribution.

3.2 Seasonal Variation of the Concentration of Metal Elements

Based on descriptive statistical analysis, large SD was found for all metal elements, especially for Fe, Al, K and Ca in soil for both the dry and rainy seasons indicated wide variation of their concentrations in soil. Thus, contamination of soil from metal elements by anthropogenic activities as well as natural soil parent materials. The highest mean concentration of Fe and Ti both the dry and rainy season (Table 1). Moreover, based on mean concentration, the level of metal elements can be ordered as Fe> Al> K> Ca> Ba> Na> P B> V> Ti> Sr> Zn> Mn> Sc> Cu > Sb >Co >Cr >Hg> As >Ni> Cd in dry season and Fe>Al> K> Ca >Ba> Na >V> Ti> Sr >Zn >Pb> Mn> Sc >Co> Cu> Sb>Cr>Hg>As>Ni>Cd in rainy season. The concentrations of metal elements for rainy reason were relatively lower as compared to the dry season and the magnitude of concentrations followed almost same pattern for both the seasons.

Table 2: Correlation between metal elements in dry season

	Ca	Al	Ti	Sb	Sc	Sr	V	Ba
Ca	1.000							
Al	0.979	1.000						
Ti	0.978	0.976	1.000					
Sb	0.972	0.965	0.966	1.000				
Sc	0.985	0.979	0.987	0.986	1.000			
Sr	0.974	0.967	0.958	0.987	0.985	1.000		
V	0.970	0.974	0.956	0.984	0.980	0.984	1.000	
Ba	0.992	0.963	0.975	0.975	0.983	0.973	0.967	1.000

3.3 Correlation between Heavy Metals

In this study, Pearson's correlation coefficients were calculated to measure the intensity degree of association between metal elements. The Pearson's correlation matrix of metal elements of Ca, Al, Ti, Sb, Sc, Sr, V and Ba in soil for the dry season is provided in Table 2. The most significant correlation was observed for Ca and Ba (0.992) in dry season and Ti and Sr (0.991) in rainy season indicating same source of pollution. In contrary, the concentration of Cr showed very weak correlations with Mn, indicated Mn is from different sources than Cr in dry season. However, the concentrations of Hg showed very weak correlations with Zn (0.569) in rainy season. High positively correlations were observed between all metal elements, such as, Sc and Ti (0.987), Sb and Sc (0.986), Sb and V (0.984), Sc and Ba (0.983), Al and Sc (0.979), Ti and Ba (0.975), As and Al (0.974), V and Ca (0.974) , As and Ba (0.970) Ti and Sb (0.966), Ni and Fe(0.927), Zn and V (0.906), Fe and Cd (0.888), Al and Mn (0.645),Cr and Hg (0.575) as well as Hg and V (0.876) (Table 2). In addition, the some parameters in on soil of waste disposal site in rainy season showed also high positively correlated as Sr and Ti (0.991), Al and V (0.986), V and Ba (0.982), Ca and Sc (0.985), Ti and V (0.978) and Co and Ca (0.957), V and Co (0.961), Fe and V (0.948), Fe and Na (0.938), Cd and Sr (0.933), Ni and Sc (0.918), Zn znd Ti (0.861), Zn and Sb (0.861), Hg and Fe (0.733), Fe and Mn (0.947) and As and Ca (0.691). Here it should be noted that concentrations of Ca, Al, Ti, Sb, Sc, Sr, V, Ba showed strong correlation with each other in both the dry and rainy season, which indicated same sources of contamination for these metals.

3.4 Principal Component Analysis

In this study, variability calculation based on eigenvector and factor loadings leads to identify distinct source of generation of metal elements in soil of the studied area. PCs of 21 for dry and 19 for rainy were considered for the metal elements and results provided in Table 3. In addition, the larger eigenvalue obtained for F1 (18.5331) that indicated large proportion of variability (88.2530%) for rainy season (Table 3). The percentage contribution of the 1st to 2nd PCs for the metal elements in dry season as represented in Equation 4 was 92.105%.

$$\left(\left\{\sum_{i=1}^{2} \lambda_i\right\} / \left\{\sum_{i=1}^{21} \lambda_i\right\}\right) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4)$$

The selection of the first two parameters as the PCs since there was significant evidence of high enough total variance from the percentage contributions. The eigenvalues λ_i $(\lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7, \lambda_8, \lambda_9, \lambda_{10}, \lambda_{11}, \lambda_{12}, \lambda_{13}, \lambda_{14}, \lambda_{15}, \lambda_{16}, \lambda_{17}, \lambda_{18}, \lambda_{19}, \lambda_{20}, \lambda_{21})$, had little contributions to the total structure of the data under study. The percentage contribution of the 3th to 21st components (Equation 5) is 7.895% (Olawoyin, 2012). This suggested that very little information, which can be considered negligible, will be lost.

$$\left(\left\{\sum_{i=3}^{21} \lambda_i\right\} / \left\{\sum_{i=1}^{21} \lambda_i\right\}\right) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (5)$$

However, the percentage contribution of the 1st PC for the metal elements in rainy season as represented in Equation 6 was 88.25%

$$\left(\left\{\sum_{i=1}^{1} \lambda_i\right\} / \left\{\sum_{i=1}^{18} \lambda_i\right\}\right) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (6)$$

Which verbalized the selection of the first three parameters as the PCs and the eigenvalues λ_i $(\lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7, \lambda_8, \lambda_9, \lambda_{10}, \lambda_{11}, \lambda_{12}, \lambda_{13}, \lambda_{14}, \lambda_{15}, \lambda_{16}, \lambda_{17}, \lambda_{18}, \lambda_{19})$, had minimal contributions to the nature of the general data. The % contribution of the 2nd to 19th PCs as illustrated in Equation 7 was 11.75% for rainy season.

$$\left(\left\{\sum_{i=2}^{19} \lambda_i\right\} / \left\{\sum_{i=1}^{19} \lambda_i\right\}\right) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (7)$$

However, the larger eigenvalue obtained for F1 (18.267) indicated large proportion of variability (86.987%) for dry season as well as for rainy season F1 was found to be 18.5331 that indicated large proportion of variability (88.253%) for rainy season. Based on the results of PCA for metal elements of dry season, the eigenvalues upto the second extracted components (F2) were found greater than 1.0 for the dry season and first extracted components (F2) were found greater than 1.0 for the rainy season. Moreover, the eigenvalues for the PCs (F3 to F21) as well as (F2 to F19) were found less than 1 can be neglected for both the dry and rainy season, respectively. Thus, variables could be reduced to 2 components model (dry season) with 92.105% variation as well as 1 component model (rainy season) that accounts for 88.253% variation (Table 3). Varimax rotation was applied to simplify the factor interpretation by reducing total number of variables that exhibit high loadings per factor. Moreover, some previous investigations indicated first principal component (PC1) and second component (PC2) refers to the contamination of soil due to anthropogenic or human activities and natural parent materials, respectively (Tahir et al., 2007). In this study, in case of dry season, factor analysis revealed that metal elements of Al, As, Ba, Ca, Cd, Co, Fe, K, Na, Ni, Sb, Sc, Sr, Ti and V were closely related to PC1 indicated derived from anthropogenic activities and rests of the metal elements of Cu, Hg, Mn, Pb and Zn in soil were related to PC2 indicated derived from natural parent materials.

In addition, the metal element of Cr was closed to PC1 and PC2 indicated derived from both the anthropogenic activities and natural parent materials (Table 4). In addition, the factor analysis of PCA for rainy season before and after the varimax rotation is provided in Table 4. It can be estimated that As, Cr, Hg, K, Mn and Na in soil were related to PC2 indicating derived from natural parent materials. Other metal elements of Al, Ba, Ca, Co, Cu, Fe, Ni, Sb, Sc, Sr, Ti and V were related to PC1 indicating derived from anthropogenic activities. Moreover, as the metal elements of Al, Ba, Ca, Co, Cu, Fe, Ni, Sb, Sc, Sr, Ti and V in soil showed closed to PC1 indicated derived from anthropogenic activities. Besides, the metal elements of Na, Pb, Cu, K, Ni, Co, Hg, Fe, As, Zn and Cd, which also positively correlated with less stronger impact because they were comparative in shorter distance from origin than that of Ca, Al, Ti, Sb, Sc, Sr, V and Ba.

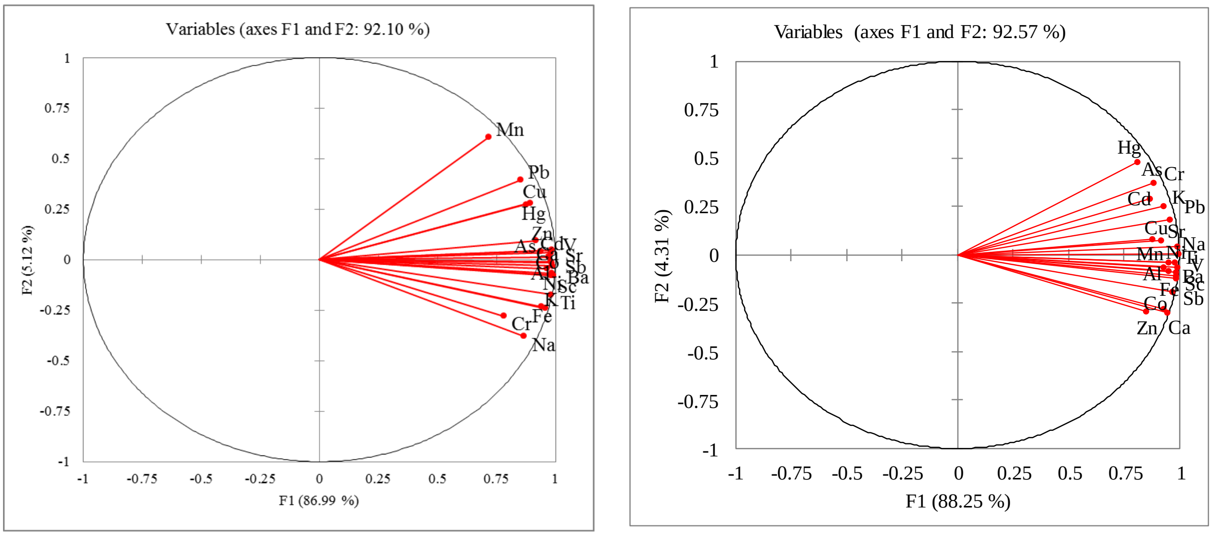
Table 3: PCA of metal elements in soil for dry and rainy seasons

PCs	Dry season			Rainy season		
	Eigenvalue	**Variability**	**Cumulative**	**Eigenvalue**	**Variability**	**Cumulative**
F1	18.267	86.987	86.987	18.533	88.253	88.253
F2	1.07	5.118	92.105	0.906	4.315	92.568
F3	0.416	1.98	94.085	0.398	1.896	94.464
F4	0.391	1.861	95.946	0.335	1.594	96.058
F5	0.23	1.095	97.041	0.263	1.252	97.310
F6	0.162	0.774	97.814	0.180	0.858	98.168
F7	0.119	0.566	98.38	0.151	0.718	98.886
F8	0.076	0.362	98.742	0.080	0.383	99.269
F9	0.058	0.277	99.019	0.055	0.26	99.529
F10	0.051	0.244	99.263	0.043	0.207	99.736
F11	0.042	0.202	99.465	0.016	0.077	99.813
F12	0.035	0.167	99.633	0.015	0.073	99.886
F13	0.026	0.122	99.755	0.009	0.045	99.931
F14	0.016	0.077	99.832	0.007	0.031	99.963
F15	0.013	0.063	99.895	0.004	0.017	99.979
F16	0.008	0.036	99.931	0.003	0.012	99.992
F17	0.004	0.02	99.952	0.001	0.005	99.997
F18	0.004	0.018	99.97	0.0005	0.003	99.999
F19	0.003	0.013	99.983	0.0002	0.001	100
F20	0.002	0.01	99.993			
F21	0.001	0.007	100			

Moreover, the metal elements of Mn and Cr having the least impact on the PCA model because they were far from each other in the same quadrant. It was noticed that Cu, Hg, Mn, Pb and Zn were located at a distance from origin of circle than that of other metal elements. This indicated the origin of these metal elements was differing from other metal elements. In a similar manner, it was clearly illustrated that; Ca, Al, Ti, Sb, Sc, Sr, V and Ba showed clear positive correlation but they have stronger impact on the PCA model than that of Na, Pb, Cu, K, Ni, Co, Mn, Fe, As, Cr and Cd, which also correlates positively with 8 variables, whereas Hg and Zn having the least impact on the PCA model. It was also found from PCA analysis that Mn, Hg, As, Cr, Na and K were located far from other metal elements indicating different origin from other metal elements.

Table 4: All explained variables and factors derived using the orthogonal varimax rotation method of dry season

