ASSESSMENT OF WATER QUALITY AND PERFORMANCE EVALUATION OF A WATER TREATMENT PLANT: A CASE STUDY

By

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Department of Chemistry

CHITTAGONG UNIVERSITY OF ENGINEERING AND TECHNOLOGY

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Philosophy in Chemistry

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August 2023

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Beloved Wife

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Loving Son

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Abu Mansur

August, 2023 Author of this Thesis

Abstract

Rapid urbanization in Bangladesh places immense stress on the government to provide essential services, with safe drinking water and sanitation being paramount challenges. Population growth and industrialization have intensified the demand for safe drinking water, making water treatment a critical aspect in safeguarding public health and the environment. This study assesses the performance of the Mohara Water Treatment Plant (MWTP) operated by the Chattogram Water Supply and Sewerage Authority (CWASA), which serves as the primary drinking water source for Chattogram City, covering the period from December, 2020 to October, 2021.

Performance evaluation of the MWTP focused on the removal efficiency of turbidity and six additional parameters: chloride, ammonia, TSS, COD, Total Coliform, and Fecal Coliform. The results demonstrated commendable performance, with removal efficiencies reaching 99.84 ± 0.03% for turbidity, 60.34 ± 12.51% for chloride, 100% for ammonia, 99.79 ± 0.05% for TSS, 97.11 ± 0.22% for COD, and 100% for both Total Coliform and Fecal Coliform.

The study also compares treated water quality to raw water across 26 parameters, aligning with guidelines from the World Health Organization (WHO), Bangladesh Standards and Testing Institution (BSTI), and Environment Conservation Rule-1997 (ECR-97). Notable findings include average Turbidity (0.38 ± 0.07 - 0.64 ± 0.01 NTU), TDS (33.33 ± 1.21 - 767.67 ± 783.25 mg/L), Conductivity (65.5 ± 1.52 – 1323.3 ± 1325.49 μS/cm), pH (6.86 ± 0.02 - 6.97 ± 0.05), Temperature (23.03 ± 0.52 - 27.4 ± 0.09°C) and various other parameters within acceptable limits.

Remarkably, heavy metal levels (Arsenic, Lead, Cadmium, Mercury, Chromium) were undetectable, further validating the plant's efficiency in producing safe drinking water. In conclusion, the MWTP consistently demonstrates strong performance, effectively removing impurities and ensuring treated water meets stringent quality standards. This achievement is instrumental in addressing the challenges posed by rapid urbanization in Bangladesh while safeguarding public health and the environment.

বিমূর্ত

বাংলাদেশে দ্রুত নগরায়নের একটি অন্যতম প্রভাব হলো মৌলিক চাহিদা সরবরাহ করার জন্য সরকারের উপর তীব্র চাপ প্রয়োগ যেখানে নিরাপদ সুপেয় পানি এবং স্যানিটেশন প্রধান চ্যালেঞ্জ। জনসংখ্যা বৃদ্ধি এবং শিল্পায়ন নিরাপদ সুপেয় পানির চাহিদা বাড়িয়ে দিয়েছে যা জনস্বাস্থ্য এবং পরিবেশ রক্ষা করার ক্ষেত্রে পানি পরিশোধনকে একটি গুরু পূর্ণ বিষয়ে পরিণত করেছে। এই গবেষণাতে চট্টগ্রাম পানি সরবরাহ ও পয়ঃনিষ্কাশন কর্তৃপক্ষের অধীনে পরিচালিত মোহরা পানি শোধনাগারের ডিসেম্বর-২০২০ থেকে অক্টোবর-২০২১ পর্যন্ত সময়ের কর্মক্ষমতা মূল্যায়ন করা হয়েছে যেটি চট্টগ্রাম শহরে সুপেয় পানি সরবরাহের প্রধান উৎস হিসেবে কাজ করে। টারবিডিটি সহ আরো ছয়টি প্যারামিটার যথা- ক্লোরাইড, আমোনিয়া, টিএসএস, সিওডি, টোটাল কলিফর্ম এবং ফেকাল কলিফর্ম এর অপসারণ দক্ষতার উপর ভিত্তি করে মোহরা পানি শোধনাগারের কর্মক্ষমতা মূল্যায়ন করা হয়েছে। ফলাফলগুলি প্রসংশনীয় কর্মদক্ষতা প্রদর্শন করে যেখানে অপসারণের দক্ষতা টারবিডিটি এর জন্য ৯৯. ৮৪ ± ০. ০৩%, ক্লোরাইড এর জন্য ৬০. ৩৪ ± ১২. ৫১%, অ্যামোনিয়া এর জন্য ১০০%, টিএসএস এর জন্য ৯৯. ৭৯ ± ০. ০৫% সিওডি এর জন্য ৯৭. ১১ ± ০. ২২% টোটাল কলিফর্ম এবং ফেকাল কলিফর্ম এর জন্য ১০০% মান পর্যন্ত পৌঁছেছে।। গবেষণায় বিশ্ব স্বাস্থ্য সংস্থা (ডব্লিওএইচও), বাংলাদেশ স্ট্যান্ডার্ডস অ্যান্ড টেস্টিং ইনস্টিটিউশন (বিএসটিআই) এবং পরিবেশ সংরক্ষণ বিধি- ১৯৯৭ (ই সিআর- ৯৭) এর নির্দেশিকা অনুসারে অপরিশোধিত পানির ২৬ টি গুণাগুণের সাথে পরিশোধিত পানির ঐ সকল গুণাগুণের তুলনা করা হয়েছে। উল্লেখযোগ্য ফলাফলের মধ্যে রয়েছে গড় টারবিডিটি এর মান (০. ৩৮ ± ০. ০৭ - ০. ৬৪ ± ০. ০১ এনটিইউ) , টিডিএস (৩৩. ৩৩ ± ১. ২১ – ৭৬৭. ৬৭ ± ৭৮৩. ২৫ মি.গ্রা./লি.) , কন্ডাক্টিভিটি (৬৫. ৫ ± ১. ৫২ – ১৩২৩. ৩ ± ১৩২৫. ৪৯ মাইক্রোসিমেন্স/সেন্টিমিটার) , পিএইচ (৬. ৮৬ ± ০. ০২ - ৬. ৯৭ ± ০. ০৫) , তাপমাত্রা (২৩. ০৩ ± ০. ৫২ - ২৭. ৪ ± ০. ০৯ ডিগ্রি সেলসিয়াস) , এবং অন্যান্য প্যারামিটারের মান ও গ্রহণযোগ্য সীমার মধ্যে রয়েছে।

উল্লেখ্য যে, ভারী ধাতুসমূহ যেমন- আর্সেনিক ,লেড, ক্যাডমিয়াম, মারকারী এবং ক্রোমিয়ামের মাত্রা সনাক্ত করা যায়নি যা নিরাপদ সুপেয় পানি উৎপাদনে প্ল্যান্টের দক্ষতাকে অধিকতর সমর্থন করে।

পরিশেষে বলা যায় যে, মোহরা পানি শোধনাগার (এমডব্লিওটিপি) ধারাবাহিকভাবে দৃঢ় কর্মক্ষমতা প্রদর্শন করে, কার্যকরভাবে দূষণ অপসারণ করে এবং পরিশোধিত পানির কঠোর মানদন্ড পূরণ করা নিশ্চিত করে। জনস্বাস্থ্য ও পরিবেশ রক্ষার পাশাপাশি বাংলাদেশে দ্রুত নগরায়নের ফলে সৃষ্ট চ্যালেঞ্জ মোকাবেলায় এই অর্জন সহায়ক।

Table of Contents

Title	**Page**

Title	Page

Title	Page

List of Tables

List of Figures

Figure No.	Figure Caption	Page No

Figure No.	Figure Caption	Page No

List of Technical Symbol

Symbols	**Elaborations**
E. coli	*Escherichia coli*
gpd	Gallon per day
mg/L	Milligram per liter
CFU	Colony Forming Unit
ºC	Degree Celsius
μS/cm	Micro Siemens per centimeter
Cft	Cubic feet
μmhos/cm	Micro mhos per centimeter
µg/L	Micro gram per liter
MLD	Million liter per day

List of Abbreviations

AAS	Atomic Absorption Spectroscopy
APHA	American Public Health Association
ATSDR	Agency for Toxic Substances and Disease Registry
AWWA	American Water Works Association
BCSIR	Bangladesh Council of Scientific and Industrial Research
BDS	Bangladesh Standards
BLD	Below Limit of Detection
BOD	Biochemical Oxygen Demand
BSTI	Bangladesh Standard and Testing Institute
COD	Chemical Oxygen Demand
CWASA	Chattogram Water Supply and Sewerage Authority
DI	Ductile Iron
DO	Dissolved Oxygen
DPHE	Department of Public Health Engineering
DWASA	Dhaka Water Supply and Sewerage Authority
EC	Electrical Conductivity
HP	Horse Power
JTU	Jackson Turbidity Unit
KW	Kilo Watt
MF	Membrane Filter
ND	Not Detected
NOM	Natural Organic Matter
NTU	Nephelometric Turbidity Unit
ORP	Environment Conservation Rules-1997
TDS	Total Dissolved Solid
TSS	Total Suspended Solid
WHO	World Health Organization
WTP	Water Treatment Plant

CHAPTER I
INTRODUCTION

1.1 Background

Water, the essence of human existence, stands as an irreplaceable lifeline. The paramount importance of safe and potable drinking water cannot be overstated, as it serves as the cornerstone for human survival (Daudet et al., 2017). Regrettably, this invaluable natural resource is persistently threatened by the adverse effects of industrialization, urbanization, and population growth, leading to recurring water contamination (Akaniwor et al., 2007). Rivers, canals, ponds, and lakes, which act as reservoirs of fresh water, bear the brunt of pollution caused by industrial effluents, urban waste, and surface runoff (Akaniwor et al., 2007). Providing clean and safe drinking water is not only a matter of paramount importance for human health but also a fundamental right and an indispensable aspect of sustainable healthcare strategies (WHO, 2011; Gorde & Jadhav, 2013). Thus, ensuring the refinement and safety of water for human consumption becomes an imperative.

Water purification entails the meticulous elimination of potentially harmful contaminants to guarantee the safety of the water supply (Werkneh et al., 2015). The quality of water delivered to consumers relies heavily on the effectiveness of purification processes that adhere to stringent criteria and standards, prioritizing public health and the drinkability of water (Yousaf & Chaudhry, 2013; Gangil et al., 2013). However, developing countries face significant challenges due to their complex institutional structures, inadequate financing in the sanitation and water supply sector, and neglect of rural areas in water-related endeavors (Nhapi, 2015). Deterioration in the quality of drinking water poses a critical threat to public health, as substandard sanitation systems and contaminated water facilitate the transmission of diseases such as diarrhea, typhoid, cholera, polio, and dysentery (WHO, 2011; WHO, 2018). Consequently, it becomes imperative to take further measures to achieve the universal goal of improved access to modernized sanitation systems in these regions (Andersson et al., 2016).

For over three decades, approximately three million residents of Chattogram City have relied on the Halda River as their primary raw water source for drinking water production at the treatment plant (Bhuyan & Bakar, 2017). Unfortunately, the incessant contamination of the river water can be attributed to unregulated industrialization, rapid urbanization, and agricultural activities (Bhuyan & Bakar, 2017).

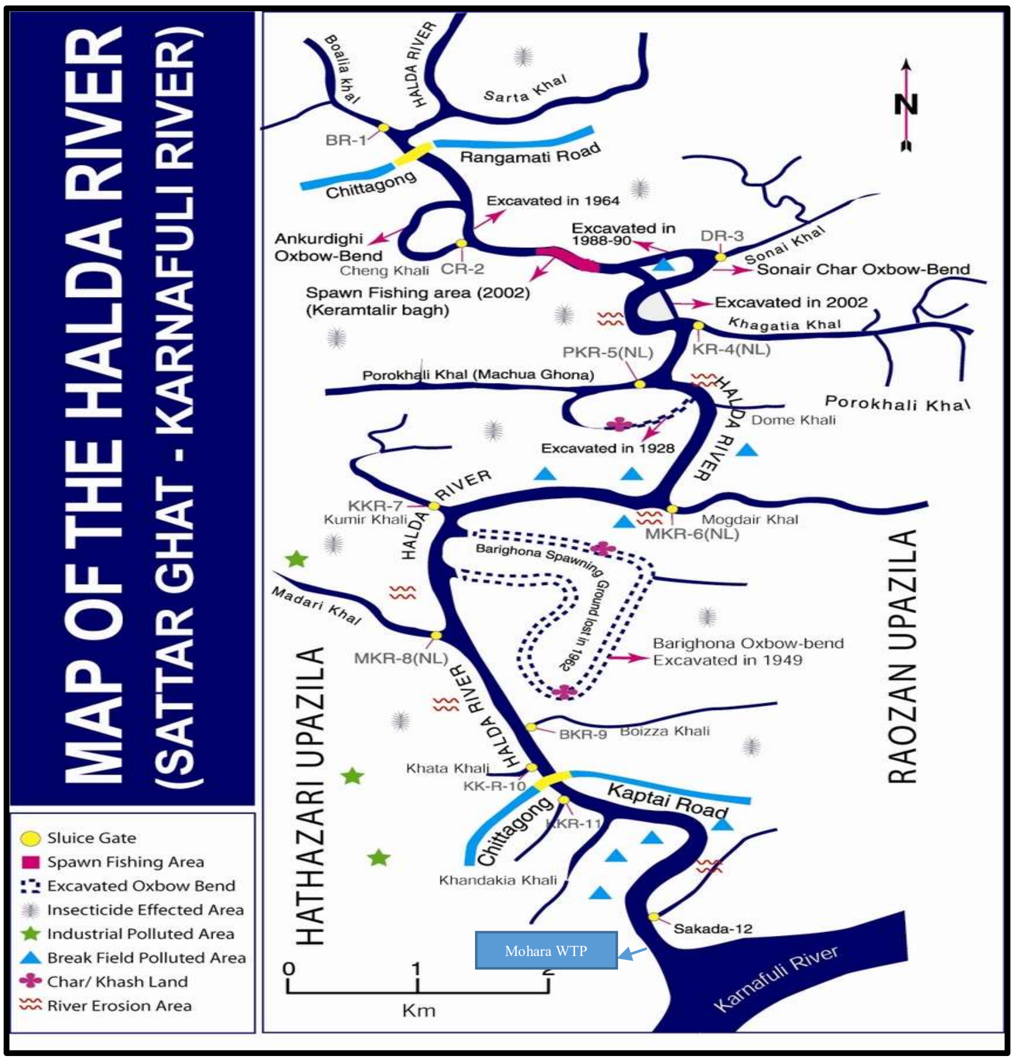

Figure 1.1: Map of the Halda River (Map Source: Akhtar et al. 2017)

In the vibrant city of Chattogram, the Chattogram Water Supply and Sewerage Authority (CWASA) plays a vital role in ensuring the provision of clean drinking water to its residents through the Mohara Water Treatment Plant (MWTP). This treatment plant draws raw water from the Halda river, which unfortunately has been experiencing a concerning escalation in contamination levels (Bhuyan & Bakar, 2017). Such a scenario poses a significant threat to both the availability of a reliable drinking water source and the overall health of the city's inhabitants. The escalating pollution of the Halda River has created a formidable obstacle in the quest for high-quality drinking water for the people of Chattogram City. CWASA is entrusted with the responsibility of supplying uncontaminated and safe drinking water through the MWTP. Merely establishing and commissioning the plant is insufficient to fulfill the objectives of effective water treatment and delivery. To uphold the standards of safe drinking water and constantly improve performance, regular evaluations and studies of the treatment plant are imperative. It is in this context that a comprehensive plan was developed for this M.Phil. dissertation, aiming to conduct an in-depth assessment of the MWTP 's performance and water quality as a case study. The findings of this study will provide valuable insights and, if needed, recommend appropriate remedial actions. The extensive documentation of this research is encompassed in this thesis paper.Building upon the outcomes of this rigorous study conducted on the MWTP, a range of tailored strategies can be devised to enhance its efficiency, optimize performance, and elevate water quality. By implementing these necessary measures, the MWTP can effectively address the challenges it faces and deliver safe drinking water that meets the expectations and needs of Chattogram City's residents.

1.2 Aim and objective

1.2.1 Research Problems

This research work focuses on addressing several key problems pertaining to the Mohara Water Treatment Plant (MWTP):

1. What is the extent of pollutant removal achieved by the Mohara Water Treatment Plant (MWTP) and its overall performance in terms of pollutant removal efficiencies?

2. How does the Mohara Water Treatment Plant (MWTP) perform in terms of water quality?

3. In what ways can the CWASA enhance the performance of the Mohara Water Treatment Plant (MWTP)?

1.2.2 Objectives

The primary objectives of this research endeavor encompass:

1. Conducting a comprehensive assessment to determine the effectiveness of pollutant removal efficiencies exhibited by the MWTP, with a specific focus on assessing its capacity to successfully eliminate contaminants such as Turbidity, Chloride, Ammonia, Total Suspended Solid (TSS), Chemical Oxygen Demand (COD), Total Coliform and Fecal Coliform from the water supply.

2. Undertaking a rigorous evaluation to ascertain the water quality achieved by the MWTP, with a particular emphasis on assessing parameters such as Turbidity, TDS, Conductivity, pH, Temperature, TSS, Total Hardness, Ca-Hardness, Chloride, Nitrate, Fluoride, Ammonia, Sulphate, Phosphate, Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn), Arsenic (As), Lead (Pb), Cadmium (Cd), Mercury (Hg), Chromium (Cr), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) to gauge the plant's efficacy in delivering treated water that meets the required quality criteria.

3. Identifying and exploring viable alternatives and strategies for enhancing the performance of the MWTP. Through an in-depth examination, this research aims to uncover practical and effective measures that can be implemented to optimize the plant's operations, improve overall efficiency, and ensure the consistent provision of safe and high-quality drinking water.

1.3 Scope

The study encompasses a range of scopes to comprehensively analyze and assess the Mohara Water Treatment Plant (MWTP), which include:

1. Conducting an extensive examination to assess the current conditions and operational aspects of the MWTP.

2. Performing a detailed evaluation of the MWTP's performance in terms of its efficiency in removing various water quality parameters. Through systematic analysis, the effectiveness of the treatment processes will be assessed, including the removal of pollutants, suspended solids and other contaminants.

3. Comparing the quality of the treated water from the MWTP with established drinking water quality guidelines such as those provided by WHO, BSTI, and ECR-97. This comparison will help determine the extent to which the treated water meets the prescribed standards and guidelines for safe drinking water.

1.4 Benefits

This research work offers various benefits that can be derived from its findings and outcomes, including:

1. Providing targeted recommendations to CWASA for improving the MWTP's efficiency and effectiveness, enhancing the quality of supplied water.
2. Advancing understanding of water treatment processes, aiding the development of more efficient strategies for similar facilities worldwide.
3. Ensuring compliance with water quality standards and regulatory guidelines, enhancing public health and safety.
4. Directly improving public health by enhancing the quality of treated water and reducing the risk of waterborne diseases in Chattogram City.
5. Facilitating knowledge sharing among stakeholders, fostering innovation and improvement in water treatment.
6. Establishing a foundation for future research and innovation in water treatment and management, benefiting professionals and researchers in the field.

CHAPTER II

LITERATURE REVIEW

2.1 General

Water, being the fundamental essence for all life forms, plays a crucial role in sustaining the existence of every living being on our planet. With the rapid expansion of cities and countryside areas, the need for the supply of water has exponentially intensified, driven by domestic, agricultural, and industrial needs (Al-Jlil et al., 2014). As a result, water has become an invaluable natural resource without which life and numerous industries would cease to function (Tebbutt, 1997). Forging the bedrock of vibrant societies necessitates an unwavering commitment to bestow upon them an indispensable lifeline: an unyielding and unwavering provision of water, an elemental requirement that nurtures growth, resilience, and collective prosperity (Reza & Singh, 2010; Janna & Al-Samawi, 2014). The provision of safe drinking water holds immense importance as poor sanitation and lack of access to clean water contribute to more than 80% of global illnesses, as reported by the World Health Organization (WHO, 2004; Ibrahim et al., 2014).

Water treatment plays a vital role in purifying water sources, transforming them into suitable and potable forms by eliminating pathogenic organisms, as well as mitigating unpleasant tastes, odors, and other undesirable chemical and physical elements (Mohammed & Shakir, 2012). A diverse range of treatment processes are employed in a sequential manner, including flocculation, sedimentation, filtration, and disinfection to effectively remove contaminants from raw water and ensure the delivery of safe and pristine drinking water. (Angreni, 2009).

In the realm of drinking water treatment, aluminum-based coagulants, commonly referred to as alum, serve as indispensable agents in the removal of particulate matter, colloidal substances, and dissolved compounds, including heavy metals, through the intricate process of flocculation (Srinivasan et al., 1999). The presence of heavy metals poses a significant threat to both the environment and human well-being on a global scale (Rajeswari, 2015).

Aluminum-based coagulants, such as aluminum sulfate ($Al_2(SO_4)_3$), play a pivotal role in addressing this pressing concern, as they aid in the aggregation and precipitation of undesirable contaminants, ensuring their effective elimination from the water matrix. By harnessing the coagulation properties of alum, water treatment facilities can mitigate the adverse effects of heavy metals, safeguarding both the integrity of the environment and the health of individuals who rely on clean drinking water.

Within the realm of traditional flocculation-filtration treatment procedures, the elimination of Suspended particles and naturally occurring organic substances extracted from untreated water is achieved by means of introducing coagulants, thereby generating water treatment residuals as a byproduct of the process (Ippolito et al., 2011). Among the pivotal stages of this treatment process lies filtration, reffered to the segregation of particles from liquid water by leveraging physical or mechanical techniques that introduce a medium capable of permitting the passage of water exclusively (Hamdy, 2016).

In the stage of disinfection, the prevailing practice at the majority of water treatment plants involves the implementation of a chlorination process, wherein dissolved chlorine is utilized as the preferred chemical for its cost-effectiveness and high efficacy in many countries (Sharma & Rather, 2015). To assess the effectiveness of disinfection in water treatment, various biological indicators are employed to gauge bacterial contamination, including Coliforms, *E.coli*, fecal coliforms and fecal streptococci (Sadik & Al-Salman, 2014). The widespread use of chlorination as the main disinfection technique in public water treatment persists, as the presence of chlorine residue safeguards against the introduction of harmful pathogens into the water supply until it is consumed. However, it is important to note that chlorine responds to the naturally occurring organic substances found within the water, leading to the formation of potentially harmful disinfection by-products with long-term consequences (Gopal et al., 2007). The disinfection process involving chlorine in drinking water treatment has the potential to transform naturally found organic matter dissolved in water into hazardous disinfectant-generated compounds, such as THM, which must be carefully monitored and managed (Zhao et al., 2009).

wide range of substances, including pharmaceuticals, degradation products from detergents, flame retardants, plasticizers, polycyclic aromatic hydrocarbons, fragrances, pesticides, insect repellents, as well as steroids that found both in plant and in animal, have been identified in the remnants that gather from the water samples gathered after purification, sanitization (using chlorine), and screening techniques (Stackelberg et al., 2007). These compounds originate from diverse sources and can persist in the water supply, posing potential concerns for water quality and human health.