Metal	**Before rotation**																					**After rotation**	
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	D1	D2
Fe	0.96	-0.24	0.02	-0.11	0.01	0.01	-0.01	-0.01	0.05	0.01	-0.01	-0.04	-0.05	-0.08	-0.04	0.00	-0.03	0.00	0.00	0.00	0.00	0.91	0.37
Mn	0.72	0.61	0.29	-0.07	0.00	0.10	-0.05	-0.11	0.02	-0.07	0.02	0.02	-0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.91
Cr	0.78	-0.28	0.32	0.44	-0.08	-0.05	0.08	-0.03	0.01	-0.01	0.02	-0.03	-0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.24
Cu	0.89	0.28	-0.11	0.25	0.09	0.08	-0.10	0.13	-0.04	-0.08	-0.06	-0.03	0.01	-0.01	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	0.55	0.75
Pb	0.85	0.40	0.18	-0.14	0.00	-0.16	0.13	0.13	0.06	0.04	-0.04	-0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.45	0.82
Zn	0.92	0.09	0.02	0.10	0.35	0.01	-0.02	-0.02	-0.01	0.12	0.04	0.03	-0.01	0.01	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.62
Ni	0.96	-0.04	-0.13	0.08	0.01	-0.01	-0.07	-0.09	0.15	0.02	-0.07	-0.04	0.06	0.00	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.80	0.53
Cd	0.94	0.04	0.14	-0.04	-0.23	0.04	-0.16	0.02	-0.07	0.12	-0.03	0.01	0.03	0.00	-0.01	0.00	0.00	0.00	0.00	-0.01	0.00	0.73	0.59
As	0.97	0.01	-0.15	0.05	-0.07	-0.08	0.03	-0.04	0.02	-0.02	-0.05	0.11	-0.03	0.01	-0.02	-0.04	0.00	-0.02	-0.01	0.00	0.00	0.77	0.59
Hg	0.88	0.27	-0.25	0.07	-0.13	0.20	0.17	-0.01	0.02	0.05	0.05	-0.03	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.54	0.74
Co	0.98	-0.08	0.01	0.02	-0.03	-0.02	-0.02	0.08	0.05	-0.03	0.08	0.10	0.06	-0.04	0.02	0.01	0.00	0.01	0.01	-0.01	0.00	0.84	0.52
Na	0.87	-0.38	0.15	-0.18	0.04	0.19	0.00	0.07	0.05	-0.04	0.01	0.00	0.02	0.04	-0.03	0.00	0.01	-0.02	0.00	0.00	0.00	0.92	0.21
K	0.94	-0.23	0.10	-0.12	0.09	0.08	0.09	-0.01	-0.06	0.00	-0.07	0.01	0.01	-0.01	0.07	-0.02	-0.01	0.00	0.00	-0.01	0.00	0.90	0.37
Ca	0.99	-0.03	-0.10	0.00	-0.05	-0.01	-0.02	0.04	-0.02	-0.01	0.02	-0.01	-0.06	0.03	0.02	0.05	-0.01	-0.01	-0.02	-0.01	-0.01	0.81	0.56
Al	0.98	-0.07	-0.07	0.01	0.00	0.01	0.07	-0.03	-0.06	-0.03	-0.08	0.03	-0.01	-0.01	-0.03	0.04	0.02	0.01	0.02	0.00	0.01	0.83	0.53
Ti	0.98	-0.17	-0.02	-0.02	0.00	0.01	-0.02	-0.01	0.00	0.01	0.01	0.02	-0.04	0.00	0.02	-0.01	0.02	0.02	-0.01	0.03	-0.02	0.89	0.44
Sb	0.98	-0.01	-0.04	-0.10	0.05	-0.10	-0.03	-0.03	-0.03	-0.06	0.04	-0.06	0.00	-0.02	-0.01	-0.02	0.03	0.00	0.00	-0.02	0.00	0.80	0.57
Sc	0.99	-0.08	-0.03	-0.05	0.00	-0.05	-0.02	0.00	-0.02	-0.01	0.02	-0.02	0.02	0.04	-0.01	-0.01	-0.01	0.04	-0.02	0.00	0.02	0.85	0.52
Sr	0.98	0.03	-0.06	-0.11	-0.01	-0.10	0.02	-0.04	0.00	-0.02	0.02	-0.01	0.02	0.05	-0.02	-0.01	-0.03	0.00	0.02	0.00	-0.02	0.77	0.61
V	0.99	0.05	-0.02	-0.03	0.01	-0.05	0.04	-0.06	-0.09	-0.02	0.04	-0.03	0.06	-0.03	0.00	0.01	-0.01	-0.02	-0.02	0.02	0.00	0.77	0.62
Ba	0.99	-0.02	-0.09	0.02	-0.04	-0.05	-0.08	0.03	0.01	0.01	0.05	-0.02	-0.05	0.01	0.04	-0.01	0.00	-0.02	0.02	0.01	0.02	0.80	0.57



All sampling points and metal elements were overlapped, indicating high correlation with each other except Mn, Pb, Hg, Cu and Zn.

(a)

All sampling points and metal elements were overlapped except Hg, As, Cr, Cd and K.

(b)

Figure 2: Correlation circle for metal elements in soil (a) dry and (b) rainy season

Additionally, plotted correlation circle exhibited a graphical representation of loading vectors for metal elements in order to determine the most influential variables interaction in this model. Variables that showed longer distances from origin of circle have larger impacts on the general architecture of the model than variables with shorter distances (Olawoyin, 2012). In the loading plot corresponding to the first two PCs (Figure 2); the eight metal elements of Ca, Al, Ti, Sb, Sc, Sr, V and Ba showed clear positive correlation because they were in the same quadrant. In addition, these metal elements have stronger impact on the PCA model because these metal elements were at a longer distance from origin.

3.5 Agglomerative Hierarchical Clustering

In case of dry season, cluster 1 comprises with metal elements of Al, As, Ba, Ca, Cd, Co, Fe, K, Na, Ni, Sb, Sc, Sr, Ti and V in soil which indicated these metal elements were generated from anthropogenic activities . In addition, cluster 2 comprises with Cu, Hg, Mn, Pb, and Zn, indicating origination from natural sources and Cluster 3 comprises with Cr which derived from both the natural parent materials and anthropogenic sources. Table 5 showed the results of cluster analysis by class for both the dry and rainy season, respectively. In case of dry season, maximum distance to centroid was found for cluster 2 of 170.279 between three clusters, indicating generation of metal elements from natural sources (Table 5). Moreover, maximum distance to centroid for cluster 1 was found comparatively smaller of 122.5230 than that of cluster 2, indicating generation of metal elements from anthropogenic activities. Cluster 3 showed maximum distances to centroid was zero, indicating it was closed to both the clusters, consequently generated from both natural sources and anthropogenic activities. In addition, for rainy season, cluster 1 comprises with Al, Ba, Ca, Co, Cu, Fe, Ni, Sb, Sc, Sr, Ti and V which indicated these metal were generated from anthropogenic activities (Figure 3). Cluster 2 comprises with As, Cr, Hg, Mn, K and Na indicating origination from natural sources and Cluster 3 comprises with Cd, Pb and Zn which derived from both natural parent materials and anthropogenic sources. Similarly, it was found that metal elements of cluster 2 indicating generation of metal elements from natural sources; whereas cluster 1 indicating generation of metal elements from anthropogenic activities and cluster 3 consequently generated from both natural and anthropogenic sources (Table 5).

Table 5: Results of cluster analysis

Season	**Dry**			**Rainy**		
Class	1	2	3	1	2	3
Objects	15	5	1	12	6	3
Sum of weights	15	5	1	12	6	3
Within-class variance	4511.6859	18600.6792	0.0000	3042.8452	12931.7	4559.68
Maximum distance to centroid	122.5230	170.2796	0.0000	89.0645	148.207	64.2498
Metal elements	Fe, Ni, Cd, As, Co, Na, K, Ca, Al,Ti, Sb, Sc, Sr, V, Ba	Mn, Cu, Pb Zn, Hg	Cr	Fe, Cu, Ni, Co, Ca, Al, Ti, Sb, Sc, Sr, V, Ba	Mn, Cr, As, Hg, Na, K	Pb, Zn, Cd

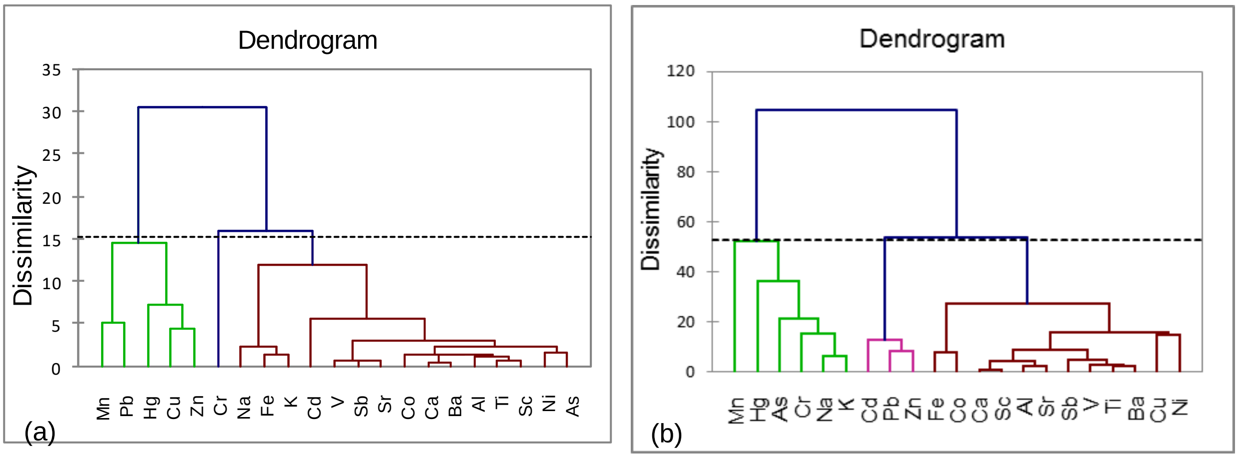


Figure 3: Dendrogram for metal elements in soil during (a) dry and (b) rainy season

3.6 Spatial distribution of metal elements

The spatial distribution of metal concentrations is a convenient tool to identify the sources of generation of metal elements as well as contamination hotspots with high metal concentrations in a visual form. The predicted map produced from different interpolation techniques for metal elements provide a field scale contamination of soil by metal elements present in waste disposal site. The predicted map of almost all the metal elements showed almost similar pattern of contamination indicated same sources of generation indicating anthropogenic activities accompanied by particular natural soil materials.

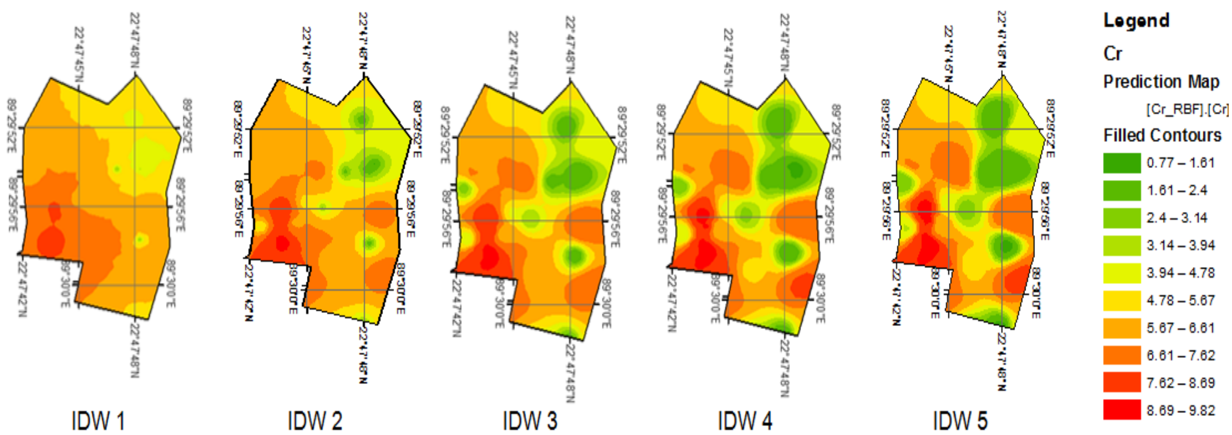


Figure 4: Spatial distribution of Cr in soil using IDW with power of 1- 5.

This provide a refinement and reconfirmation of the result obtained from statistical analyses of Pearson's correlation and AHC. Figure 4 showed spatial distribution of metal element of Cr generated from both natural and anthropogenic activities to visualize the extent up to which the severities of contamination of this metal element exist. Moreover, from produced prediction surface, it was found that for all the metal elements most of the contaminated hotspots were found near the central point of the disposal site for all studied metal elements.

4. CONCLUSION

Results of Pearson's correlation reveals that almost all the metal elements were strongly correlated with each other indicating these metal elements were derived from the same generation sources. In addition, results of PCA depicts that Cu, Hg, Mn, Pb, and Zn in soil derived from natural parent materials, while, Al, As, Ba, Ca, Cd, Co, Fe, K, Na, Ni, Sb, Sc, Sr, Ti and V in soil from anthropogenic activities and Cr from both the natural and anthropogenic sources in dry season. It can be demonstrated that As, Cr, Hg, K, Na and Mn in soil derived from natural parent materials; Al, Ba, Ca, Co, Cu, Fe, Ni, Sb, Sc, Sr, Ti and V from anthropogenic activities as well as Cd, Pb and Zn from both the natural parent and anthropogenic sources in rainy season. Results from AHC also proved the same generation sources of metal elements as similar of PCA in soil for both the dry and rainy seasons. Produced prediction surface for all the interpolation techniques showed most of the contaminated hotspots was found near the central point of the disposal site for all studied metal elements. Here, it can be concluded that contamination of soil by heavy metals can be minimized by controlling anthropogenic activities. Moreover, inhabitants nearby the waste disposal site should be shifted to keep safe from the adverse effects of intake foods growing in this contaminated soil as well as water which is also contaminated by heavy metals in soil.

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EVALUATION AND SPATIAL DISTRIBUTION OF HUMAN HEALTH RISK ASSOCIATED WITH HEAVY METALS IN SURFACE AND GROUND WATER FROM WASTE DISPOSAL SITE AT KHULNA

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ABSTRACT

The heavy metal releases from waste disposal site contains extensive ranges of carcinogen and non-carcinogenmetal compounds that signify a potential risk to public health. The main focus of this study was to evaluate the non-carcinogen health risk associated withheavy metals in surface and groundwater nearby waste disposal site. To these attempts, fifteen surface water and fifteen groundwater samples were collected from different selected production wells located adjacent to the waste disposal site at Rajbandh, Khulna, Bangladesh.In the laboratory, the concentrations ofheavy metals of Fe, Mn, Cr, Cu, Pb, Zn, Ni, Cd, Na, K, Ca and As in water were measured through the standard test methods. To assess the health risk, chronic daily intake (CDI), hazard quotient (HQ) and hazard index (HI) were computed using exposure and risk models proposed by US.EPA (1989).The exposure routessuch as dermal and ingestion were considered. The inhabitants were categorized as adult and child. According to US.EPA, limit of HI/HQfor non-carcinogen is less than unity and carcinogen risk is more than unity.Result reveals that the values of CDI, HQ and HI for metal in surface and ground water for rainy season was found comparatively higher than that of dry reason. Results indicated that the values of HQ and HI were found to be higher for child than that of adult as well as reasonable maximum exposure (RME) displayed higher values of HI than that of central tendency exposure (CTE).In this study, Pearson's correlation and principal component analysis (PCA) were performed using XLSTAT and results indicated that Fe, Mn, Cu and Ca were generated from anthropogenic sources except Cd, Cr, Ni, Pb, K and As from natural sources. The concentration of heavy metals, CDI, HQ and HI was distributed spatially. The uncertainty of exposure and risk parameters were analyzed using 1-D Monte Carlo Simulation @risk 7.5 with 10000 iterations.

Keywords: *Waste disposal site, water, chronic daily intake, reference dose, hazard quotient, hazard index, health risk.*

1. INTRODUCTION

Decision making around the disposal of municipal solid waste (MSW) is complex and becomes more difficulty in developing countries. The only safe solution is to dispose in a way that environment is not affected. This requires significant investments from the already squeezed budgets of governments, which continue to have other pressing priorities for spending (Manyin et al., 2009). In most of developing countries MSW management services take third chance in municipal priorities after water supply and sanitation.Drinking water is a major issue in human life. No one can survive without drinking water. Bangladesh is vulnerable to water insecurity partially because of its environmental circumstances. Heavy metals are important pollutants in surface waters, causing persistent environmental hazardsthat can seriously harm human and ecological health (Lin et al., 2007;Atli et al., 2008; Perianez et al., 2009). Heavy metals in surface waters originatefrom natural processes, such as atmospheric deposition and geological weathering, and fromanthropogenic activities (in emissions such as industrial wastewater and domestic sewage). Thecontributions of these sources are different in different regions and in different seasons, so heavy metalconcentrations in surface water and groundwatercan vary both spatially and seasonally. Information on these variationsis important for decision makers involved in environmental risk management (Huang et al., 2012;Kumar et al., 2013;Li et al., 2010; Matache et al., 2009; Lenoble et al., 2013). Evaluating environmental impact of contaminants in soils must start with a robust determination of theirconcentration and spatial distribution.