It is crucial to evaluate the effectiveness of individual treatment processes within a water treatment plant (WTP) to ensure overall success. To achieve this, numerous factors, including fluctuations in the quality of the water source and unit operations and the necessary technical criteria or features, are considered to ensure that each unit performs adequately (Zhang et al., 2012).

A comprehensive and meticulous evaluation of the technical condition is of utmost importance, encompassing a thorough examination of both the structural and technical aspects, as well as the functional and technical facets. Giving equal attention to both the volume and caliber of the generated water is of utmost significance. By conducting a detailed and exhaustive assessment, water treatment facilities can gain invaluable insights into the state of their infrastructure and operations, allowing them to identify any areas that require attention and implement appropriate measures to ensure the efficient and effective production of high-quality water. (Kučera et al., 2016).

In order to assess the effectiveness of a water treatment plant (WTP), there are two approaches that can be taken. One approach involves evaluating all the individual treatment processes to determine their overall performance, while the other approach focuses on selecting a key unit within the plant to determine if the entire facility is operating properly. In a study conducted by Wei et al. (2010), the disinfection unit was chosen as the key unit for estimating the performance of the WTP. However, there have been numerous other works that have assessed the performance of WTPs by evaluating all the treatment units, starting from the screening unit (if present) and extending to the disinfection or chlorination unit, in order to determine whether the

WTP is achieving satisfactory performance. Some of these studies include the works of Ali et al. (2012), Mishera & Kadu (2014) and Ahmadli et al. (2017).

In addition to the assessment approaches mentioned earlier, another method to evaluate water treatment plants (WTPs) involves testing the quality of water produced in these treatment units. The evaluation of WTPs can be influenced by the water sources utilized in these plants, leading to variations in the classification of water quality parameters. Studies conducted by Alobaidy et al., (2010) and Eassa & Mahmood (2012) have explored this trend. Typically, physicochemical parameters are considered as the primary indicators for assessing the standard of excellence in both the raw and refined waters of a water treatment center However, there are several research works, such as the one conducted by Varadhajan (2009), that also incorporate biological parameters when evaluating the quality of treated water.

In the context of Bangladesh, traditional water treatment plants (WTPs) play a crucial role in supplying drinking water to both large and small cities through the efforts of water supply authorities. Extensive research has been conducted to thoroughly assess the performance of these WTPs, with a particular focus on the quality of treated water and the effectiveness of various treatment units within the plants. Recent investigations in Iraq have also contributed significantly to the estimation and evaluation of water treatment processes, as observed in studies conducted by Al-Jeebory & Ghawi (2009), Mohammed & Shakir (2012) and AL-Sulaimen (2014). Additionally, numerous studies in Iraqi municipalities have sought to evaluate the efficiency of WTPs by analyzing physicochemical parameters as reliable indicators of water quality in treated water. These studies, including the works of Abdal-Hussein (2015), Shakir (2016), and Ahmed (2016), have shed light on the performance and efficacy of Iraqi WTPs. Moreover, the inclusion of biological parameters as supplementary factors in assessing the performance and efficiency of Iraqi WTPs has been emphasized in various studies, such as those conducted by Al-Bayatti et al., (2012) and Al-Hashimi et al., (2017). Notably, specific pollutant removal, such as Polycyclic Aromatic Hydrocarbons, has been a key focus in evaluating the performance of WTPs in Iraq, as illustrated by the noteworthy research of Mohammed et al., (2010).

A multitude of researchers from diverse countries have conducted extensive studies and published papers focusing on the performance evaluation of water treatment plants. The literature review reveals the uniqueness and specificity of each evaluation, tailored to the particular characteristics of the respective treatment plant. Zahra et al. (2016) specifically investigated the performance evaluation of the Qom treatment plant in terms of turbidity and coliform removal. Their findings demonstrate that the treated water quality aligns with the national Iranian standards, indicating the effective functioning of the treatment system. Manoj et al. (2013) conducted research on the methods and criteria utilized for assessing the performance of conventional water treatment plants. Their results indicate an increase in dissolved oxygen (DO) levels and a decrease in water acidity, signifying the successful operation of the aeration process. However, in cases where the influent water exhibited high turbidity, the clariflocculator and filtration units failed to achieve the allowable limits. In their study on water treatment plant performance, Madhu & Soumyashree (2016) observed that the raw water during the summer season had low turbidity and was free from odor. After treatment, the water quality met the permissible limits specified in drinking water standards. Hussein & Adnan (2014) focused on the performance assessment of the Al-Karkh water treatment plant in Baghdad. The research showed that the daily average measure of Turbidity in the given water exceeded 2% of the guidelines established by Iraqi and WHO. However, the two-day average measurement of Turbidity met 99% of the standards set by the USEPA. The 30-day average turbidity result demonstrated a 32% compliance with USEPA guidelines. These diverse research endeavors highlight the importance of evaluating water treatment plant performance and provide valuable insights for improving the efficiency and reliability of water treatment processes.

2.2 Water quality analyses

Conducting thorough water quality evaluations using representative samples is imperative before selecting the origins of surface or groundwater. The most desirable approach would be to undertake on-site evaluations coupled with the retrieval of samples for additional investigation in laboratory environments (WHO, 2004). It is important to ensure accurate and detailed evaluations of water quality in order to make informed decisions regarding the suitability and safety of water sources.

2.3 Water quality parameters

Different aspects affect the quality of water and they belong to three main categories, namely physical characteristics, chemical features, and biological domains. These parameters are crucial as they directly impact the safety and suitability of water for human consumption. By analyzing these parameters, valuable insights can be gained regarding the quality of a water source. These established limits are essential in determining whether water meets the necessary criteria for drinking purposes, ensuring the provision of safe and reliable drinking water for the population as stated by Gupta & Saharan in 2009.

2.3.1 Physical aspects of drinking water quality

Drinking water can be judged by many things including its color, smell, taste, and how clear it is. Some other important factors are how much chlorine is left in the water, the temperature, and how much of certain things like minerals are dissolved in it. These parameters play a significant role in assessing the overall quality of water and are crucial for conducting comprehensive quality tests. The examination of water quality involves the evaluation of both physicochemical and aesthetic parameters, providing a holistic understanding of its suitability for various purposes (De Zuane, 1996).

2.3.1.1 Physiochemical examination

Residual chlorine

The organizations entrusted with the responsibility of supplying drinking water prioritize the implementation of robust measures to safeguard against waterborne illnesses. There are multiple disinfection agents available for this purpose, and chlorine is extensively utilized as a disinfectant in numerous countries worldwide. Using chlorine to disinfect things has many benefits. It is cheap, works well, and is easy to measure in labs and outside. One notable benefit that sets chlorine apart from other disinfectants is its ability to leave a residual disinfectant, which acts as a protective barrier against potential recontamination during the distribution, transportation, and storage of water at the household level. The presence of chlorine residual within the distribution system serves as an important indicator of effective treatment and safeguards against post-treatment contamination risks. This underscores the crucial role of chlorine in ensuring water safety and maintaining public health standards (Taylor & Francis, 2007).

pH

The pH scale measures the acidity or alkalinity of a solution, including water. Pure water is neutral with a pH of 7, indicating an equal concentration of hydrogen ions (H^+) and hydroxide ions (OH^-) at 1 x 10^{-7} moles per liter. Acids have a pH below 7, indicating a higher concentration of hydrogen ions, while bases have a pH above 7, indicating a higher concentration of hydroxide ions. Water having a low pH can lead to the corrosion of metals or the dissolution of metal substances. (Masduqi & Assomadi, 2016). Water with an elevated pH level can result in a bitter taste, the formation of pipeline deposits, and reduced effectiveness of chlorine. The pH level has a significant impact on the efficacy of chlorine disinfection. It is crucial to measure pH simultaneously with chlorine residual to ensure optimal disinfection. If the pH exceeds 8.0, the effectiveness of disinfection decreases. Certain chlorine comparators allow for the simultaneous measurement of pH and chlorine residual, enabling convenient monitoring of both parameters as highlighted by the insightful work of Muhammad et al. (2013)

Total dissolved solids (TDS)

Water possesses a remarkable capacity to dissolve a diverse array of inorganic and organic mineral deposits or salts, including but not limited to chloride, bicarbonates, sulfates, magnesium, potassium, sodium and an array of other compounds. These mineral deposits can impart an unpleasant taste and dilute the visual color of water. Presently, there is no definitive consensus regarding the potential drawbacks or benefits of water exceeding the maximum permissible level of 1,000 ppm as established by the WHO. The presence of total dissolved solids (TDS) in drinking water arises from various sources, including sewage, urban runoff, industrial wastewater, and more. As a result, conducting a TDS test serves as a valuable indicator for monitoring and managing the overall quality of water. (Muhammad et al., 2013).

Electrical conductivity (EC)

Electrical conductivity (EC) is a commonly employed parameter to assess the water quality and its ability to conduct electric current. Several factors, including ion concentration, mobility and valence as well as temperature, have an impact on EC. Although pure water does not conduct electricity well, it possesses excellent heat insulating properties. However, an increase in the concentration of ions enhances the EC of water. The overall level of dissolved solids in water directly influences its EC. EC is a measure of the solution's ability to transmit an electric current, primarily driven by its ionic content. Adhering diligently to the benchmarks established by the esteemed WHO, the threshold for EC in drinking water quality is meticulously set at a maximum limit of 400 μS/cm. However, the conductivity landscape of potable waters unfolds with a mesmerizing array of fluctuations, spanning a broad spectrum that typically spans from 50 to 1500 μmhos/cm, thus showcasing a captivating tapestry of remarkable diversity. These intriguing insights, as espoused by the scholarly contributions of Gaur in 2008, underline the unique intricacies embedded within the realm of water conductivity, as it intertwines with the pursuit of ensuring the bestowal of safe and exceptional drinking water.

Turbidity

Turbidity serves as a fascinating gauge of water's veiled allure, quantifying its inherent cloudiness and haziness. It embodies the interplay of light, revealing the captivating optical characteristics that reside within the aqueous realm. Establishing a direct relationship between turbidity and the concentration of suspended substances by weight is difficult due to the influence of particle size, shape, and refractive index on the light scattering properties. Suspended matter, such as clay, silts, organic and inorganic particulates in fine division, soluble colored organic compounds, plankton, and various microscopic organisms, contributes to the occurrence of turbidity in water. The importance of turbidity cannot be understated when assessing water quality, as it has a direct impact on both the suitability of the water for consumption and the efficiency of treatment methods, particularly with respect to the use of chlorine disinfection. Turbidity affects chlorine demand, offers protection against microorganisms, and can potentially stimulate bacterial growth. In every water treatment process that incorporates disinfection, it is of utmost importance to uphold low levels of turbidity, ideally below the threshold of 1 NTU. To ensure successful disinfection, it is advisable to keep the turbidity level of water below 5 NTU (Nephelometric Turbidity Units), as suggested by John et al. in their research conducted in 2012. For optimal disinfection outcomes, it is preferable to aim for maintaining a turbidity reading of below 1 NTU.

2.3.1.2 Aesthetic parameters of drinking water quality

Aesthetic parameters refer to water characteristics that can be directly perceived through the senses. These parameters include turbidity, color, taste, and odor. Monitoring these aspects is of utmost importance in ensuring the quality of public water supplies. If these aesthetic parameters exceed acceptable levels, it may result in the rejection of the water source, prompting the adoption of alternative sources that may have lower quality. Fortunately, the qualitative assessment of these parameters can be easily and economically conducted in the field, making it a practical approach for ongoing water quality monitoring.

Color

The color of drinking water serves as another vital aesthetic parameter. The presence of different pigmented elements, such as iron compounds and plant matter, is responsible for this. While color may not necessarily have adverse health effects, it is important to note that highly intense color is undesirable. The intensity of color can be assessed by visually contrasting the sample against clear water. Colored or stained water, whether for aesthetics or safety concerns, cannot be consumed. Drinking water should ideally be devoid of any discernible color, as the presence of noticeable color is considered unacceptable due to both aesthetic considerations and potential toxicity concerns. Therefore, when investigating public water supplies, it is valuable to meticulously observe and document any visible coloration during the sampling process. Any changes or the emergence of new colors in the water serve as indicators that further investigation is warranted. (WHO, 2004).

2.3.2 Chemical aspects of drinking water quality parameters

Different things like natural resources, industries, and farming activities can change what's in the water we drink. If harmful chemicals get into our drinking water, it can make us sick right away or cause health problems over time. Levels of substances identified in drinking water seldom surpass the minimum requirement for acute health concerns, causing long-term health consequences to occur frequently as stated by Benignos in his study in 2012. Drinking water quality is assessed based on several significant chemical or inorganic parameters. These parameters encompass various factors such as magnesium, hardness, chloride, calcium, fluoride, sulfate, alkalinity, , phosphate, nitrate and potentially harmful metals including, lead, copper, cadmium, iron, mercury, manganese, chromium (Cr^{+6}) and more.

2.3.2.1 Hardness

The hardness of drinking water is predominantly determined by the presence of calcium and magnesium compounds, encompassing carbonates, bicarbonates (which can be alleviated through boiling), as well as sulfates and chlorides (which can be eliminated through chemical precipitation utilizing sodium carbonate and lime). Hard water is characterized by elevated mineral contents that generally pose no significant harm to human health. Calcium carbonate ($CaCO_3$) is commonly employed as a benchmark for measuring water hardness due to its abundant calcium and carbonate ions in hard water. It's important to note that the acceptability of water hardness can vary considerably from one community to another. The range of calcium ion detection level in terms of taste is from 100 to 300 mg/L. Typically, the maximum allowable level for overall water hardness is established at 500 mg/L in the form of $CaCO_3$. The WHO stated in guidelines established in 2004 that drinking water shouldn't have a total hardness level above 300 mg/L.

2.3.2.2 Alkalinity

Alkalinity is defined as the ability of water to neutralize acids. It arises from the presence of various ions, including hydroxides, carbonates, and bicarbonates. Water's pH below 7. 0 points to its acidic properties, whereas a pH higher than 7. 0 indicates alkaline traits. Corrosion of metallic pipelines can result from the presence of acidic water. It's imperative to preserve a harmonious pH level in water sources for consumption in order to combat the deleterious effects of acid. On the other hand, an excess of alkalinity can lead to numerous unfavorable effects. According to Muhammad et al. (2013), the alkalinity level of water is determined by the total amount of dissolved solids and must not exceed 500 mg/L as per the criteria of the WHO.

2.3.2.3 Nitrate (NO_3)

The presence of nitrate (NO_3) in the drinking water is indicative of the existence of organic substances. Regarded as one of the most significant parameters affects the standard of potable water, notably its association with health issues such as blue baby syndrome in infants. Elevated levels of NO_3, exceeding 100 mg/L, can lead to methemoglobinemia, a condition that impairs the ability of a baby to receive sufficient oxygen (Roberts, 2006). NO_3 contamination sources include the industrial effluents, nitrogen cycle and the use of nitrogenous fertilizers, among others. As per the guidelines set by the WHO, the maximum allowable values for nitrate as NO_3 in drinking water are 50 mg/L and 3 mg/L as NO_2 for nitrite. (Alan et al., 2000).

2.3.2.4 Phosphate (PO_4)

Phosphates are frequently encountered in surface water as a common water quality parameter. Their occurrence can be mainly linked to origins like sewage discharges, which transport synthetic detergents that carry phosphate, industrial discharges, or overflow from farming regions that have received fertilizers made of inorganic components. Groundwater typically contains minimal levels of phosphates, unless it has been contaminated. Phosphorous, being a vital nutrient for algal growth, can play a significant role in the eutrophication of lakes and reservoirs (Alan et al., 2000).

2.3.2.5 Sulphate (SO_4)

Sulphate is a prevalent component detected in surface water, stemming from a multitude of sources. The formation of sulphates in water can be attributed to various sources such as the decay of mineral buildups with sulphates and seawater intrusion. Sulphides ion, sulphites ion and also thiosulphates occurring in well-aerated surface waters may also oxidize to form sulphates. Furthermore, industrial operations like tanning and pulp paper production are responsible for releasing waste products that contribute to the presence of sulphates.

In the realm of potable water sources, high sulphate levels may lead to taste-related complications and, when coupled with magnesium or sodium, may result in laxative effects similar to those exhibited by Epsom salts. The concentration of sulphate in natural water can vary widely, ranging from a few milligrams to several hundred milligrams per liter. So far, no significant adverse effects on human health have been reported due to sulphate exposure. In 2004, the WHO established guidelines specifying that the highest acceptable amount of sulphate concentration in potable water is 250 mg/L SO_4. This determination considers both taste preferences and the possibility of corrosion.

2.3.2.6 Chloride ion (Cl^-)

Chloride content in water is occasionally of special importance, particularly sodium chloride derived from the dissolution of hydrochloric acid salts such as table salt (NaCl), as well as sodium carbonate ($NaCO_2$). The sources of chlorides in water include wastewater, road salts, animal feed and storm sewers, among others. (Terence, 1979). Surface water bodies generally maintain relatively lower chloride concentrations, which are crucial for supporting fundamental physiological processes within their ecosystems. However, elevated levels of Chloride ion$^-$ in water can lead to the corrosion of metallic pipes, structures, and equipment, while also posing risks to plant growth and development. It's very important to follow the rules from the WHO to make sure our water is safe. They say the most chloride ion in our water should be 250 mg/L.

2.3.2.7 Iron (Fe) and Manganese (Mn)

Iron and Manganese are prevalent minerals typically found in higher concentrations in groundwater compared to surface water sources. These minerals, when present in excess, can be irritating and should be avoided in drinking water, with recommended limit of iron levels to 0. 3 mg/L and manganese levels to 0. 4 mg/L. Elevated concentrations of iron and manganese can result in unappealing discoloration on clothes and plumbing fittings, whereas the proliferation of iron bacteria may obstruct screens, filters and deteriorate metal pipes. When a water sample is stirred, one can detect the existence of iron or manganese through the formation of a dark liquid precipitate with a reddish-brown or black hue.

2.3.2.8 Calcium (Ca)

Calcium, an essential element crucial for growth and well-being, holds utmost significance within the human body. Its abundant presence, predominantly residing in bones and teeth, amounts to approximately 95 percent. Insufficient intake of calcium can lead to detrimental effects such as rickets, impaired blood clotting, and increased susceptibility to bone fractures. The recommended daily intake falls within the range of 1 to 2 grams, with dairy products serving as a primary source. Intriguingly, certain indications suggest that regions supplied with hard water, rich in calcium, exhibit reduced incidence of heart disease—a noteworthy advantage to public health (Environmental Protection Agency, 2001). The WHO (1996) states that drinking water can contain up to 75 mg/L of calcium within the safe limit.

2.3.2.9 Magnesium (Mg)

Magnesium (Mg) is really important for our body and we need it a lot. About 15-20% of how hard something is comes from this thing called $CaCO_3$. In our bodies, we have about 25 grams of Mg. The amount of Mg allowed in water should not be more than 150 mg/L according to WHO rules (Muhammad et al., 2013)

2.3.2.10 Toxic substances

The presence of certain toxic chemical constituents in drinking water, when found at significant concentrations, poses a potential health hazard. Among these harmful elements are hexavalent chromium, copper, lead, and others.

2.3.2.11 Dissolved Oxygen (DO)

The presence of oxygen in water is less soluble and can be affected by variations in temperature and pressure. It also serves as an indicator for water treatment processes and significantly impacts corrosiveness. Calculating the dissolved oxygen (DO) content involves comparing it to the saturation level, which represents its maximum solubility under specific pressure and temperature conditions, procured from the surrounding air. Although oxygen is not the only gas found in water, it makes up a significant proportion, contributing to about 38% of the dissolved gases, which is twice the amount found in the air. According to De Zuane's research in 1996, the amount of DO in freshwater changes depending on the temperature and pressure. At 0°C, it can reach 14. 6 mg/L, while at 20°C, 25°C, and 35°C under a pressure of 1 atm, the amount would measure approximately 9.1 mg/L, 8.3 mg/L, and 7 mg/L, respectively. The Health Authority never issued WHO guidance levels for DO standards, primarily because it lacks toxicity. Furthermore, the relatively low concentration of DO and its constant fluctuation due to changes in pressure and temperature limit its significance from a health perspective. However, DO does have practical implications in terms of corrosion effects on piping lifespan and can result in psychological impacts on consumers, such as discoloration and unpleasant flavor profiles.

2.3.3 Bacteriological aspects of drinking water quality

The microbiological characteristics of water are determined by the presence and abundance of microorganisms within it. Even in high-quality domestic water sources, a wide variety of microorganisms can coexist. Though most of the microorganisms in water are not dangerous, contamination of water can introduce such pathogens, which are disease-causing microorganisms responsible for ailments like cholera, gastroenteritis, and hepatitis (Kasrils and Simang, 2001). Detecting the presence of all possible pathogenic organisms is a complex task, leading to the utilization of indicator organisms as proxies to indicate the potential presence of pathogens. Various types of indicator organisms are employed to check if water at home is clean or not, with the total coliforms bacteria and the fecal coliforms being the most prevalent among them. These organisms serve as valuable markers in evaluating the safety and suitability of drinking water.

2.3.3.1 Total coliforms

To prevent any misunderstanding among organisms in the same group, it is more appropriate to refer to coliform organisms as total coliforms. It is important to note that total coliforms are not indicative of fecal pollution or direct health risks. However, they do provide essential information about the quality of the water source. The convenience of detecting and counting total coliforms has made them a popular microbial indicator for measuring the quality of drinking water. Characteristics that often define these bacteria are their ability to grow in the presence of substances such as bile salts that slow down growth, their shape being rod-shaped, and not forming spores, as well as being gram-negative. They do not possess oxidase and can generate gas, acid as well as aldehyde by lactose fermentation at a temperature range of 35-37°C within 24-48 hours (According to the Evaluation of Drinking Water Microbial Safety report published in 2002).

2.3.3.2 Fecal coliforms

"Fecal coliforms" encompass a specific subset of total coliforms, characterized by their ability to ferment lactose at temperatures ranging from 44-45°C. Within this group, the genus *Escherichia* predominates, although species such as *Klebsiella*, *Enterobacter*, and *Citrobacter* also contribute to a lesser extent. Among these microorganisms, *Escherichia coli (E. coli)* stands out as a reliable indicator of fecal origin due to its consistent presence in the feces of humans, mammals, and birds, while being rarely detected in unpolluted water or soil in temperate climates. This distinction was emphasized in the comprehensive study by Fujioka et al. (1999). It is important to recognize that the potential risk associated with the presence of coliforms depends on the health status and sensitivity of the individuals involved. Although the WHO guideline stipulates a zero count per 100 mL for *E. coli*, it is crucial to consider that even low or intermediate counts may still pose a certain level of risk.