GIS based spatial distribution map is generally used to display the distribution of metal contamination has been widely used toassist the interpretation of environmental data and to distinguish between natural and anthropogenic inputs(Manta 2002).There are two main sources of heavy metals in the soil (Li et al.,2009b): (i) natural background, which represents the heavy metalconcentration derived from parent rocks; (ii) anthropogenic contamination, including agrochemicals, organic amendments, animal manure, mineral fertilizer, sewage sludge and industrial wastes. In the last severaldecades, the natural input of several heavy metals to soils due to pedogenesis has been exceeded by the human input, even on global andregional scales (Facchinelli et al., 2001; Nriagu and Pacyna, 1988).The main objectives of this study were to know the hazard index of selected chemical heavy metals in different routes within two seasons of a year at the Rajbandh near a landfill site, to know the sources of metal contamination by principal component analysis (PCA), to show the distribution of chemical metal concentrations, chronic daily intake (CDI) values of heavy metals, hazard index (HQ) values of heavy metals using ArcGIS.

2. METHODOLOGY

The sampling of water, measurement of the concentrations of heavy metals in water, models used for assessing health risk, principal component analysis and Monte Carlo simulation used in this study are presented and hence described in the following articles.

2.1 Sampling of Groundwater and Surface Water

Before collecting water samples the bottle was washed by distilled water several times. Then the bottles were air or sun dried. Then 2-3 mL a solution was used as preservative. The preservative was prepared by mixing concentrated nitric acid and distilled water at a ratio of 1:1. Then the bottle was kept for 24 hours at room temperature. After that the bottles were prepared for collecting water sample. In this study, fifteen groundwater samples were collected from selected production wells or tube wells located adjacent to the waste disposal site at Rajbandh of Khulna, Bangladesh. Moreover, fifteen surface water samples were collected from pond located at the mentioned locations. All the sampling points were gathered with the help of GPS and shown in Figure 1. These study periods covered both the dry and rainy seasons.

2.2 Laboratory Investigations

Both the water samples were collected from the site and then brought to DPHE, Khulna, Bangladesh. The concentrations of heavy metals of Fe, Mn, Cr, Cu, Pb, Zn, Ni, Cd, Na, K, Ca, As in water were measured through atomic absorption spectrophotometer (AAS).

2.3 Risk Assessment Methodology

In this study, for assessing health risk, the risk modelsproposed by Li and Zhang (2010); US.EPA (2004) and Wu et al. (2009)were used. Human can get exposed to water contaminations inthreemain pathways including dermal absorption, direct ingestion, and inhalation through nose.Among them dermal and ingestion are vital in health risk for both groundwater and surface water (US.EPA, 1989; US.EPA, 2004; Wu et al., 2009). In this study, for assessing health risk from ground and surface water, the exposure routes of dermal and ingestion were considered and hence discussed in the followings.

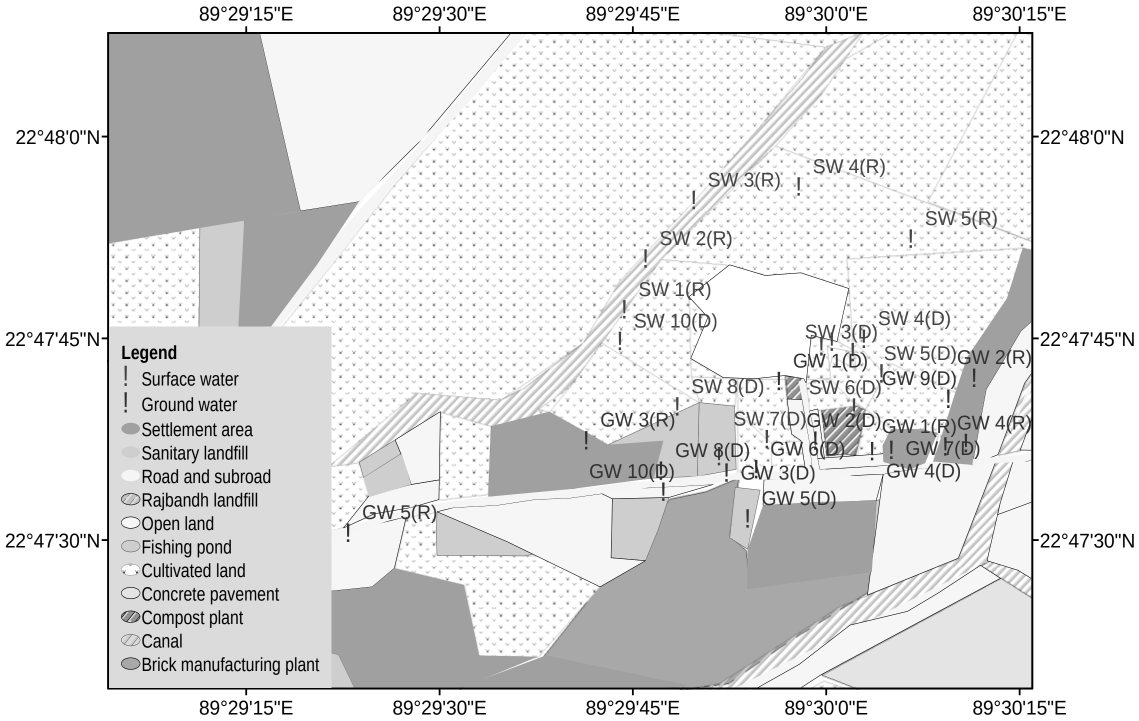

Figure 1: Surface and groundwater sampling locations nearby waste disposal site at Rajbandh, Khulna

2.3.1 ExposureModel for Incidental Ingestion

$$CDI_{ing} = \frac{C_W * CR * ABS_s * ET \ * EF * ED}{BW * AT}$$

Where, CDI_{ing} = Chronic daily intake for ingestion,Cw = metal concentration in water (mg/L),CR = contact rate (L/hr),ABS_s = absorption factor (%), ET = expose time (hr/event),EF = exposure frequency (days/year),ED = exposure duration (years),BW = body weight (kg),AT = average time (days).

2.3.2 ExposureModel for Dermal Absorption

$$CDI_{dermal} = \frac{C_W * CF * SA * PC * ABS_s * ET * EF * ED}{BW * AT}$$

Where,CDI_{derm} = chronic daily intake from dermal contact with heavy metals in water, Cw = concentration of estimated heavy metals in water (mg/L), SA = skin surface area availablefor contact (cm^2), CF = volumetric conversion factor for water (L/cm^2), PC = metal specific dermal permeability constant (cm/hr), ABS_s = absorption factor (%).

2.3.3 Risk Model for Hazard Quotient

$$HQ_{ing/dermal} = \frac{CDI_{ing/dermal}}{RfD_{ing/dermal}}$$

Where,HQ $_{ing/derm}$ is hazard quotient via ingestion or dermal contact (unitless) andRfD$_{ing/derm}$ is oral/dermal reference dose (mg/kg-day). The RfD$_{ing}$ and RfD$_{derm}$ values were obtained from literature elsewhere (Li and Zhang, 2010; US.EPA,1989; Wu et al., 2009; Liang et al., 2011).Recognized reference dose values are tabulated in Table1.

2.3.4 Risk Model for Hazard Index

$$HI = \sum_{i=1}^{n} HQ_{ing/dermal}$$

Where, HI$_{ing/derm}$ is hazard index via ingestion or dermal contact (unitless). When HQ/HI exceeds unity, there may be a concern for potential human health risks caused by exposure to non-carcinogenic elements (US.EPA, 1989).

Table1: The permeability, dermal and ingestion reference doses of heavy metals

Chemicals	Permeability ,PC (cm/hr)	Reference dose, RfD$_{ing}$ (mg/kg-day)	Reference dose, RfD$_{derm}$ (mg/kg-day)	References
Fe	1.00E-03	7.00E-01	1.40E-01	Li and Zhang,2010;US.EPA,1989;Wu et al.,2009;Liang et al., 2011
Mn	1.00E-03	2.40E-02	9.60E-04	
Cr(+6)	2.00E-03	3.00E-03	7.50E-05	
Cu	1.00E-03	4.00E-02	8.00E-03	
Pb	4.00E-03	1.40E-03	4.20E-04	
Zn	6.00E-04	3.00E-01	6.00E-02	
Ni	4.00E-03	2.00E-02	5.40E-03	
Cd	1.00E-03	5.00E-04	2.50E-05	
Na	1.00E-03	2.00E-02	1.60E-02	
K	1.00E-03	2.00E-02	1.60E-02	
Ca	1.00E-03	2.00E-02	1.60E-02	
As	1.00E-03	3.00E-04	1.23E-04	

3. Results and Discussion

The results of exposure and risk models, principal component analysis, geostatistical analysis and Monte Carlo simulation are discussed in the following sections.

3.1 Health Risk Analysis of Selected Chemicals in Water

The suitability of water samples mainly depends upon some heavy metals as stated earlier (WHO, 2008). From analysis of HQ it was quite clear that the water sample labeled as GW-1, collected in rainy season in RME condition was more hazardous for child .The computed HQ and HI for different heavy metals for child in RME for different exposure routes are provided in Table 2and computed HQ is represented in Figure 2. From Table 2 it was noticed that for total hazard, chemical hazardous sequel should be like as Ca> k> Na> Cd> Cr> Pb> Mn> Cu> As> Fe> Ni> Zn and the route of ingestion showed comparatively the higher hazardous effect than that of dermal route. Figure 2 shows that individual Ca possess more hazards in RME condition as it has maximum HQ value compared to others.

Table 2: Computed HQ and HI of GW-1 in rainy season (RME condition for child)

Chemicals Name	Water Concentrations (mg/L)	HQ		HI
		Water Dermal contact	Incidental Water Ingestion	
Fe	4.6	2.25E-02	4.38E-02	6.64E-02
Mn	0.351	2.51E-01	9.76E-02	3.48E-01
Cr(+6)	0.04	7.32E-01	8.90E-02	8.20E-01
Cu	0.95	8.14E-02	1.58E-01	2.40E-01
Pb	0.05	3.27E-01	2.38E-01	5.65E-01
Zn	0.15	1.03E-03	3.34E-03	4.36E-03
Ni	0.062	3.15E-02	2.07E-02	5.22E-02
Cd	0.029	7.96E-01	3.87E-01	1.18E+00
Na	12	5.14E-01	4.00E+00	4.52E+00
K	23	9.86E-01	7.67E+00	8.66E+00
Ca	65	2.79E+00	2.17E+01	2.45E+01
As	0.004	2.23E-02	8.90E-02	1.11E-01
Total HI		6.55E+00	3.45E+01	

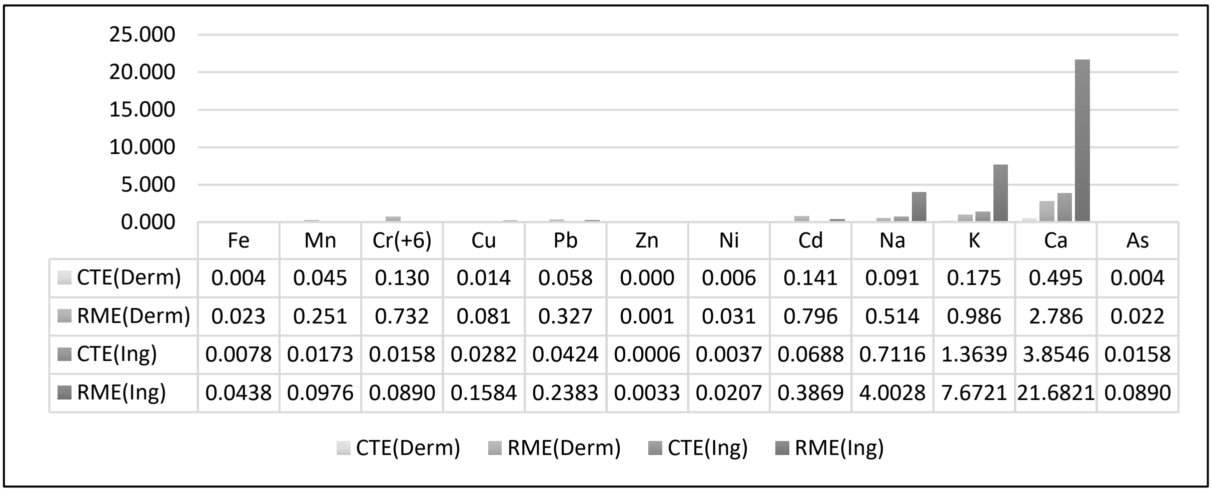

Figure 2: HQ for child in CTE and RME condition of groundwater for rainy season

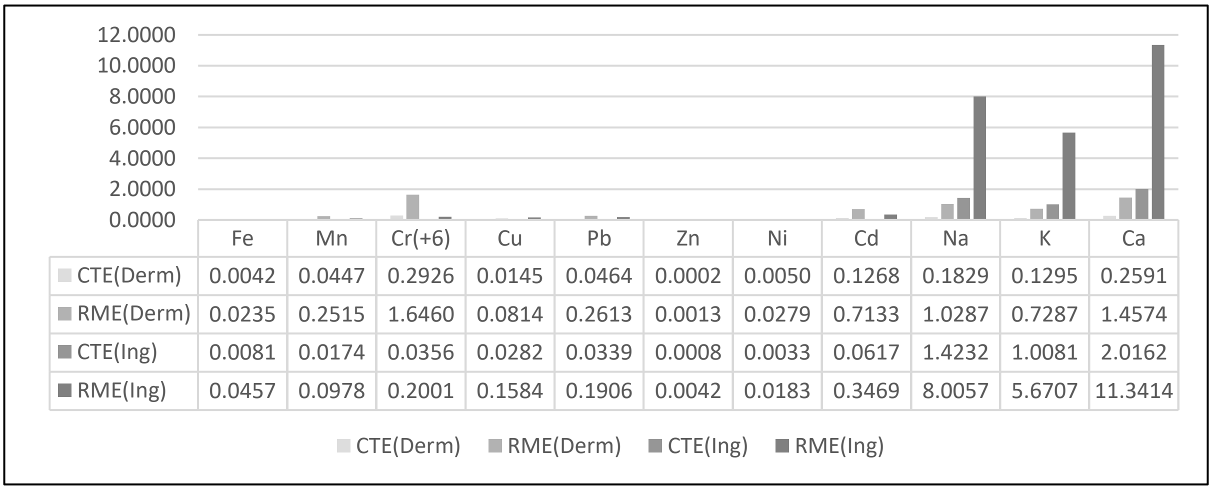

Figure 3: HQ for child in CTE and RME condition of surface water for rainy season

Figure 3 reveals that the values of HQ in case of ingestion route for surface water were found to be higher than that of dermal condition. In addition, RME showed the higher values of HQ in compare to CTE. The metal of Ca possess more hazards in RME condition during rainy season as it has maximum HQ value compared to others. Based on results of HQ, the chemical hazardous sequel should be like as Ca> Na> K> Cr> Cd> Pb> Mn> Cu> Fe> Ni> Zn and among two routes ingestion possess more hazardous effect for surface water.