2.3.4 Heavy Metals

Heavy metals are characterized by their remarkable specific gravity, exceeding five times greater than that of water. Specifically, at a temperature of 4°C, water has a particular weightiness known as the specific gravity of 1. This measurement refers to the density of a solid material in relation to an equivalent volume of water. Notably, some of the well-known toxic metals, such as Cadmium (specific gravity 8.65), Iron (specific gravity 7.9), Lead (specific gravity 11.34), and Mercury (specific gravity 13.546), boast specific gravities at least five times greater than that of water, as documented in Lide's comprehensive work from 1992. However, it is essential to recognize that certain heavy metals, when present in trace amounts, play a vital nutritional role in maintaining a healthy life. Elements such as Copper, Zinc, Iron and Manganese, in their different varieties, are frequently present in fruits, vegetables, crops and multivitamin products that are available commercially. Moreover, heavy metals also find application in diagnostic medicine. To illustrate, Roberts pointed out in 1999 that gallium is administered through direct injection during radiology procedures, chromium is included in parenteral nutrition blends, and lead is utilized as a protective barrier against radiation in x-ray machinery. Heavy metals have extensive industrial applications, but they can pose a threat when they accumulate in the body's soft tissues without being properly metabolized. These toxic metals can enter the human body through various pathways, including food, water, air, and even skin absorption in settings such as agriculture, manufacturing, pharmaceuticals, industrial processes, and residential construction. Adults commonly come into contact with heavy metals through occupational exposure, while children predominantly ingest them, often through normal hand-to-mouth activities like interacting with contaminated soil or consuming non-food items like Fragments of paint coating and soil particles. Less common ways of being exposed to harmful substances or situations include radiological procedures, improper administration or monitoring during IV nutrition, mishandling of thermometers, and intentional acts of self-harm or violence, as discussed in the research of Lupton (1985) and Smith (1997). Heavy metals released into the environment can persist for decades, posing health risks. Numerous methods are employed to remediate these pollutants, but many of them are expensive and yield limited results. At present, phytoremediation is considered to be a highly viable, economical, and eco-friendly option for extracting or eliminating non-active metals and metal pollutants from polluted soil and water. Bieby et al. showcased a ground-breaking technology. An effective strategy to address the problem of heavy metal contamination is presented by the publication in 2011.

2.3.4.1 Arsenic (As)

Arsenic (As) is an elemental constituent abundant having the atomic number 33 and the atomic weight of the substance is 74. 92. With a specific gravity of 5.73, this semi-metallic substance exhibits a melting point: 817°C at 28 atm. Notably, it undergoes boiling at really high temperature of 613°C, accompanied by 1 mm Hg vapor pressure, which becomes evident at 372°C. Remarkably, Arsenic possesses neither odor nor taste, rendering it inconspicuous (Mohan et al., 2007). Regrettably, this hazardous compound occupies the pinnacle position by ATSDR notorious "Top 20 List" of toxic substances as well as causes most cases of severe poisoning due to heavy metals in adults.

2.3.4.2 Lead (Pb)

Lead (Pb), a chemical constituent, boasts an atomic number of 82 and an atomic weight of 207.19, displaying a specific gravity of 11.34. It manifests as a bluish or silvery-grey metal, characterized by a melting point of 327.5°C and a boiling point of 1740°C under standard atmospheric pressure. Found naturally, Pb exhibits four isotopes with atomic weights of 208, 206, 207, and 204, ordered by decreasing abundance (Wikipedia). Pb, which holds the number two spot on ATSDR's highly regarded "Top 20 List" of poisonous substances, is the primary cause of numerous instances of heavy metal poisoning in children, according to Roberts (1999). Throughout the globe, Pb is present in numerous natural sources and is one of the most extensively dispersed trace metals. Notably, the bulk of environmental Pb assumes an inorganic state, encompassing various oxidized configurations (Jackson et al., 2005).

2.3.4.3 Mercury (Hg)

Mercury (Hg), an innate metal, assumes diverse forms within its natural existence. Exhibiting a lustrous and odorless liquid state, metallic Hg captivates with its shimmering silver-white appearance. Uniquely, it holds the distinction of being the sole pure metal to remain in a liquid state at room temperature, owing to its remarkably low melting point of −39°C. Leveraging its advantageous physical and chemical properties, including a low boiling point of 357 °C and effortless vaporization, mercury continues to play a pivotal role in numerous industrial applications (Chang et al., 2009). Earning the third rank on the ATSDR's prestigious "Top 20 List" of harmful and dangerous substances, Hg stands as a formidable threat. Originating naturally, it arises from the earth's crust degassing and emissions from volcanoes, existing in various manifestations: elemental from or metallic from, inorganic compounds and also organic compounds. Among these, mostly reduced form is Hg^0 metal, while the two remaining forms involve ionic states, namely the mercurous ion and mercuric ion (Hg^{2+}), particularly under low pH conditions. Notably, the Hg^+ ion proves unstable in environmental settings, undergoing dismutation into Hg^0 and Hg^{2+}.

2.3.4.4 Cadmium (Cd)

Cadmium (Cd) holds the unenviable seventh spot on ATSDR's list of toxic and hazardous elements. Primarily arising as a byproduct from the mining and smelting processes of Pb and Zn, Cd emerges in trace amounts within most rocks, coal, and petroleum, often found in conjunction with Zn. Notably, geological deposition of this chemical constituent can serve as a potential source of contamination in groundwater and surface water, particularly when exposed to soft, acidic aquatic environments. Intriguingly, there is no substantiated evidence indicating its indispensability to human beings, as it lacks any recognized biological necessity (Hogan, 2010).

2.3.4.5 Chromium (Cr)

Chromium (Cr), a metal that elicits considerable concern for both human health and the environment, exhibits its presence predominantly in two oxidation states found in nature: Cr (III) and Cr (VI). Cognizant of the potential risks associated with chromium, both WHO (2011) and Bangladesh standards (DPHE, 2020) have established strict maximum permissible limits (MPLs) for Cr in drinking water, setting it at a mere 0.05 mg/L. Intriguingly, a comprehensive analysis of numerous studies highlights intriguing variations in Cr concentrations within surface waters. Notably, the Buriganga River emerged as a notable hotspot, showcasing the highest mean Cr concentrations during both winter (1.96 ± 0.18 mg/L) and summer (1.43 ± 0.53 mg/L) seasons (Mohiuddin et al., 2011). Subsequently, the Balu river also exhibited elevated levels (1.02 ± 0.24 mg/L) (Hasan et al., 2014). These alarming findings can be attributed to the rampant discharge of industrial waste, coupled with inadequate treatment of domestic and municipal waste, leading to heightened Cr contamination. Conversely, the upper Ganges river (Padma river) presented the lowest mean Cr concentration at a mere 0.0007 mg/L (Haque et al., 2020), owing to its robust water flow and substantial distance from pollution sources.

2.4 Standard of Drinking Water Quality guide fulfillment criteria:

2.4.1 Water treatment

The primary objective of water treatment is to ensure the provision of potable water that is chemically and bacteriologically safe for human consumption while meeting the quality requirements of industrial users (John, 1977). The treatment of drinking water encompasses a range of approaches, from simple physical treatment and disinfection to comprehensive physical and chemical treatment. Figure 2.1 illustrates the process diagram specifically for the MWTP. The initial three steps, following the raw water pump station, primarily focus on the removal of colloids (including certain microorganisms) and natural organic matter (NOM). Subsequently, step 4, involving rapid sand filtration, serves as a polishing step, further eliminating residual colloidal material post-step 3 (sedimentation). Countries worldwide strive to ensure that the quality of raw water is of such caliber that it necessitates minimal intervention, such as bank filtration or low-speed sand filtration, along with sterilization, to meet drinking water standards (Enderlein & Williams, undated). Surface water sources typically harbor an assortment of colloidal impurities, contributing to water turbidity. Coagulation, flocculation, adsorption, and filtration processes collectively facilitate the removal of harmful chemicals and turbidity. Chlorine is widely employed as a primary disinfectant and residual disinfectant within the distribution system. The Jar Test, a laboratory experiment, assesses coagulation and flocculation characteristics in untreated water. It replicates the conditions and processes occurring in the coagulation-flocculation clarification stages of water and wastewater treatment plants (Albraham, 2006). The performance of each treatment unit directly influences the efficiency of downstream treatment units.

Pertinently, the presence of suspended solids confers a protective shield upon many microbes, rendering their disinfection resistance notably higher.

Similarly, clarification significantly impacts filter performance by reducing solid loading. Improper dosing of coagulant or the carryover of floc from sedimentation chambers can lead to an accelerated head loss, shortening the filter run (WHO, 2004). It is imperative for all treatment units to operate efficiently to ensure an effective treatment process.

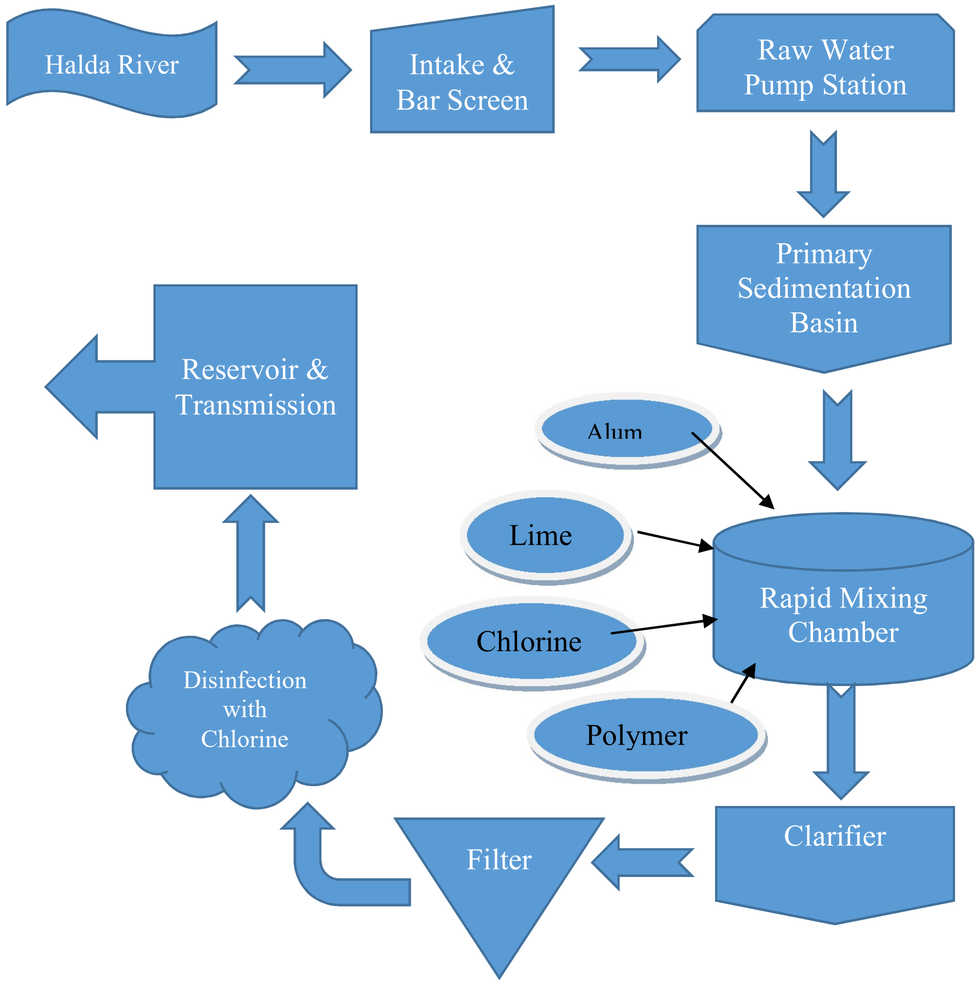

Figure 2.1: Water treatment process.

2.4.2 Coagulation - Flocculation

In water treatment plants, the inclusion of the coagulation process serves to facilitate the aggregation of minute particles into larger, more settleable entities that can subsequently be eliminated through sedimentation and/or filtration (AWWA, 1990). These particles contributing to turbidity can be classified based on their size, with those larger than 1μm settling relatively quickly, while colloidal particles (smaller than 1μm) do not settle readily under normal circumstances. It is important to note that color can also stem from colloidal particles, although their nature differs from that of turbidity particles (Seskatchewan environment, 2003). Colloidal particles can further be categorized as hydrophobic (water-hating) or hydrophilic (water-loving).

Hydrophobic particles predominantly consist of clay particles, exhibiting a negative charge that leads to mutual repulsion. Conversely, hydrophilic particles primarily comprise organic materials, contributing to the observed color. These hydrophilic particles are enveloped by a layer of water molecules, preventing their collision and subsequent growth, which would promote settling.

Chemicals like aluminum sulphate and ferric chloride, when introduced into water, react with the available alkalinity to generate a sticky substance with a positive charge (Seskatchewan environment, 2003). In cases where alkalinity is insufficient, the addition of hydrated lime or soda ash becomes necessary to facilitate the desired chemical reaction. This positively charged sticky material diminishes the electrical charge on hydrophobic particles and accelerates the process of agglomeration. The agglomerated particles undergo mechanical agitation, fostering collisions and resulting in the formation of floc, delicate feather-like gelatinous masses. This mechanical agitation of coagulated particles is referred to as flocculation. It is important to recognize that the speed and extent of coagulation, flocculation, and the removal of turbidity and color are highly sensitive to variations in pH conditions (Heinonen & Lopez, 2007). Metal coagulants typically exhibit acidic properties, and their addition consumes alkalinity. In situations where the water has low alkalinity, the addition of coagulant may deplete the available alkalinity, resulting in a pH drop to levels that are unsuitable for effective coagulation and treatment. On the other hand, highly buffered waters with high alkalinity may require substantial coagulant dosage to achieve pH levels conducive to coagulation. The ideal pH range for alum coagulation falls between 5.5 and 8.0, making it a preferred choice for treating relatively high-quality surface waters due to its effective coagulating properties (John, 1977). The determination of optimal levels of chemical agitation and pH adjustment relies solely on empirical experimentation, carried out using a jar tester, a dedicated testing unit. It is important to emphasize that while coagulation involves chemical processes, flocculation is primarily a physical process. Coagulation efficacy depends on factors such as pH, intensity of agitation, and chemical dosage. Therefore, conducting a jar test remains the most reliable approach to ascertain the appropriate dosing for coagulation.

2.4.3 Sedimentation

The term "clarification" or "sedimentation" refers to the process of settling the flocs formed during coagulation and flocculation, allowing them to separate from the treated water (Ministry of Health, 2005). It is important to distinguish this process from the pre-settling of highly turbid waters in a primary sedimentation basin, where the water is left undisturbed to promote the settling of compact masses comprising particles and coagulants. During clarification, gravity takes effect as the larger and denser clumps gradually settle out, enabling their removal from the water phase.

2.4.4. Filtration

In water treatment facilities, filtration plays a pivotal role in the removal of suspended particulate matter, serving as a crucial process (AWWA, 1990). The objective of water treatment filtration is to remove a diverse range of particulate matter, encompassing various types of contaminants. These include clay and silt particles, colloidal substances, precipitated natural organic matter, metal salt precipitates formed during coagulation, precipitates from lime softening processes, as well as precipitates of iron and manganese. Furthermore, microorganisms present in the water are also targeted for removal during filtration. This comprehensive filtration process ensures the reduction of disinfectant demands and prevents the shielding of organisms from disinfection, ultimately enhancing the quality of filtered water (AWWA, 1990). Maintaining an appropriate filtration rate and conducting effective backwashing of granular media filters are essential practices to uphold optimal performance and achieve the desired quality of filtered water.

2.4.5. Disinfection

2.4.5.1 Chlorine

The primary objective of implementing water disinfection measures is to kill microbial pathogens and effectively prevent the transmission of waterborne diseases (AWWA, 1990). These diseases typically originate from enteric pathogens, a group of organisms that are spread through the fecal-oral route. Disinfection serves as an active barrier against a wide range of pathogens, particularly bacteria, during the treatment of drinking water. Its application is crucial for both surface water and groundwater sources, depending on the level of fecal contamination present (John, 1977). In order to provide additional protection against low-level contamination and inhibit microbial growth within the distribution system, residual disinfectant levels are maintained. However, it is important to note that while chemical disinfection, such as chlorine disinfection, can reduce the overall risk of waterborne diseases, it may not completely eliminate all pathogens, especially protozoan pathogens like Cryptosporidium and certain viruses. Additionally, the effectiveness of disinfection may be compromised when pathogens are present within flocs or particles, as they can be shielded from the action of disinfectants (WHO, 2004). High turbidity levels can also offer protection to microorganisms, impede disinfection effectiveness, promote bacterial growth, and contribute to increased chlorine demand (O'Neill et al., 1994). The efficacy of chlorine as a disinfectant is significantly influenced by pH interactions. Although chlorine is widely utilized as the primary disinfection agent and for residual disinfection in the distribution system, it is essential to consider that residual chlorine concentrations above approximately 0.6 mg/L may impact the taste and acceptability for certain consumers (WHO, 2004).

CHAPTER II

MATERIAL AND METHODS

3.1. Mohara Water Treatment Plant (MWTP)

Serving as the lifeline for numerous neighborhoods in Chattogram city, the Mohara Water Treatment Plant (MWTP) diligently supplies clean and safe drinking water to the bustling urban landscape. Situated in the southeastern region of Bangladesh, the vibrant city of Chattogram serves as a pivotal seaport and ranks as the country's second largest urban center (Chattogram District, Chittagong Division). Nestled along the picturesque banks of the Karnaphuli River, the city boasts a strategic location near the Bay of Bengal and lies in proximity to Myanmar (Burma) (Figure 3.1). The precise geographical coordinates of MWTP are 22°20′18″ N and °49′54″ E. Catering to the water needs of numerous residential areas, the MWTP stands as a vital facility within the city. With its establishment dating back to 1987, the MWTP has played a crucial role in ensuring the availability of potable water. Operating at a capacity of 90000 m3/d, the plant efficiently treats raw water sourced from the Halda river, which enters through intake pipes situated along its banks. Although the plant has not undergone any significant expansions since its initial construction, various maintenance efforts have been undertaken to uphold its operational efficiency.

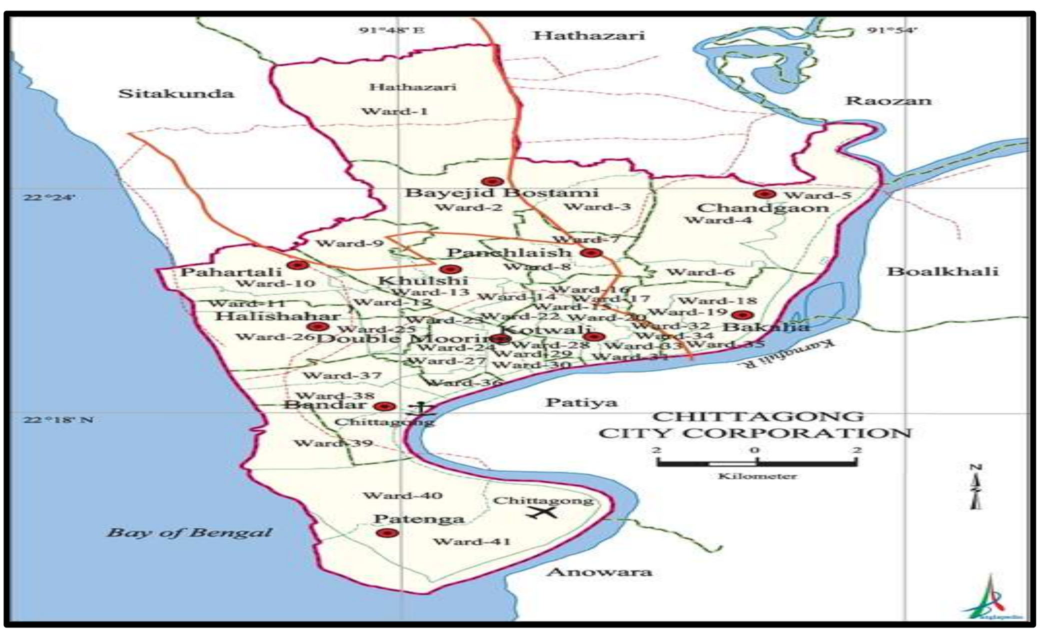

Figure 3.1: Map of Chattogram city (Map Source: Zahur, 2019)

3.1.2. Process Description

Designed as a traditional water treatment facility, the MWTP implements a series of five crucial stages to ensure the provision of high-quality drinking water to the residents it serves. The strategic placement of the MWTP can be observed in the informative depiction presented in Figure (3.3). Let's explore the distinctive stages and facilities of the MWTP in detail:

Figure 3.2: View of Mohara Water Treatment Plant (Source: CWASA)

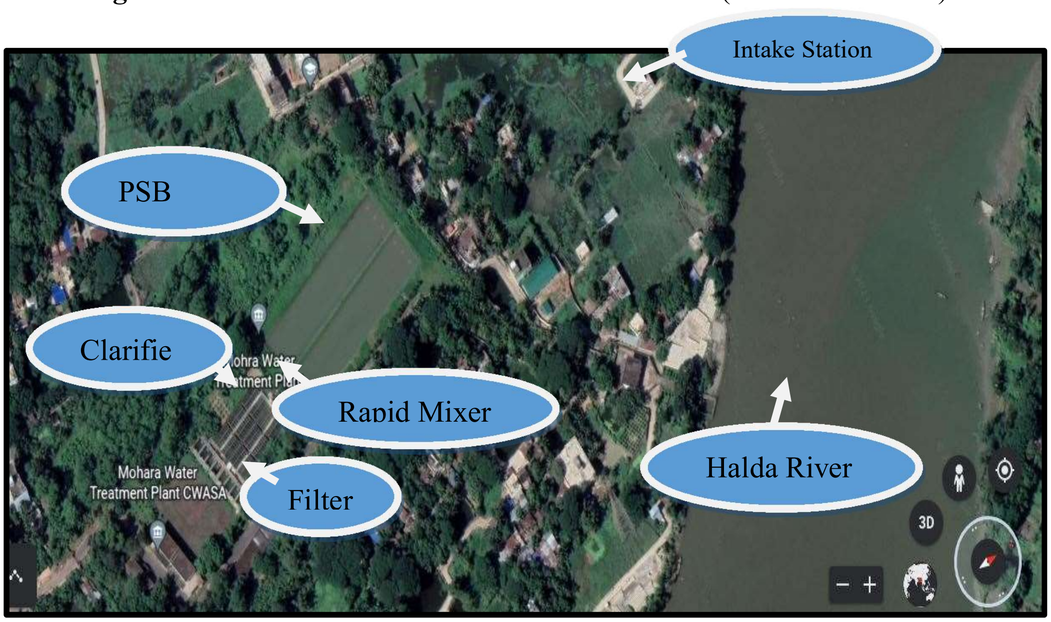

Figure 3.3: Location Map of Mohara Water Treatment Plant (Source: Google Earth)

3.1.2.1 Intake

Intake station of MWTP is located on the bank of the Halda river Figure 3.4 (a, b). A screening device at the inlet, along with five pipes, each with a diameter of 400 mm, gather untreated water to the plant from Halda river with the help of 2 nos. of duty and 3 nos. of standby raw water pumps continuously. Pump motor capacity is 40 cum/min and 132 KW each.