Table-3: Correlation coefficient matrixfor CDI and HQ(CHILD/RME/INGESTION) of metals in ground water for dry season (below the diagonal) and rainy season (above the diagonal)

Variables	Fe	Mn	Cr(+6)	Cu	Pb	Zn	Ni	Cd	Na	K	Ca	As
Fe	**1**	0.681	-0.437	0.530	-0.241	0.743	0.264	-0.638	-0.901	-0.248	0.732	0.698
Mn	0.739	**1**	-0.363	0.970	-0.464	0.977	0.632	0.123	-0.461	0.438	0.969	0.513
Cr(+6)	0.404	0.586	**1**	-0.171	0.791	-0.326	0.492	0.306	0.617	0.483	-0.310	0.000
Cu	0.777	0.939	0.797	**1**	-0.330	0.948	0.767	0.309	-0.248	0.632	0.947	0.428
Pb	0.485	0.682	0.929	0.825	**1**	-0.309	0.233	-0.102	0.461	0.065	-0.279	-0.250
Zn	0.751	0.982	0.546	0.913	0.636	**1**	0.644	0.014	-0.472	0.373	0.999	0.464
Ni	-0.543	-0.642	-0.062	-0.474	-0.184	-0.758	**1**	0.379	0.098	0.816	0.652	0.456
Cd	0.611	0.144	0.434	0.397	0.285	0.142	0.046	**1**	0.751	0.844	0.022	-0.344
Na	-0.751	-0.565	-0.199	-0.536	-0.423	-0.605	0.504	-0.154	**1**	0.521	-0.448	-0.692
K	0.861	0.819	0.749	0.926	0.773	0.832	-0.529	0.607	-0.569	**1**	0.382	0.065
Ca	0.384	0.727	0.452	0.631	0.559	0.745	-0.716	-0.019	-0.157	0.619	**1**	0.437
As	-0.550	-0.138	-0.233	-0.301	-0.199	-0.241	0.320	-0.686	0.499	-0.553	0.009	**1**

3.2 Pearson's correlation Analysis

In this study, Pearson's correlationcoefficients were calculated forCDI and HQ of selected heavy metals. The values of correlation between the selected heavy metals for CDI and HQ values of selected heavy metals were shown in Table 3. Interpretation of Table 3, the interrelationship studies between different variables are very helpful tools in promoting research and opening new frontiers of knowledge. The study ofcorrelation reduces the range ofuncertainty associated with decisionmaking (Patil and Patil, 2010).

Fromresults of Pearson's correlations matrix on groundwater duringdry season, it was observed the highpositively correlated values between Cu and Mn(0.939), Pb and Cr(0.929), Zn and Mn(0.982), Zn and Cu(0.913), K and Cu(0.926), and in rainy season between Cu and Mn (0.970) , Zn and Mn (0.977), Ca and Mn (0.969) , Cu and Zn (0.948) , Ca and Cu (0.947), Ca and Zn (0.999) were observed. In contrast, in dry season low negatively correlated values between Cr and Ni (-0.062), Cd and Na (-0.154), Cd and Ca (-0.019), As and Mn (-0.138) were observed. Interpretation of Table 4, fromresults of Pearson's correlations matrix on groundwater for CDI values of different selected heavy metals duringdry season, it was observed the highpositively correlated values between Mn and Fe (0.74), Cu and Fe (0.78), Zn and Fe (0.75), K and Fe (0.86), Cu and Mn (0.94), Zn and Mn (0.98), K and Mn (0.82), Zn and Cu (0.91), Pb and Cu (0.82), K and Cr (0.75), Cu and Cr (0.82), Pb and Cr (0.93), K and Pb (0.77), K and Zn (0.83), Ca and Zn (0.75). In rainy season strongly correlated values between Mn and Cu (0.97), Cr and Pb (0.79), Cu and Zn (0.95), Mn and Zn (0.98), Cu and Ni (0.77), Cd and Na (0.75), Ni and K (0.82), Cd and K (0.84), Mn and Ca (0.97), Cu and Ca (0.95) were observed.

3.3 Principal Component Analysis (PCA)

Principal component analysis (PCA) was employed in order to understand the association among the heavy metals.PCA can be used to identify thesources of contamination (Facchinelli et al., 2001).Natural and anthropogenic sources are one of the root cause of metal element contamination which has caused widespread and variable the hazardous possibilities of environmental and health effect. Moreover, some previous investigations indicated first principal component (PC1) and second component (PC2) refers to the contamination of water due to anthropogenic or human activities and natural parent materials, respectively (Tahir et al., 2007).

Table4: Principal component loadings for heavy metals in groundwater for both seasons

	Dry season			**Rainy season**		
	PC1	PC2	PC3	PC1	PC2	PC3
Eigenvalue	7.1	1.9	1.5	5.9	3.7	1.7
Variability (%)	59.3	16.0	12.8	49.0	30.9	14.1
Cumulative %	59.3	75.3	88.1	49.0	79.9	94.0
Fe	0.86	0.28	-0.29	0.81	-0.48	0.31
Mn	0.91	-0.32	-0.01	0.98	0.14	-0.16
Cr(+6)	0.72	0.11	0.65	-0.36	0.67	0.63
Cu	0.96	-0.05	0.19	0.92	0.38	-0.13
Pb	0.79	-0.03	0.51	-0.43	0.34	0.73
Zn	0.93	-0.30	-0.13	0.97	0.12	-0.03
Ni	-0.63	0.37	0.59	0.61	0.70	0.37
Cd	0.44	0.81	0.12	-0.07	0.85	-0.49
Na	-0.65	-0.14	0.47	-0.61	0.76	-0.15
K	0.97	0.18	0.07	0.30	0.94	-0.09
Ca	0.69	-0.55	0.06	0.96	0.13	-0.03
As	-0.46	-0.70	0.34	0.65	-0.19	0.45

Principal component (PC) loadings for heavy metals in groundwater for both dry and rainy season are shown in Table 4.In dry season, three principal components (PCs) with eigenvalues>1that explains about 88% of the total variance of the dataset were obtained. PC1accounted as almost 59% of the total variance, and Fe, Mn, Cr, Cu, Pb, Zn, K and Ca are closely associated to it and these heavy metals were generated from anthropogenic sources. The PC2 accounted almost 16% of the total variance, and Cd is closely associated to it and generated from natural sources. In Rainy season, three PCs with eigenvalues>1 that explains about 94% of the total variance of the dataset were obtained. The PC1 accounted of almost 49% of the total variance, and Fe, Mn, Cu, Zn, Ca and Aswere closely associated to it. PC2 accounted almost 31% of total variance, and Cr, Ni, Cd, Na and K were closely associated to it.

Figure 4 shows the graphical representation of PCA output, at scree plot (Figures 4a and 4b) it represents the eigenvalues of all the nine factors where in Table 4 only three factors having eigenvalues>1 were shown. Figure 4c, represents the factor loading values for dry season. Where horizontal axis represents PC1 and vertical axis represents PC2, when the distance of a point is far from center and close to a positive side of an axis then the metal represented by this point is closely related to that factor what was represented by this axis. From Figure 4c, the heavy metals of Fe, Mn, Cr, Cu, Pb, Zn, K and Ca representing points are closely attached to positive PC1 axis staying near the circumferential line. So they aresourced from PC1 i.e from anthropogenic sources. When a point is exactly orthogonal to an axis, it represents that there is no relation between the point and axis. Accordingly, Figure 4d shown for rainy season represents the similar type of pattern as dry season.

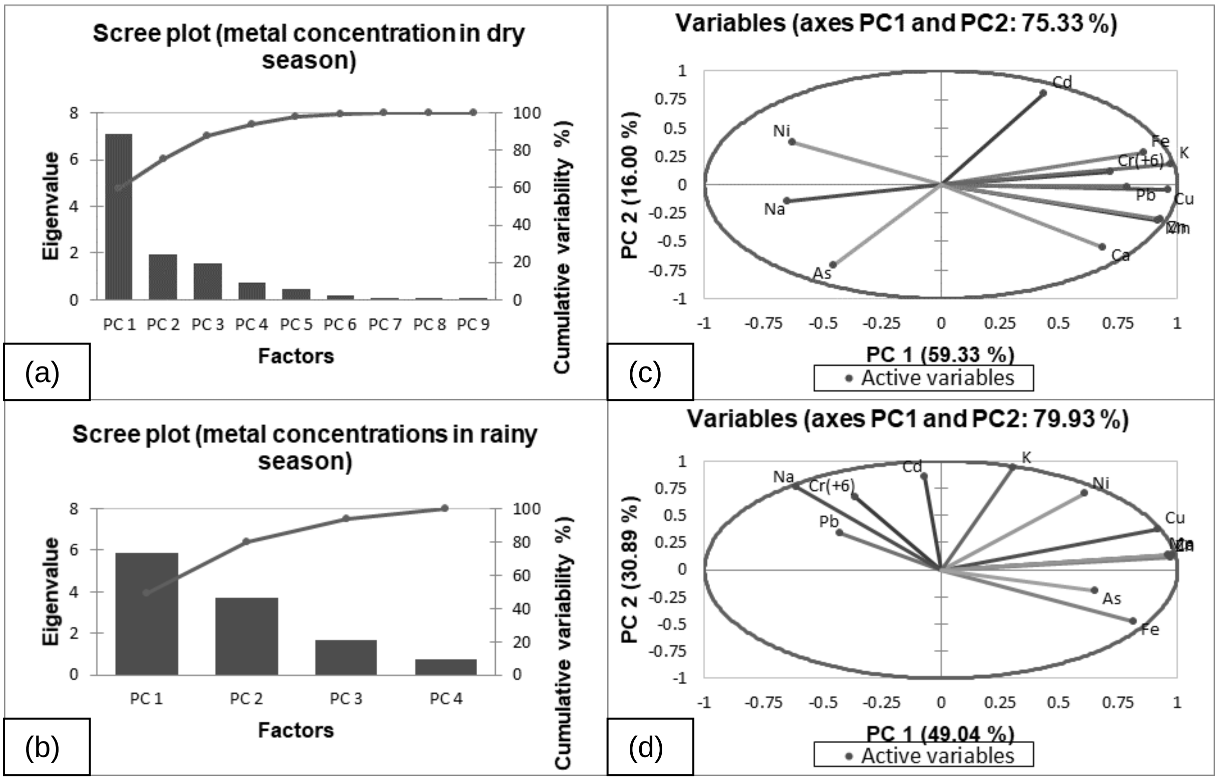

Figure4: Graphical representation of PCA output (a) scree plot for dry season; (b) scree plot for rainy season; (c) variables for dry season and (d) (c) variables for rainy season.

3.4 Spatial Distribution of Heavy MetalsinGroundwater

The spatial distribution of metal concentrations is a useful aid toassess the possible sources of enrichment and to identify hotspotswith high metal concentrations. The estimated maps of Ca and Cd are presented in Figure5a and Figure 5b, respectively; several hotspots of high metal concentration were identified by the geochemical maps. From the distribution Figure 5a, it is found that for Ca highest concentration lies in north and east side of disposal site (denoted by red 0) and south-west is less concentrated with Ca. The metal of Cd showed highest concentration is within the east side of selected disposal site (Figure 5b)

3.5 Spatial distribution of CDI values for surface water

Distribution of CDI for Ca, Fe, K and Na are represented in Figure 6. From the distribution map, it is found that for CDI value of Ca highest intake lies in north and west side of disposal site (denoted by red 0) and less intake values are found to spread within south side of the disposal site. Accordingly distribution for Fe, K and Na is presented in Figure 6. For all the heavy metals CDI values distribution criteria is almost similar which indicates that all the values are from the same source.

3.6 Spatial distribution of HQ values for Groundwater

The most serious issue is the hazard quotient values in health risk analysis. For groundwater a typical distribution of Ca, Cd, K, Na are shown in Figure 7. From distribution, north and east side of disposal site are most hazardous for Ca, and opposite sides are less hazardous.

But hazard quotient values for Cd is very much less compared to Ca. Similarly, for K north side is dangerous compared to other sides and for Na medium type of hazard is exist.

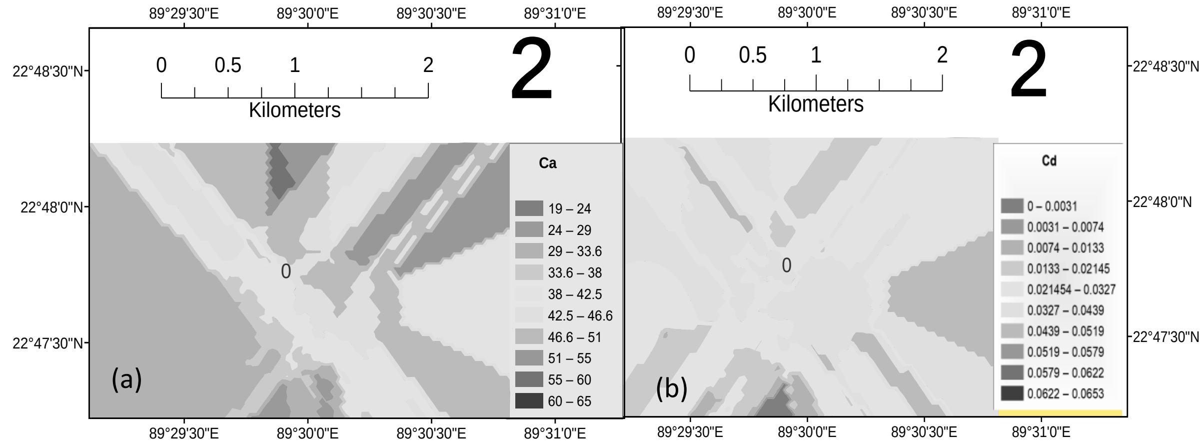

Figure 5: Spatial Distribution of Heavy Metal concentrations in Groundwater

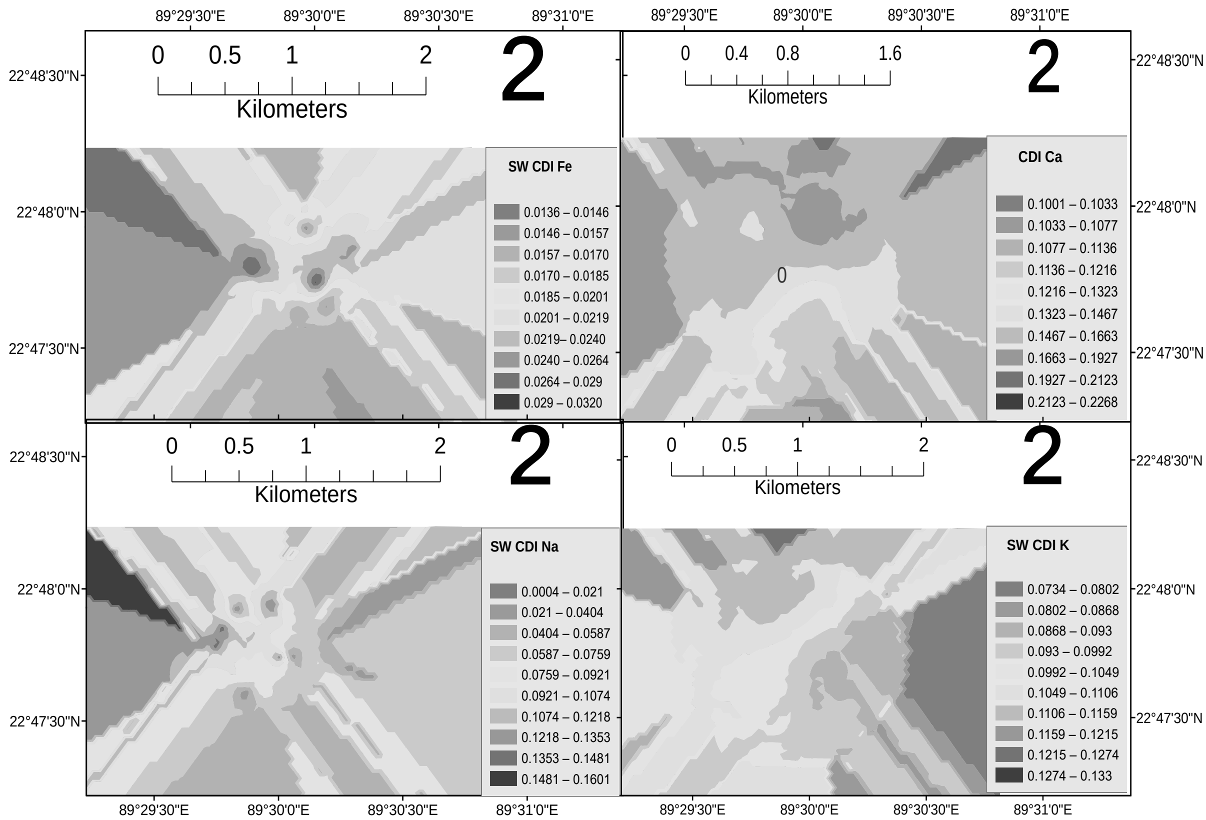

Figure 6:Spatial Distribution of CDI values of surface water

3.7 Uncertainty Analysis (1-D Monte Carlo Simulation)

The term uncertainty is interpreted as a lack ofknowledge about factors affectingexposure or risk models(Iman and Conover 1982;Kilic and Aral 2008).These uncertaintiescan be linked to the parameters used inexposure model (e.g. errors orinaccuracies in the measurement), to risk models input parameters,population characterization) (Lee et al.,2004; US.EPA, 2005; Wang et al., 2007;Chowdhury et al., 2009).The analysis ofuncertainty of exposure parameters and risk outputs (HQ, Hi) were performed using 1-D MCS @RISK 7.5 with 10000 iterations.

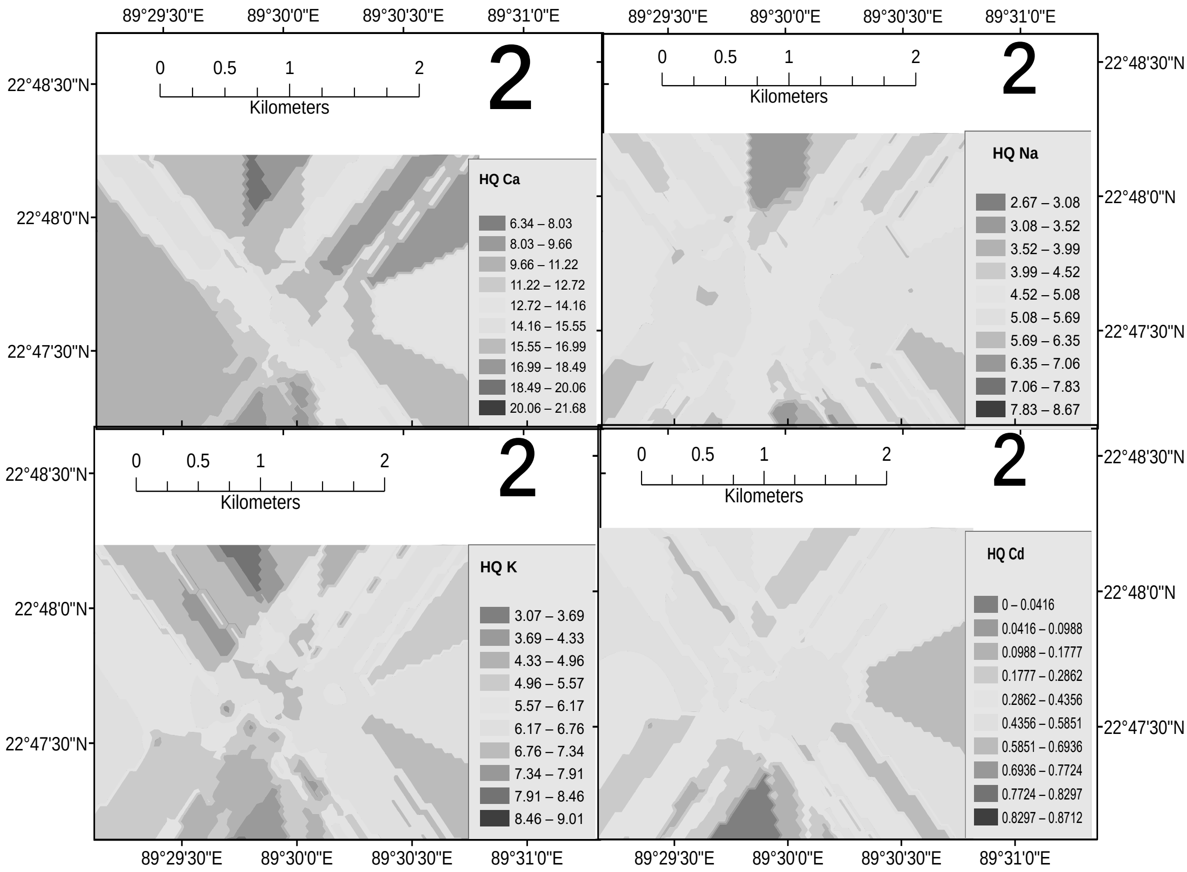

Figure7: Spatial distribution of HQ values for Groundwater

Graphical representation of input parameters (BW) of exposure model is shown in Figure 8. To select and fit a probability distribution, the body weight of the exposure populations was compiled using @RISK 7.5. In the Figure 8, the height of the bars (the yaxis) represents the relative frequency ofbody weight in the population and thespread of the bars (the x-axis) is thevarying amounts body weight (kg).Sincebody weight is a continuous randomvariable, the probability distribution canalso be represented graphically with aprobability density function (PDF) (Figure-8a) as well as CDF (Figure-8b).Theminimum, maximum, mean, standarddeviation and numberof iterations are alsopresented in the box.There is a greater area under the curve (greater probability density) in the 60-80kg range than 0-60kg or 80-90 kg. By selecting a normal distribution to characterize inter-individual variability, we can state more precisely that 60 kg corresponds to the 5th percentile and 80 kg corresponds to the 95th percentile, so approximately 90% (i.e., 0.95–0.05=0.90) of the BW is likely to exist between 60 and 80 kg with a mean value of 70 kg. Theprobabilistic calculation of riskinvolves random sampling fromeach ofexposure variable distributions.

The output of the exposure assessment process is a distribution of risk estimates. When the calculation of risk (or any other model endpoint) is repeated many times using MCS to sample the variables at random, the resulting distribution of risk estimates can be displayed in a similar fashion. In addition, the normal distribution of HI for the metal of Ca in SW1 for Child is shown in Figure 9. The total normal distribution is represented by both the PDF and CDF which represented the same distribution including summary of statistics, but are useful for conveying different information.

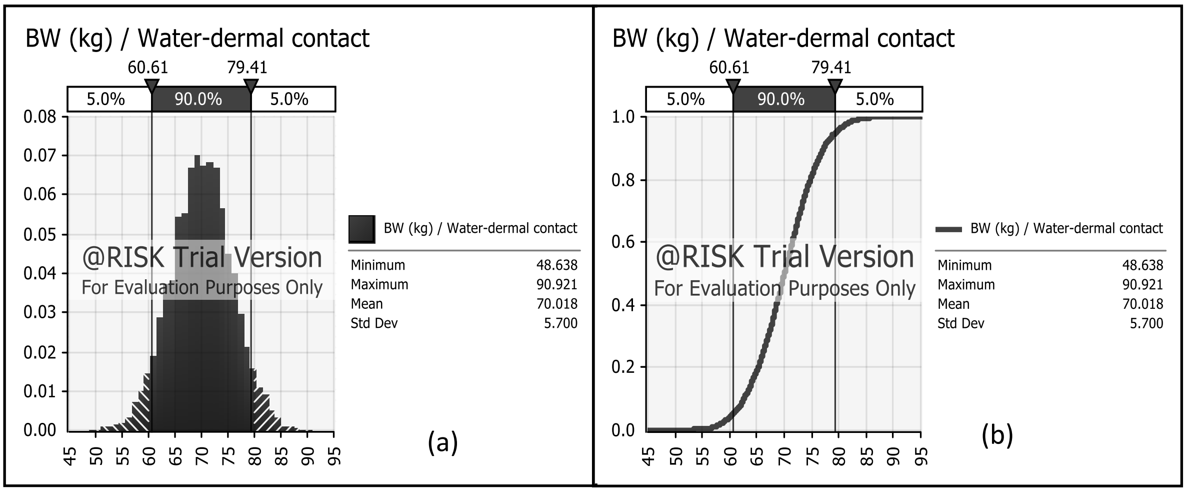

Figure 8: Normal distribution of BW for water dermal contact as (a) Bell-shaped curve represents the PDF and (b) S-shapedcurve represents the CDF

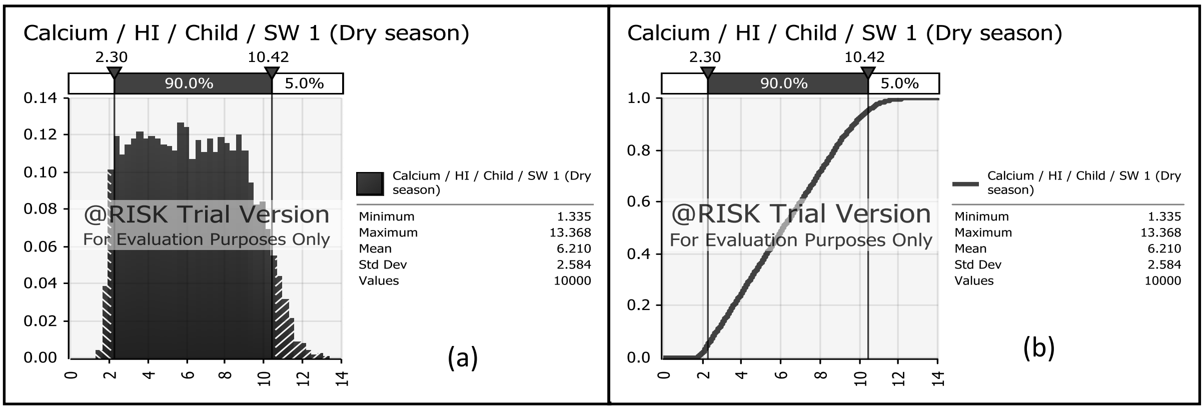

Figure 9: Normal distribution of HI of Calcium inSW1 for Child as (a) Bell-shaped curve represents the PDF and (b) S-shaped curverepresents the CDF.

4. CONCLUSIONS

Result reveals that the values of CDI, HQ and HI for metal in surface and ground water for rainy season was found comparatively higher than dry reason.In addition, HQ for ingestion route was comparatively higher than that of dermal for almost all metals. However, Ca showed the highest values of HI with 2.45E+01, exceed the acceptable non-carcinogen limit of 1. On the basis of HI, metals hazardous sequel should be like as Ca> k> Na> Cd> Cr> Pb> Mn> Cu> As> Fe> Ni> Zn in groundwater. Furthermore, results reveal that the values of HQ in case of ingestion route for surface water were found to be higher than that of dermal condition. In addition, RME showed the higher values of HQ in compare to CTE. Ca possess more hazards in RME condition during rainy season as it has maximum HQ valuefor surface water. Results of Pearson's correlation and PCA indicated that Fe, Mn, Cu and Ca were generated from anthropogenic sources, while, Cd, Cr, Ni, Pb, K and As from natural sources.

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ASSESSMENT OF CONTAMINATION POTENTIAL OF GROUNDWATER ADJACENT TO THE WASTE DISPOSAL SITE AT KHULNA: CONTAMINATION INDICES, MULTIVARIATE STATISTICS AND GEOSTATISTICAL APPROACH

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ABSTRACT

The main focus of this study was to evaluate the contamination potential of groundwater using various contamination indices available in the literature. To these attempts, fifteen water samples were collected from selected production well located nearby waste disposal site at Rajbandh, Khulna, Bangladesh. In the laboratory, the concentrations of heavy metals of Fe, Mn, Cr, Cu, Pb, Zn, Ni, Cd, Na, K, Ca, As, Mg in water were measuredthrough standard test methods. The groundwater contamination indices such as groundwater quality index (GWQI), degree of contamination (C_d), heavy metal pollution index (HPI) and heavy metal evaluation index (HEI) were used to quantify the level of contamination. In this study, for evaluating the level of contamination, the standard limit and ideal values of groundwater were obtained from BIS (10500:2012) and BDS (1240:2001), respectively. Numerous researchers published various limits for GWQI, C_d, HPI and HEI for categorized the level of contaminations such as excellent water, good water, poor water and very poor water. In this study, result of GWQI reveals that 26.67% of total water samples belong to very poor, while, 73.33% belong to poor water. The correlation between these four indices indicated that GWQI and C_d provided better results with consistent value.Result of Pearson's correlataion depicts that most of the heavy metals were barely correlated.In addition, results of PCA indicated that As in groundwater was contaminated from anthropogenic activities, while, Na, Ca and Mg were from natural sources. The heavy metals and various indices were distributed spatially. Finally, it is expected that outcomes of this study will provide a guideline for decision makers taking proper measures for groundwater quality management all over the world.

Keywords:*Disposal site, groundwater, heavy metal, contamination indices, PCA.*

1.INTRODUCTION

Waste disposal site or Landfilling is widely used inmunicipal solid waste (MSW) management practices in developing countries (Mangimbulude, Breukelen, Krave, Straalen, & Röling, 2009).landfills have been the most common method of organized MSW disposal and remain so in many places around the world.MSW landfill is a method of disposing of refusal on land by utilizing the principles of engineering. Leachate, a toxic liquid generated in municipal landfill contains large amounts of organic and inorganic contaminants by means of physical, chemical and microbiological changes. The leachate will continuously migrate through the soil strata and eventually the groundwater systemthat have been contaminated with heavy metals such as lead, copper, zinc, iron, manganese, chromium, cadmium and these heavy metals in MSW lead to serious problems because they cannot be bio-degraded. Khulna, the third largest city of Bangladesh is located at the south-western part of the country. It has an increasing growth rate of 5% having total population of 2.3 million in Khulna zilla(BBS, 2011).In addition, water is the basic and one of the vital physical components to run the livelihood. But safe and adequate sustainable drinking water is all that the mankind need. With an increasing rate of this population, demand of drinking water also increases. River, pond, rain, and groundwater are the main source of water. But, in coastal region like Khulna, salinity of water induced many problem. Rivers in Khulna region are established as polluted(Sabbir et al., 2010; Ahmed et al., 2015). It also includes heavy metal contamination (Kibria, Hossain, Mallick, Lau, & Wu, 2016). Groundwater is a valuable renewable resource and usually microbiologically safe and chemically stable in the absence of direct contamination(WHO, 2011). The quality of groundwater primarily depends on geological formation of a particular region as well as anthropogenic or human activities. In this study, fifteen water samples were collected from production well located nearby waste disposal site at Rajbandh, Khulna, Bangladesh. In te laboratory, the concentrations of relevant heavy metals of Fe, Mn, Cr, Cu, Pb, Zn, Ni, Cd, Na, K, Ca, As, Mg in water samples were measured through standards test methods. The groundwater contamination indices such as groundwater quality index (GWQI), degree of contamination (C_d), heavy metal pollution index (HPI) and heavy metal evaluation index (HEI) were used to quantify the level of contamination.