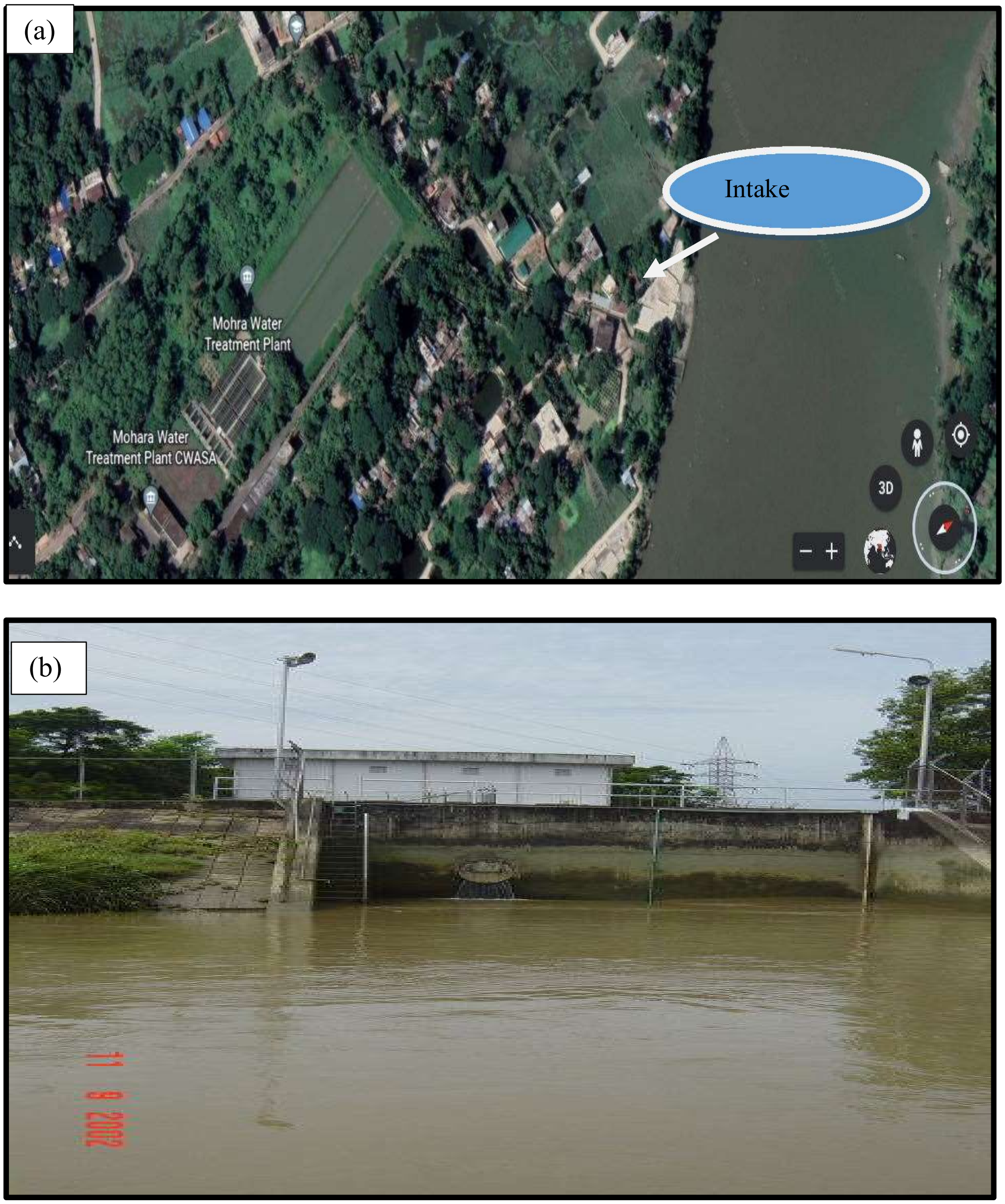

Figure 3.4 (a, b): Intake Station of MWTP (Source: Google Earth and CWASA)

3.1.2.2 Primary Sedimentation Basin

There are 2 Nos. of primary sedimentation basins as shown in Figure 3.5(a, b) with dimension of 100*440 ft. water from the intake station comes directly to these basins through 48 inch DI pipe. These basins are designed to reduce the heavy sediments loads to the clarifier during monsoon. In winter, raw water directly passes to the rapid mixing chamber through a by-pass system. Desilting basins overflow rate is 311 gpd/sft and detention time is 120 minutes.

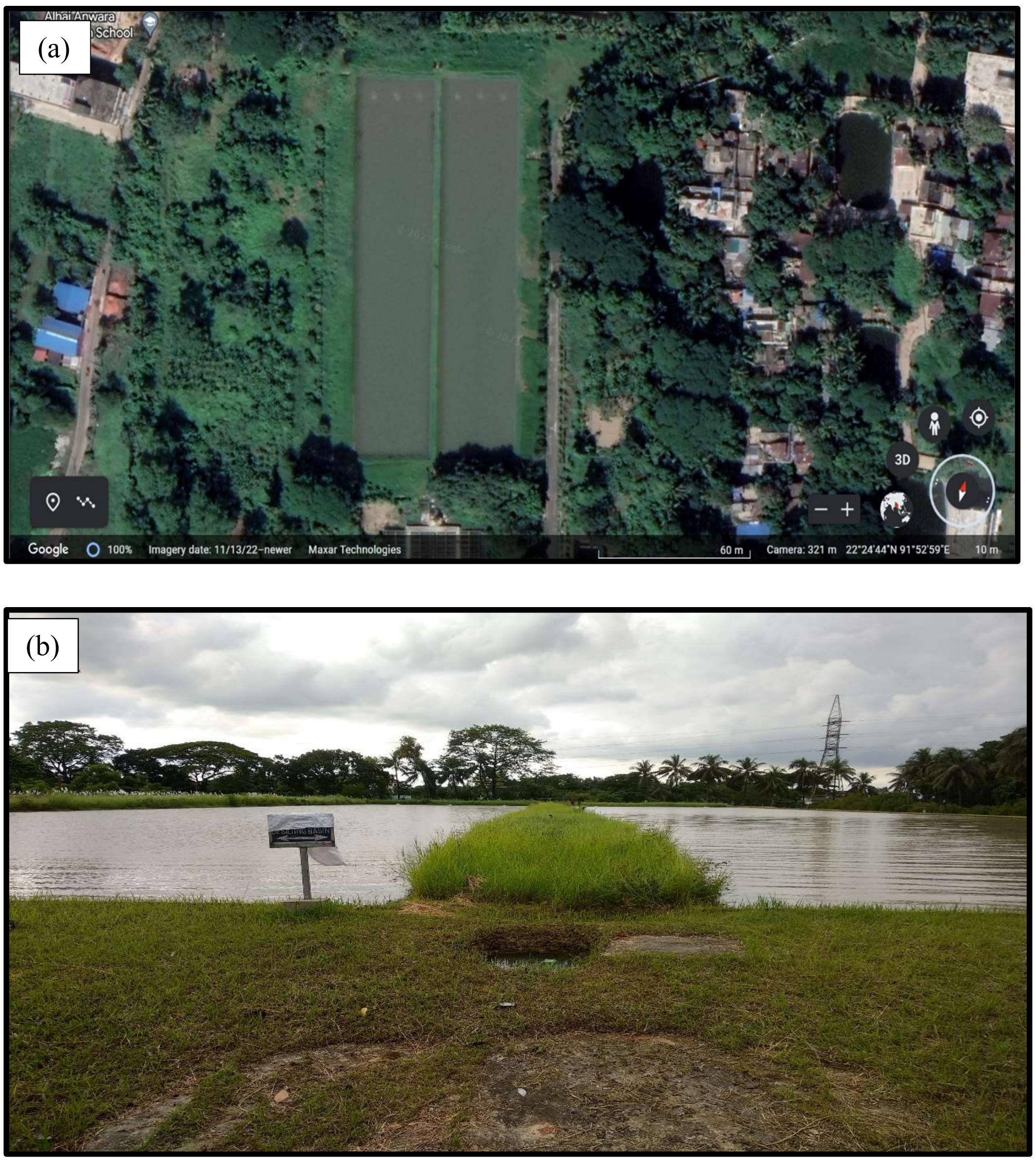

Figure 3.5 (a, b): Primary Sedimentation Basins of MWTP (Source: Google Earth and CWASA)

3.1.2.3 Rapid Mixing Chamber

Rapid Mixing Chamber is the first treatment for incoming raw water. Water from desilting basins /raw water pump station comes to the rapid mixing chamber through 48 inch DI Pipe. In this stage alum (aluminum sulfate), hydrated lime (if needed), polymer (as coagulant aid) and chlorine (to reduce algal growth) are added as solution in the 400 cft mixing chamber with the help of two rapid mixing agitator of 7.5 HP each with detention time 10 second/chamber. The water in its untreated form undergoes continuous coagulation in a Rapid mixing chamber with the addition of alum as shown in Figure 3.6(a, b).

Figure 3.6 (a,b): Rapid mixing chamber of MWTP (Source: Google Earth and CWASA)

3.1.2.4 Clarifiers

There are 24 nos. up flow hopper type clarifiers (Figure 3.7 (a, b). Water from rapid mixing chamber come to the bottom of each clarifier through a 12 inch dia Ductile Iron pipe from the incoming channel. Velocity of incoming water is reduced considerably when it comes to the top of the clarifier. Minimum flow velocity of clarifier is 8.9 ft/hr with detention time 1.2 hrs. and over flow rate is 1333 gpd/sft. Almost all the settle able materials settle down in the clarifiers and clean water are collected to the filters.

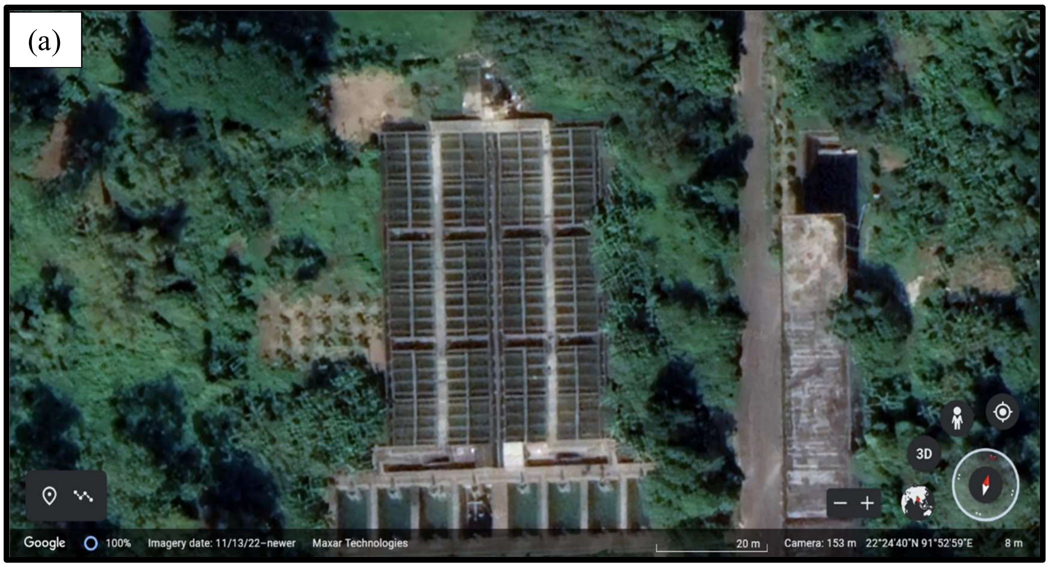

Figure 3.7 (a, b): Clarifiers of MWTP (Source: Google Earth and CWASA)

3.1.2.5 Sand Filtration

There are 8 nos. of conventional type rapid gravity sand filters in MWTP (Figure 3.8(a, b)). Water from clarifiers comes to the filters and passes through sand and gravel media. All suspended materials and most of the bacteria are entrapped in filter media and clean water are collected in the contact chamber for disinfection.