2.MATERIALS AND METHODS

2.1.Study Area

Khulna is the south-western sea-adjacent third largest city in the geography of Bangladesh on the banks of Rupsha and Bhairabriver. It's located at 22°49′0″N 89°33′0″E with a total area of 4394.46 km^2. The selected disposal site at Rajbandh(Figure 1)is a place 7 km north from Khulna city center which is currently used for open filling of MSW.The waste disposal site i.e. causes contamination of surrounding surface water bodies, groundwater sources and underlying soil layer. For drinking and irrigation purpose groundwater is the main source in Khulna division and that's why toxicity control in such area is a mandatory work to do.

Figure 1: Water sampling location from production wells nearby

2.2. Collection of groundwater

Before collecting water samples the bottle was washed by distilled water several times. Then the bottles were air or sun dried. Then 2-3 mL a solution was used as preservative. The preservative was prepared by mixing concentrated nitric acid and distilled water at a ratio of 1:1. Then the bottle was kept for 24 hours at room temperature. After that the bottles were prepared for collecting water sample. In this study, fifteen groundwater samples were collected from selected production wells or tube wells located adjacent to the waste disposal site at Rajbandh of Khulna, Bangladesh. Moreover, fifteen surface water samples were collected from pond located at the mentioned locations. All the sampling points were gathered with the help of GPS shown in Figure 1. These study periods covered both the dry and rainy seasons.

2.3. Laboratory Investigations

Both the water samples were collected from the site and then brought to DPHE, Khulna, Bangladesh. The concentrations of heavy metals of Fe, Mn, Cr, Cu, Pb, Zn, Ni, Cd, Na, K, Ca, As in water were measured through atomic absorption spectrophotometer (AAS).

2.4.Drinking water evaluation indices

To evaluate the level of contamination of groundwater, various indices such as groundwater quality index (GWQI), degree of contamination (C_d), heavy metal pollution index (HPI) and heavy metal evaluation index (HEI) proposed by different researchers were used and hence discussed in the following articles.

2.4.1. Ground water quality index:

GWQIhelps to determine the acceptability of drinking water.Groundwater quality of the collected water samples from different production well nearby waste disposal site was investigatedusing the following Equation 1.

$$GWQI = \sum SI_i = \sum(W_i \times q_i) = \sum[\left(\frac{w_i}{\sum_{n}^{i=1} w_i}\right) \times \left(\frac{C_i}{S_i} \times 100\right)] \quad (1)$$

Where C_i is the concentration of each heavy metal, S_i is the limit values, $w_i$is the assigned weightage, q_i is water quality rating, W_i is the relative weight, $SI_i$is the sub-index of *i*thheavy metal. In this study, the weight factors and limit values proposed by (Nabizadeh et al., 2013)and (Vasanthavigar et al., 2010) were considered for evaluating GWQI provided in Table 1

Table 1: Parameters, weight factors and limit values considered for GWQI

Parameter	Units	Weight factor (w_i)	Relative Weight (W_i)	Limit value(s_i), BIS
Fe	mg/l	4	0.10	0.300
Mn	mg/l	4	0.10	0.3
Cr(+6)	mg/l	4	0.10	0.05
Cu	mg/l	2	0.05	1.5
Pb	mg/l	4	0.10	0.01
Zn	mg/l	3	0.07	5
Ni	mg/l	3	0.07	0.1
Cd	mg/l	4	0.10	0.005
Na	mg/l	4	0.10	200
K	mg/l	2	0.05	12
Ca	mg/l	2	0.05	200
As	mg/l	4	0.1	0.01
Mg	mg/l	2	0.05	100
	$\sum w_i =$	42	$\sum w_i = 1.00$	

2.4.2.Heavy metal pollution index(HPI)

Heavy metal pollution index (HPI), is a rating method that qualify water quality with respect to heavy metals by assigning unit weightage (W_i). The unit weightage (W_i) is defined inversely proportional to the standard value (S_i) (Mohan et al.,1996).In this study, HPI was computed using the following Equation (2).

$$HPI=\frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (2)$$

Where, $Q_i$is the sub-index of the *i*th parameter and $W_i$is unit weight of the *i*th parameter and *n* is the number of parameters. The sub-index $Q_i$is computed byEquation (3)

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i(-)I_i\}}{(S_i - I_i)} \quad (3)$$

Where, M_i, I_i, and $S_i$denote for the 'monitored value', 'ideal value' and 'standard values' of the *ith* parameter respectively. The negative sign (−) denotes for numerical difference of the two values, ignoring the algebraic sign. Moreover, the unit weightage $W_i$was computedusing following Equation (4).

$$W_i = \frac{K}{S_i} \quad (4)$$

Where K is proportional constant.
In this study, the concentration limits i.e., standard value (S_i) and ideal value (I_i) for each heavy metal in water were taken from BIS (2012) andBDS (1240:2001), respectively.

2.4.3.Heavy metal evaluation index(HEI)

Heavy metal evaluation index (HEI) is a method of evaluating water quality parameter contaminated with heavy metal and interpret a thorough investigation of the level of contamination in groundwater(Prasad & Jaiprakas, 1999).In this study, HEI was calculated using the following Equation (5).

$$HEI= \sum_{i=1}^{n} \frac{H_c}{H_{mac}} \quad (5)$$

Where, H_c and H_{mac} are monitored and maximum admissible value, respectively.

2.4.4.The degree of contamination (C_d)

The degree of contamination of groundwater was computed fromthe following Equation (6)(Backman, Bodiš, Lahermo, Rapant, & Tarvainen, 1998),

$$C_d = \sum_{i=1}^{n} C_{fi} (6)$$

Where, $Cf_i = (\frac{C_{ai}}{C_{ni}}) - 1$ (6)

Where,$Cf_i$is the contamination factor, $C_{ai}$and $C_{ni}$are the analytical value and upper permissibleconcentration for the *i*th component respectively, and *n* is indicated for the normative value. Here, $C_{ni}$was taken as maximum permissible concentration

2.5.Multivariate Statistical Analysis

In this study, Pearson's correlation, principal component analysis (PCA) and cluster analysis (CA) were performed using XLSTAT. Pearson correlation was carried out in this study to demonstrate the correlation coefficient matrix of the water quality data in which coefficients of correlation data was calculated using the following Equation (7).

$$r = \frac{\sum(xy) - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2][n(\sum y^2) - (\sum y)^2]}} \quad (7)$$

2.6.Geo-statistical Modeling

For Geostatic Modeling, Ordinary Kriging(OK) was performed using ArcGIS as an optimal interpolation based on regression against observed values of surrounding data points, weighted according to spatial covariance values(Bohling, 2005).The spatial variation can be illustrated by thefollowing Equation (8) proposed byDelhomme (1978).

$$\hat{z}(X_o) = \sum_{i=1}^{n} \lambda_i Z(x_i) \qquad (8)$$

Where ẑ is the Estimated value of an attribute at the point of interest x_o, z is the observed value at the sample point x_i, n is the number of sampled points, λ_i is the weight assigned to the sampled point.

3.RESULTS AND DISCUSSION

The results of groundwater quality, various indices, the correlations and the spatial distribution of heavy metals are presented and hence discussed in the following articles.

3.1.General Characteristics of Groundwater Quality

The descriptive statistics such as maximum, minimum mean, standard deviation (SD) and variance of heavy metal in groundwater of production well nearby disposal site are provided in Table 2. The values of SD indicates how much the parameters deviates from the mean value. In this study,the maximum SD was found for Ca (33.88218) denoted that the concentration of Ca was spread widely from the mean value of it. The heavy metal of Ni have the lowest SD (0.010898) indicated that it is closely related to the mean value. The variance is the squared numerical value of SD of the randomly selected parameter. In this study maximum and minimum variance follow standard deviation of parameters respectively.

Table 2: Descriptive statistics of physiochemical parameters of heavy metal in study area

Parameter	Maximum	Minimum	Mean	Std. Deviation	Variance	BIS (2012)	BDS (2001)
Fe	2.3	0.01344	0.426193	0.539286	0.290830	0.3	1
Mn	0.352	0.016	0.219326	0.299833	0.089900	0.3	0.1
Cr (+6)	0.135648	0.007	0.040888	0.024517	0.000601	0.05	0.01
Cu	0.95	0.34	0.554938	0.162604	0.026440	1.5	0.05
Pb	0.05755	0.02	0.02598	0.012682	0.000160	0.01	0.05
Zn	1.8	0.029	0.576960	0.542613	0.294429	5	3
Ni	0.089	0.033	0.052305	0.010898	0.000118	0.1	0.02
Cd	0.07	0	0.142028	0.177738	0.031590	0.005	0.003
Na	120	8	31.82222	29.55271	873.3627	200	150
K	30.83	11	15.52592	4.207834	17.70587	12	10
Ca	258	13	40.36790	33.88218	1148.002	200	75
As	0.045	0.002	0.013889	0.01270	0.000161	0.01	0.05
Mg	116	43	56.87511	7.976963	63.63193	100	30

3.2.Evaluation of Drinking Water Quality

Ground water quality index is used for rating the suitability of ground water for drinking purpose (Abbasi & Abbasi, 2012). (BIS, 2012) and BDS (2001) have given the maximum permissible concentration of the selected parameter.Vasanthavigar(2010) showed a procedure for measuring the water quality index in 15 sampling points having GWQI values ranges from 114.338 to 226.535 with a mean of 182.308 (Table 3). GWQI Result reveals that 26.67% of total water samples (GW2, GW3, GW4, GW5) belong to very poor water as well as remaining 73.33% of total water samples belong to poor water (GW1, GW6, GW7-15). C_d refers to the minimum, maximum and mean value of pollution level i.e. 0.140, 12.196 and 7.544 respectively (Table 4).HEI ranges from 2.77 to 255.13. In this study based on HEI 73.33% of samples were less polluted water, 6.67% of samples contain medium polluted water and 20%

of them is high polluted water.From the comparing perspective, the three classification kinds GWQI, HEI, C_d gives a similar result regarding water quality in Khulna region i.e. poor or very poor quality of water where the HPI value announced that the sample water is not suitable for drinking purpose. However among the four indices, GWQI & C_d interprets good result, marks the ground water as poor and very poor water but not unsuitable for drinking at all.

Table 3: Groundwater indices evaluation: Drinking water quality indices.

Sample ID	**GWQI**	**C_d**	**HEI**	**HPI**
GW1	157.33	5.017488	3.21652	502.122
GW2	203.66	9.798888	37.4223	1016.86
GW3	226.53	12.19627	2.98990	1315.00
GW4	220.77	11.53266	2.77199	1341.08
GW5	220.77	11.53	255.133	1341.08
GW6	114.34	0.14	126.039	67.7539
GW7	160.69	5.015611	4.71165	920.573
GW8	190.04	8.791011	4.58955	889.238
GW9	193.13	8.674593	4.53077	913.778
GW10	198.28	9.218133	3.70521	1251.90
GW11	159.48	5.049558	17.7109	838.600
GW12	164.70	5.562125	3.84595	983.282
GW13	122.03	1.336918	5.79016	295.899
GW14	197.45	9.1897201	2.99868	988.249
GW15	205.41	10.10532	3.88761	1141.37
Minimum	114.34	0.14	2.77199	67.7539
Maximum	226.53	12.19627	255.13	1341.08
Mean	182.31	7.54	31.96	920.45

Table 4: Classification of the groundwater quality of the study area based on modified categories of quality indices value.

Index Method	**Category**	**Degree of pollution/ Water Class**	**Number of locations**	**% of Sample**	**Sample ID**
HPI	<45	Low	0	0	
	45-90	Medium	1	6.67	GW6
	>90	High	14	93.33	GW1, GW2, GW3, GW4, GW5, GW7, GW8, GW9, GW10, GW11, GW12, GW13, GW14, GW15
HEI	<10	Low	11	73.33	GW1, GW3, GW4, GW7, GW8, GW9, GW10, GW12, GW13, GW14, GW15
	10-20	Medium	1	6.67	GW11
	>20	High	3	20	GW2, GW5, GW6
Cd	<10	Low	12	80	GW1, GW2, GW6, GW7, GW8, GW9, GW10, GW11 GW12, GW13, GW14, GW15
	10-20	Medium	3	20	GW3, GW4, GW5
	>20	High	0	0	

GWQI	<50	Excellent water	0	0	
	50-100	Good Water	0	0	
	100.1-200	Poor water	11	73.33	GW9, GW10, GW11, GW12, GW13, GW14, GW15
	200.1-300	VeryPoor water	4	26.67	GW2, GW3, GW4, GW5
	>300	Not suitable for drinking water	0	0	

Pollution source and factors affecting ground water quality

Multivariate statistical techniques e.g. correlation analysis, principle component analysis (PCA) and cluster analysis (CA) are commonly used in environmental engineering studies to understand the sources of pollutants better(Mendiguchía, Moreno, Galindo-Riaño, & García-Vargas, 2004). PCA obstains observation vs. factors graph and variables vs. factors graph. In this study F1 & F2 indicates anthropogenic and natural sources of pollution. The graphical representation of observation vs. factors shows that GW5, GW11 are polluted by antropogenicsources where natural sources pollutes the GW6,GW12,GW7 sample points. GW1,GW2,GW8 are polluted by more or less of both sources as their points are significantly far from the factors (Figure 2). From the variables vs. factors graph it can be seen that the heavy metal of As contamination occurs due to anthropogenic pollution and the Na, Ca, Mg pollution is the result of natural pollution. Cu, K, Cr pollution of site are strongly inter-related based on the sources of pollution as they rely closly on the graph (Figure 2).

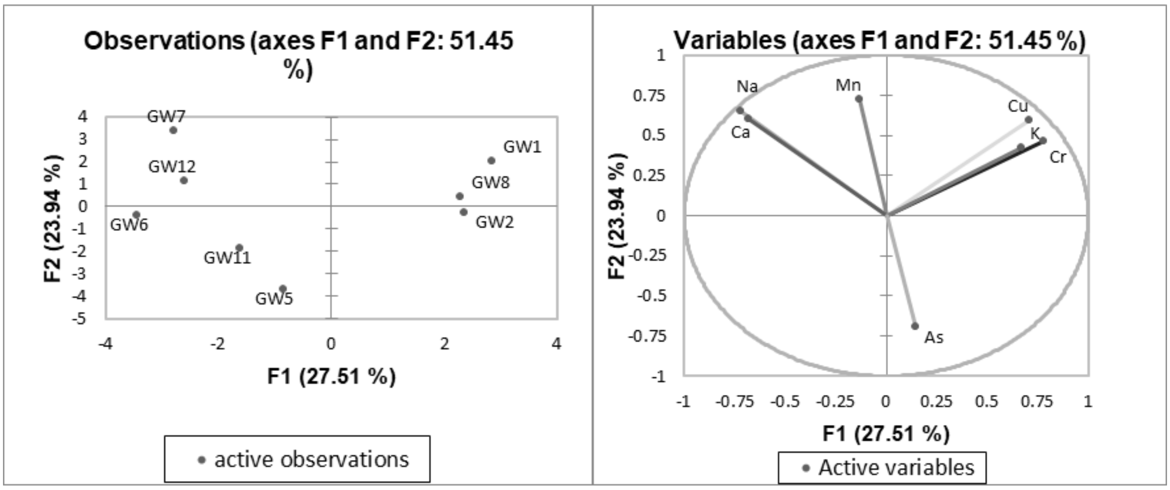

Figure2: PCA Analysis for active observation and active variables

Table 5: Varimax rotated principal component analysis for groundwater samples.

SiteQ mode	F1	F2	` F3	F4	F5
GW1	2.842	2.047	-1.053	-2.019	-0.737
GW2	2.348	-0.264	-0.219	-0.628	0.358
GW3	1.687	-0.639	1.271	1.248	-0.903
GW4	0.213	-2.167	1.061	0.830	0.648
GW5	-0.846	-3.673	1.084	-2.526	-0.260
GW6	-3.432	-0.373	-2.866	-0.001	1.142
GW7	-2.777	3.387	2.826	-0.052	-0.198
GW8	2.279	0.434	-0.096	-0.320	0.213
GW9	1.362	0.515	-0.990	1.406	-1.139
GW10	0.010	-1.249	-0.583	1.200	-0.721
GW11	-1.618	-1.854	-0.645	0.766	-1.228
GW12	-2.606	1.142	0.244	-0.813	-1.409
GW13	-0.332	2.117	-1.636	-0.107	0.660

GW14	0.523	0.924	0.722	1.025	1.052
GW15	0.347	-0.346	0.881	-0.008	2.522

3.3.Spatial similarity and sampling sites grouping

Q-mode Cluster analysis was performed to establish the dendrogram of source-based similarities among disposal site and the factor points. This Dendrogram (Figure 3) denotes the similarities in sources with respect to experimented parameters in a sample cluster. (Bodrud-Doza et al., 2016).

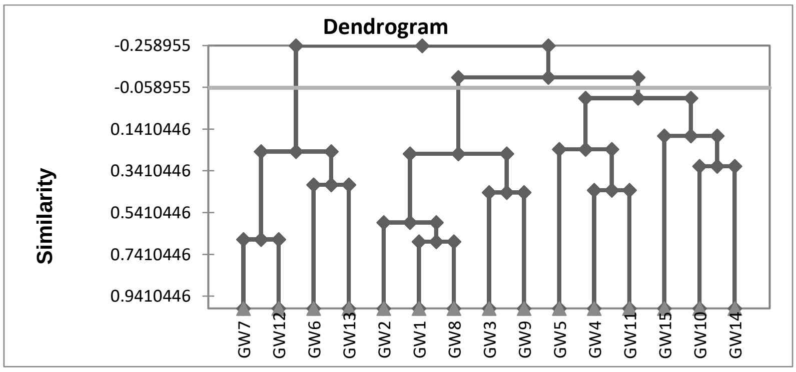

Figure 3: Dendrogram of similarity of parametersand sample locations

The 15 sampling site categorized into three clusters; cluster 1 includes 5 sampling points which areGW1-3, GW8-9. Six sample points fall into cluster 2 category and they are GW4-5, GW10-11, GW14-15. Cluster 3 have 4 sampling points at GW6-7 and GW12-13. Cluster categories express the similarity of pollution sources among the sampling points. Main sources of contamination are agricultural fertilizer, domestic sewage drainage, leaching of parent materials, agricultural runoff and so on. The contamination is grouped of two kinds e.g. natural sources and human activity sources.

3.5.Spatial distribution map

From Arc GIS, various types of spatial distribution was found from different indices which is shown in Figure 4. As for GWQI, the Eastern part of the landfill area shows higher values than the western area which denotes poor water and very poor water respectively. On the other hand, northern part of the landfill shows better quality of water than the southern part. As for C_d, it shows a lot similar distribution to the GWQI. This poor quality of water could be the reason for leaching of ions as well as discharge of wastes or agricultural impacts too (Sahu & Sikdar, 2008). Although the distribution of HPI and HEI shows a complex distribution pattern, the distribution of them shows more or less similar pattern. For both distribution, southern part of the area shows very poor water quality than the other sides. Anthropogenic sources may be responsible for this high number of HEI and HPI.

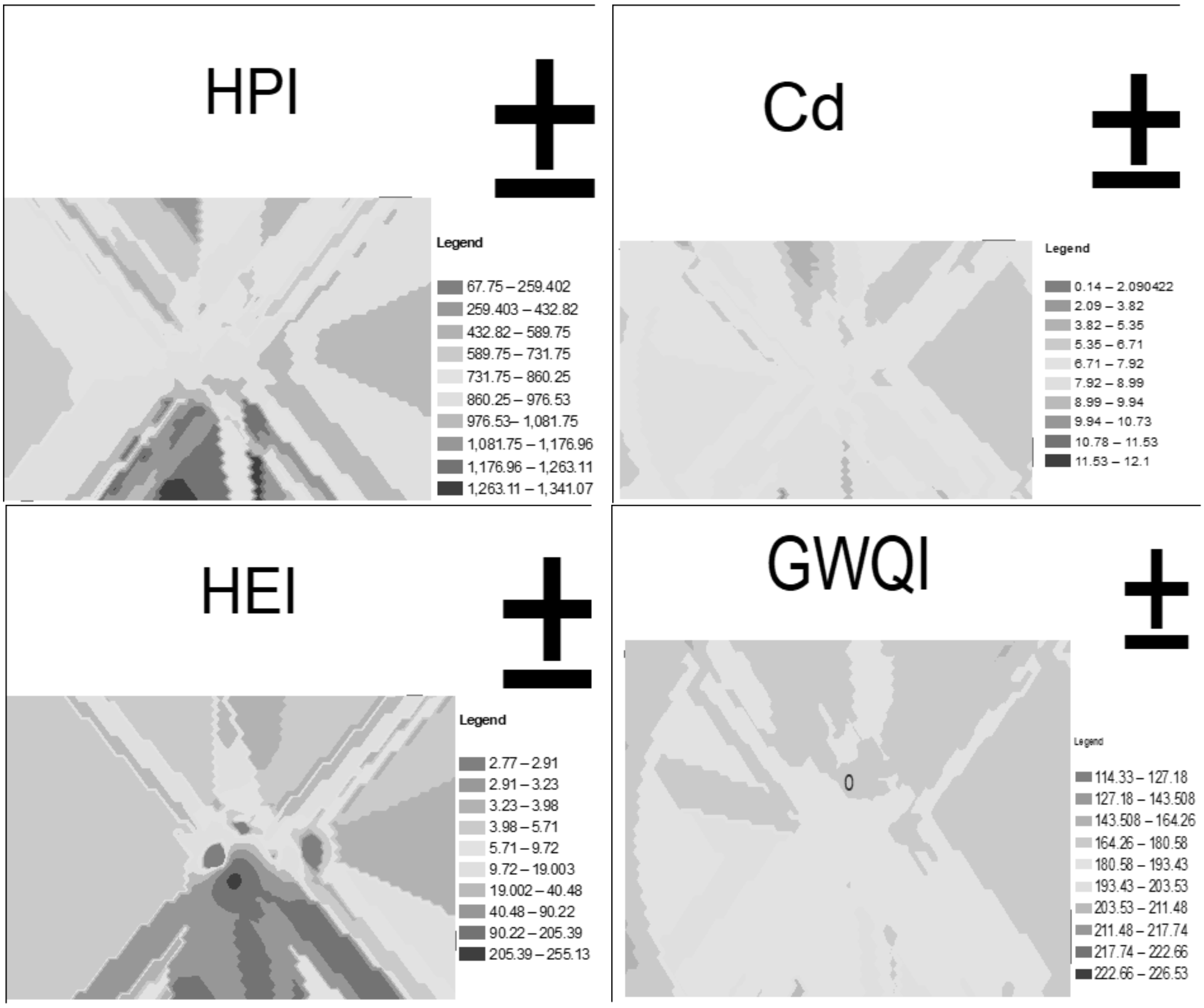

Figure 4: Spatial Distribution map for Four indices near Rajbandh, Khulna.

3.6.Correlation matrix analysis

Pearson's correlation was used to measure the interrelationship and coherence pattern among of groundwater quality parameters. Correlation matrix(Table 6) showed inter-parameter relationships agreed with the results obtained from XLSTAT reported with a 95% confidence level.These correlation results indicated mixed source either anthropogenic origin or geogenic, which was identified by F1 and F2 respectively.Anthropogenic sources dominant due to waste disposal.Whereasnatural activities involved in groundwater chemical alteration.Waste disposal may be attributed the main sources of this groundwater hydro chemical evolution in the study area.The Pearson’s correlation matrix of metal elements in groundwater is provided in Table 6. The most significant correlation was observed for Na and Ca (0.938). However, the concentrations of Fe showed very weak positive correlations with Cr (0.005). This indicated that Fe was from different sources than Cr (Yao, Li, Xie, & Yu, 2012). Based on the results of Pearson’s correlations matrix on waste disposal site, it was observed the high positively correlations between Na and Ca (0.938), Cr and Cu (0.831), Ca and Mg (0.714), Cu and K (0.675), Pb and K (0.632) as well as Mn and Na (0.534) in Table 6.

Table 6: Pearson's correlation matrix of heavy metals in water of wate disposal site

	Fe	Mn	Cr	Cu	Pb	Zn	Ni	Cd	Na	K	Ca	As	Mg
Fe	**1**												
Mn	-0.158	**1**											
Cr	0.005	0.204	**1**										
Cu	0.245	0.317	0.831	**1**									
Pb	0.249	0.086	0.547	0.500	**1**								
Zn	-0.127	0.130	-0.281	-0.009	-0.002	**1**							
Ni	-0.067	-0.414	-0.417	-0.537	-0.052	0.075	**1**						
Cd	-0.067	-0.094	0.023	0.131	0.209	0.056	-0.102	**1**					
Na	-0.306	0.534	-0.326	-0.160	-0.170	0.346	0.055	-0.016	**1**				
K	0.251	-0.036	0.651	0.675	0.632	-0.147	-0.055	0.442	-0.152	**1**			
Ca	-0.207	0.330	-0.268	-0.116	-0.131	0.331	0.064	-0.119	0.938	-0.111	**1**		
As	0.431	-0.581	-0.285	-0.293	0.060	0.108	0.108	-0.131	-0.500	-0.051	-0.390	**1**	
Mg	0.081	0.211	-0.072	0.020	0.164	0.212	0.342	-0.246	0.627	0.269	0.714	-0.154	**1**

4.CONCLUSIONS

In this study, to evaluate the level of contamination of groundwater collected from different selected production well located adjacent to the waste disposal site, various indices of GWQI,Cd,HPI and HEI were used.Results of GWQI reveals that 26.67% of total water samples (GW2, GW3, GW4, GW5) belong to very poor water, while, remaining 73.33% of total water samples belong to poor water (GW1, GW6, GW7-15). In addition, C_d refers to the minimum, maximum and mean value of contamination level i.e. 0.140, 12.196 and 7.544 respectively.HPI ranges from 67.76 to 1341.08 with a mean value of 920.45.In this study based on HEI 73.33% of samples were less polluted water, 6.67% of samples contain medium polluted water and 20% of them is highly polluted. From comparing perspective of these indices, GWQI and C_d indicated that the quality of water of production wells were poor and very poor condition respectively but not unsuitable for drinking purposes. The results of Pearson's correlations indicated that most of the heavy metals had highly positive correlations. Furthermore, results of PCA indicated that the contamination of As was from anthropogenic activities, while, Na, Ca and Mg from natural sources. The spatial distribution of various indices reveals that the contamination of water was found comparatively higher in the production well located near the disposal site as well as decreases in relation to the increasing of water sampling distances.

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APPLICATION OF A LOW-COST CERAMIC FILTER TO AN ALGAE BASED WASTE STABILIZATION POND SYSTEM

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ABSTRACT

Natural treatment systems (stabilzatin pond, constructed wetland) are gaining attention in developing countries having favourable climatic conditions. But further polishing of the effluents in a cost-effective manner is still a great challenge. In this study, a low-cost ceramic filter was applied to algal based Waste Stabilization Ponds (WSP) system for further improvement the effluent's quality. The applicability is investigated through lab-scale experiment using synthetic domestic wastewater. The low cost ceramic filter was made with 80% clay-soil and 20% rice bran on weight basis. The filter was fully submerged in a glass–made rectangular aquarium reactor. Synthetic wastewater was fed continuously into the reactor that contained algae (mainly Scenedesmus) mixed liquor; the effluent through the filter was obtained using a suction pump. The analyses results of different warter quality parameters of effluents showed that solid-liquid separation was occurred effectively with high organic removal (92% BOD removal) and 50% Nitrogen removal. Low filter clogging tendency (washing frequency: 0.025 times/d) was observed under the flux value of 0.01 m/d. Simple physical cleaning was found effective for filter maintenance. It is concluded that the ceramic filter can be effectively applied for up gradation of the effluent quality of WSPs or other similar treatment systems.

Keywords: *Stabilization pond, clay, ceramic filter, algae, natural treatment, low-cost technology*

1. INTRODUCTION

Instead of conventional one, natural treatment systems for wastewater (aquatic pond e.g., algae based waste stabilization pond, duckweed based waste stabilization pond, hyacinth pond; terrestrial e.g., soil aquifer treatment, overland flow; wetland e.g., natural marshes, free water surface constructed wetland, subsurface flow wetland) are considered more advantageous, especially for developing and tropical countries due to simplicity, low cost, least maintenance, entirely natural, small carbon footprint and highly efficient. (Crites et al., 2006).

Although the use of waste stabilization pond (WSP) as natural treatment system has already been recognized worldwide, the presence of high concentration of total suspended solids in the effluents, mainly algae, being the single major shortcoming of this technology and the systems often fail to meet reuse standards that are more stringent day by day (Neder et al., 2002; Short, 2008). As such, up gradation of WSPs is necessary which can provide significant removal of TSS, mainly algae while maintaining the major advantages of the pond systems (i.e. simplicity, low cost and low maintenance). Various physico–chemical and biological methods have been evaluated to enhance algae separation from the effluents of WSPs to meet the requirements for its intended re–use or disposal in receiving water bodies. These methods include membrane filtration (Asai, 2010), fine sand/silt filtration (Naghavi and Malone, 1986), sand filtration (Esen et al., 1995), intermittent sand filtration (Harris et al., 1977), rock filtration (Saidam et al., 1995), lime treatment (Folkman and Wachs, 1973), constructed wetlands (Tsalkatidou et al., 2009), roughing filters with constructed wetland (Kimwaga et al., 2004), electro–coagulation (Azarian, 2007), Moringa Oleifera coagulant (Mwangi et al., 2008), floating aquatic plant root mats (Kim and Giokas, 2003), duckweed, attached–growth media (Short, 2008), coagulation–flocculation, in–pond chemical precipitation of suspended materials, biological harvesting, granular media filtration (Neder et al., 2002). However, these technologies have some disadvantages such as: high installation cost, operational and maintenance difficulties, high sludge production, requirement of chemical compounds, requirement of low loading rates, inconsistent performance etc. Such drawbacks could be counter balanced by using low cost ceramic filters. A low-cost ceramic filter made with locally available and cheap materials (clay soil and rice bran) was developed for the application of arsenic (As) removal from groundwater and significant removal of As was achieved due to effective Fe-As floc separation performance of the filter (Hasan et al., 2012; Nakajima et al., 2010; Shafiquzzaman et al., 2011). Another study showed its potential application to MBR process for the separation of activated sludge under aerobic condition (Hasan et al., 2011; Hasan et al., 2014). This ceramic filter seemed to be applicable to algae based WSP system for the separation of algae to further improvement of its effluents. Therefore, the aim of this study to investigate the applicability of this ceramic filter to an algae based WSP system through lab-scale experiment.

2. METHODOLOGY

2.1 Manufacturing of low cost ceramic filter

The low-cost ceramic filter was manufactured according to the previous study (Hasan et al., 2012; Nakajima et al., 2010; Shafiquzzaman et al., 2011). The ingredients of the filter were clay soil and rice bran which were collected from a local brickfield and a rice processing factory respectively in Khulna city, south–western part of Bangladesh. The ratio of clay soil (dried, ground and sieved by 0.5 mm mesh) and rice bran (dried and sieved by 1 mm mesh) was 80:20 on weight basis. Sufficient amount of water was added with the mixture to make dough for making filter. A hollow cylindrical shape of the filter (10 cm height, 10 cm outer diameter and 4 cm inner diameter) was made with the dough by using a dice of wood and PVC pipe. After sun dried the filter was burnt at 900^oC in a small scale local kiln in the same region. The pore size of the filter was 1–5 µm. The manufacturing cost for one ceramic filter was estimated to be US$0.2–0.3.

2.2 Experimental set up and specification

Figure 1 shows the schematic interpretation of the experimental set up. A glass–made rectangular aquarium tank (28 litre effective volume with 60 cm (Length) × 30 cm (Width) × 26 cm (Height)) was used where the ceramic filter (filter area: 0.04 m^2) was fully submerged in algae mixed liquor. The reactor was artificially lightened (6000±500 lux and 12 hrs. cycle of dark and light) and was totally covered by black fabrics to prevent entering the light from outside. Synthetic wastewater (domestic), with glucose as the carbon source was fed continuously into the reactor. The initial concentration of BOD, N and P were kept constant as 20 mg/L, 40 mg/L and 4 mg/L respectively. The permeate effluent was obtained through the filter by suction pump. The algae mixed liquor was prepared by culturing the algae (mainly Scenedsmus and collected from Lake Biwa, Japan) around two weeks according to the conditions stated in Table 1 using the same synthetic wastewater. A pressure gauge was connected to record the transmembrane pressure (TMP). Water heater was also placed in the reactor to maintain the temperature of 25^oC.

The experiment was continued for 70 days with a flux value of 0.1 m/d and HRT of 7 days. The reactor was monitored by daily (at morning: after 30 minutes of light on and at evening: before three hours of light off) measurements of the reactors volume, temperature, pH, dissolved oxygen (DO) and TMP. The reactor volume was kept stable by controlling the feeding pumps. The BOD, T–N, NO_2–N, NO_3–N, PO_4–P concentrations in the effluent and SS and Chlorophyll–a (Chl–a) for algae concentrations in the reactor were measured periodically.

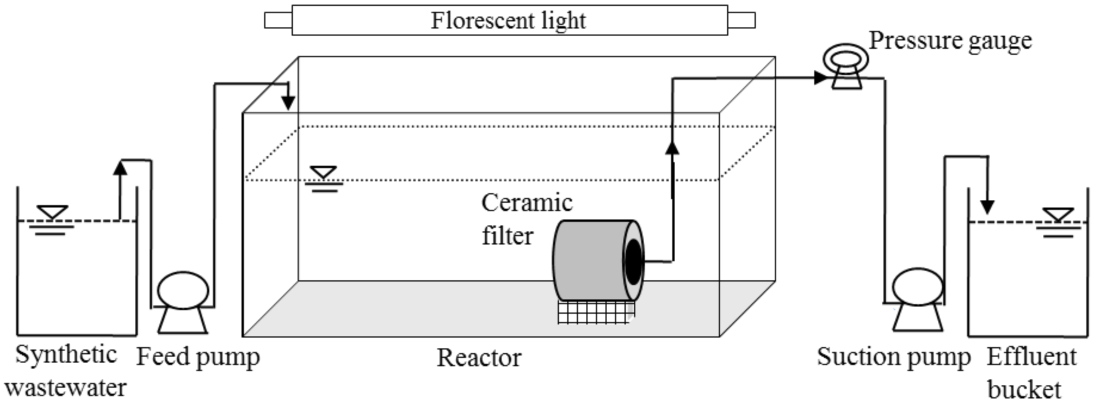

Figure 1: Sketch diagram of the experimental set up.

Table 1: Algae culture conditions

Parameters	Descriptions
Membrane module	Flat type, 0.4 µm pore size, Kubota, Japan
Reactor volume (L)	28
HRT (d)	7
Light: Dark cycle (hr)	12:12
BOD (mg/L)	20
P (mg/L)	4
N (mg/L)	40

2.3 Analytical methods

BOD, T–N, NO_2–N, NO_3–N and PO_4–P were measured by using the Japan Industrial Standard method (JISC, 2008). Molybdenum blue-ascorbic acid reduction colorimetric method was used for PO_4–P. T–N was measured by potassium peroxodisulfate digestion followed by ultraviolet spectrometry method. HITACHI U-2900 spectrophotometer was used for PO_4–P and T–N measurement. pH and DO were measured by using pH meter (HORIBA, F–21) and DO meter (HACH HQ 30d), respectively. Chl–a was measured by UV method (HPLC) using HITACHI U–2900 Spectrophotometer.

3. RESULTS

3.1 Operational conditions

It was observed that average value of pH at morning was 8.4±0.2 while at evening it was 8.5±0.2 during 70 days of operation. The higher value at evening might be due to uptake of CO_2 by algae during photosynthesis period. Therefore, the differences were observed in the morning and evening. The DO concentrations were found almost 2–3 times higher at evening time (average value: 8.5±1.6 mg/L) rather than morning (average value: 3.2±1.0 mg/L) which are also due to the O_2 production by algae during photosynthesis. Although the temperature was kept at 25°C, the high temperature during the evening time (average value: 29.5±1.1 ^{o}C) rather than morning time (average value: 25.7±0.5 ^{o}C) might be caused by the thermal radiation of the lights. In the case of actual stabilizing ponds, the wind aids re–aeration, but in this experiment the reactor was covered with black fabrics, so the influence of wind etc. cannot be considered. Though zooplankton and detritus also exist in SS in this study, but majority percentage would be algae as DO increases in evening period. The concentration of SS and Chl–a was 49.6±11.0 mg/L and 0.18±0.07 μmol/L respectively.

3.2 Organic removal

Figure 2 shows the BOD concentration in influent and effluent. Though the influent BOD concentration was 20 mg/L but the actual measurement was found 23.36 ± 1.30 mg/L on average. The average value of effluent BOD was 1.84 ± 2.0 mg/L and it took almost one week to decrease the BOD concentration <5 mg/L from 23.36 mg/L. Therefore, 92% BOD removal rate was achieved that indicated sufficient biodegradation of organic matter in 7 days HRT.

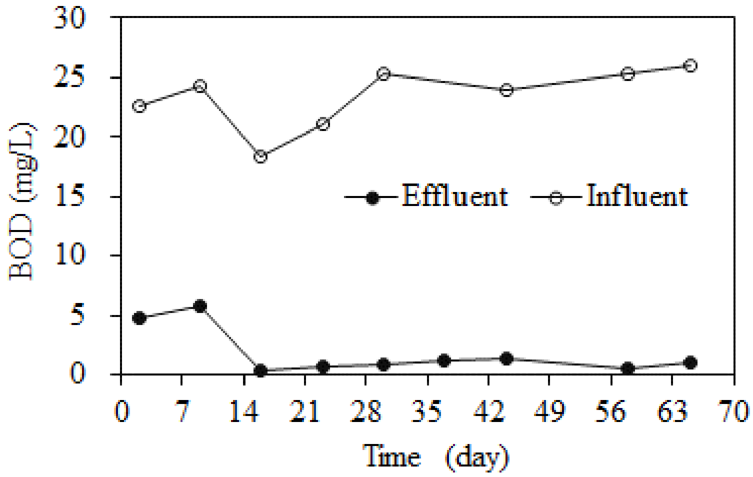

Figure 2: BOD concentrations in influents and effluents.

3.3 Nitrogen removal

Figure 3 shows the change of nitrogen (T–N, NO_2–N and NO_3–N) concentrations with time According to figure 3, NO_2–N concentrations decreased whereas NO_3–N concentration increased during 0 to 21 days and then remain stable. This suggested that nitrification was carried out via oxygen supply by photosynthesis of algae. The deviation between summation of NO_2 (3.9 ± 5.7 mg/L), NO_3 (12.2 ± 4.1 mg/L) and T–N (21.3 ± 3.5 mg/L) emphasized insignificant denitrification activities due to lack of organic carbon. Consequently, the nitrogen removal rate was around 50%.

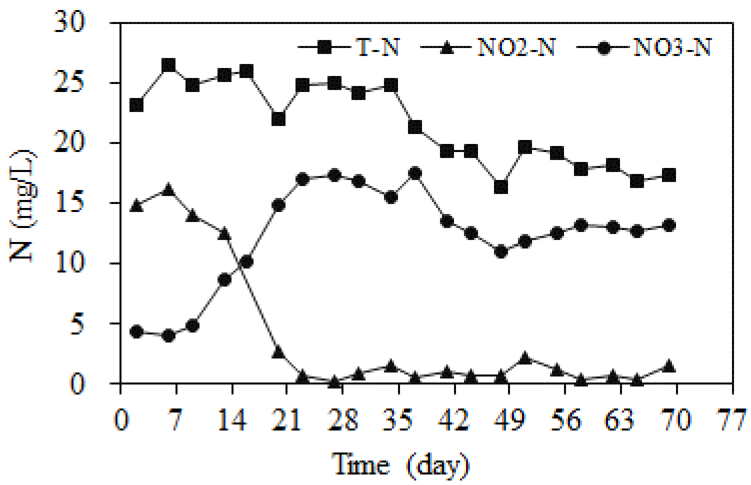

Figure 3: Nitrogen concentrations in effluents.

3.4 Phosphorus removal

Low removal of phosphorus was observed during the experiment (figure 4). Literature also reported the lower removal rate of phosphorus in the stabilizing pond which would to be approximately 15% to 50% (Garcia et al., 2000). It also stated that phosphorus removal in the stabilizing pond method is insignificant in the absence of added chemical for coagulation and reported that phosphorus can be reduced to 1 mg/L or less by adding aluminium sulphate or ferric chloride (Reed, 1995).

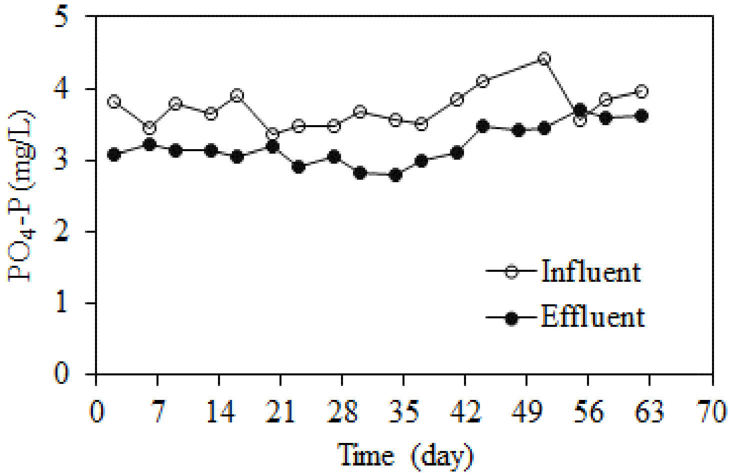

Figure 4: Phosphorus concentrations in influents and effluents.

3.5 Filter maintenance

A green layer of accumulated algae on filter surface was found during the operations that increase the Transmembrane Pressure (TMP). While reach the TMP value equal to 3.0 MPa the filter was cleaned physically using soft brush with water rinse and found effective to reclaim the flux performance (figure 5). Therefore, reversible fouling of the filter was observed during the operations. It was required only one time cleaning the filter during 70 days of operation indicated low clogging tendency (washing frequency: 0.025 times/d) under flux value of 0.1 m/d. Also, if necessary the filter could be replaced by a new one because its manufacturing procedure was easy and inexpensive.

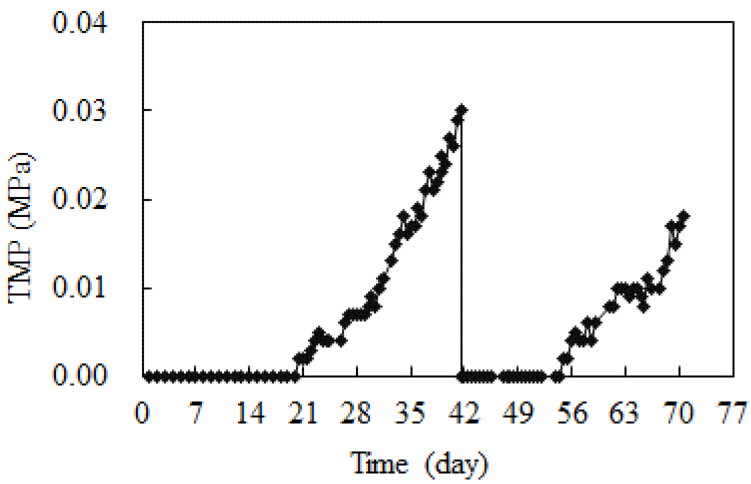

Figure 5: TMP profile during 70 days of operation.

4. CONCLUSIONS

The main conclusions could be summarized as follows:
Efficient solid-liquid separation, especially algal community was achieved while using the low-cost ceramic filter; 92% BOD and 50% nitrogen removal was observed; low clogging tendency of filter was found under flux value of 0.1 m/d; simple physical cleaning was found effective for filter maintenance; more trials are required to identify optimum hydraulic loadings and associated size and shape of the filter prior to real–scale application.

ACKNOWLEDGEMENT

This work was partly supported by the Open Research Centre Project for Private Universities Matching Fund from the Ministry of Education, Culture, Sports, Science and Technology, Japan. The contribution of Mr. Seiki Kitamura during data collection was highly acknowledged.

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