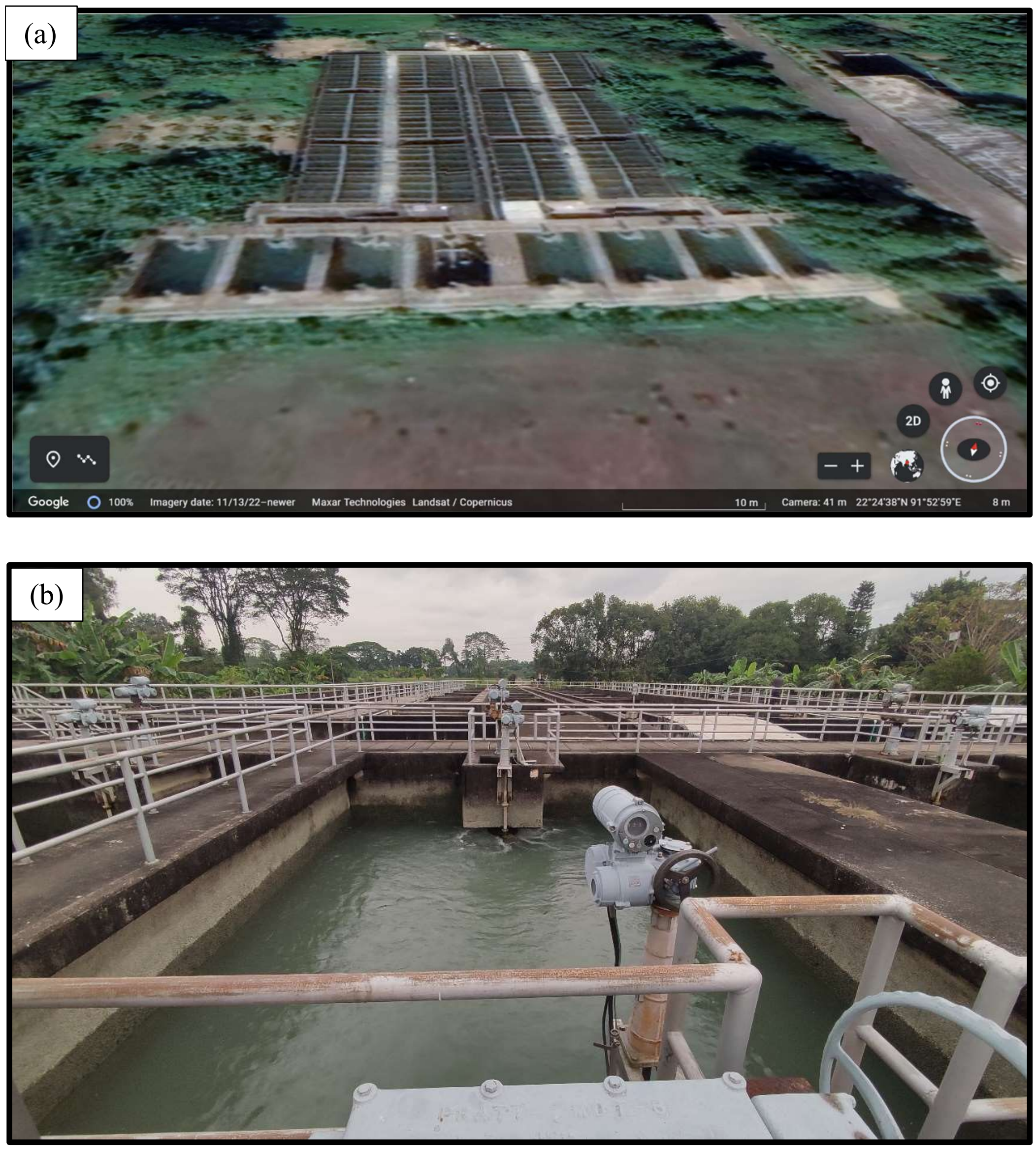

Figure 3.8 (a, b): Rapid gravity sand filters of MWTP (Source: Google Earth and CWASA)

3.1.2.6 Disinfection

Following the process of filtration, the water continues on to the disinfection chamber situated at the rear of the filters. Prior to storing and distributing treated water, the addition of chlorine takes place. A minimal level of chlorination is implemented where approximately (120-140) kg of chlorine is added daily. Chlorine contact time in this contact chamber is 30 minutes.

3.1.2.7 Storage and other Facilities

The MWTP comes with a water tank that has the ability to store 11. 3 ML of water. The plant also contains chemical components including chlorine structures (Figure 3.9). Various components such as administrative buildings, retail spaces, water distribution pumps, and other elements make up the ensemble.

Figure 3.9: Chemical and Chlorine Building of MWTP (Source: CWASA)

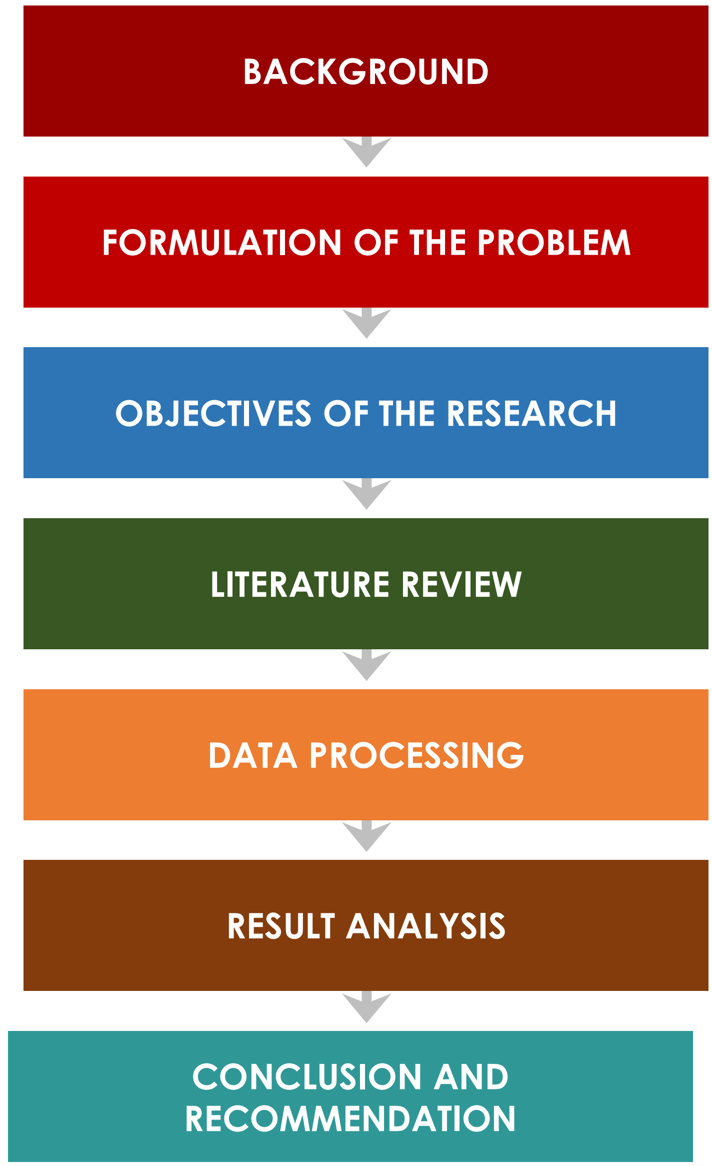

Figure 3.10: Research methodology

3.1.3 Water Sampling

The treatment unit considered for study consists of intake (Raw water), Primary Sedimentation Basin, Clarifier, Filtration unit and Transmission unit (after chlorination). Total 88 grab samples were collected from the exit points of these units twice a day (low tide and high tide) in a month for the December 2020 to August 2021. Samples at respective station were collected following the detention time of the water treatment plant units. The standard methods (APHA, 2012) were followed when utilizing sampling tools. For bacteriological tests, 250 mL glass bottles with metallic screw caps were employed. These bottles were pre-sterilized by being placed in an oven at 160°C for a duration of 2 hours. To counteract any remaining chlorine in the purified water, a small amount of 10% sodium thiosulfate solution (0.2 mL) was introduced. Glass bottles with a capacity of 1 liter constitute the second category of bottles. These containers serve as vessels for obtaining water samples for physicochemical analysis. DO and BOD_5 experiments were conducted using light and dark bottles, respectively, each with a capacity of 300ml. The glass bottles underwent a thorough cleaning process involving the use of soap and multiple rounds of rinsing with both tap and distilled water.

3.2. Laboratory Tests

The gathered samples were utilized to conduct significant evaluations on various water quality factors, including: TDS, Turbidity, EC, Temperature, TSS, Total Coliform, Fecal Coliform, pH, Hardness, Chloride, Nitrate, Ammonia, Sulphate, Phosphate, Arsenic, Iron, Zinc, Copper, Manganese, Lead, Cadmium, Mercury, DO, BOD, COD etc. All these tests except Lead, Cadmium, Mercury and Chromium were carried out in MWTP Laboratory of CWASA. Lead, Cadmium, Mercury and Chromium test were carried out in BCSIR Laboratories, Chattogram using AAS (Atomic Absorption Spectroscopy). For each water sample, we delved into an analysis covering 28 specific parameters. To ensure the integrity of our data, we upheld stringent practices, including thorough equipment sterilization, meticulous aseptic protocols, the incorporation of control samples, measurement of blanks, and conducting triplicate analyses. Furthermore, we adhered to internationally recognized sampling techniques and analysis procedures to safeguard data quality. Table 3.1 lays out the globally recognized methods, equipment, and testing standards. FAAS measurements for Pb, Cd, Hg, and Cr in various water samples were carried out using a Thermo Scientific iCE 3000 Atomic Absorption Spectrometer (AA). Each measurement was repeated three times for enhanced precision. To establish a baseline, deionized water served as the blank solution, while a meticulously prepared working standard solution was employed for constructing the calibration curve. The calibration curve itself was generated by plotting the absorbance on the y-axis against the concentration on the x-axis. The instrument's detection limit, as per its spectrometer parameters, is detailed in Table 3.2. The assessment of water quality involved a comparison of the test results against the established standards for drinking water quality, including those set by Bangladesh Drinking Water Standard (BSTI), Environmental Conservation Rules-1997 (ECR-97), and World Health Organization (WHO) guidelines as of 2011.

Table 3.1: List of water quality parameters tested with name of the equipment and methods utilized.

Sl. No.	Parameters	Equipment utilized	Method Used	Comments
1	TDS	Hach Sension 5	EC Probe	On site lab
2	Turbidity	Aqualytic Turbidity Meter	Nepehelometric	On site lab
3	EC	Hach Sension 5	EC Probe	On site lab
4	Temperature	Hach Sension 5	Temperature Probe	On site lab
5	TSS	Analytical Balance and Drying Oven	Gravimetric	On site lab
6	pH	Hanna HI8424	pH Electrode	On site lab
7	DO	Aqualytic DO Meter	Optical DO Sensor	On site lab
8	BOD	BOD Incubator	5-Day BOD	On site lab
9	COD	Aqualytic Photometer, Aqualytic COD reactor	Reactor Digestion Method	On site lab
10	Arsenic	Hach EZ As Test Kit	Colorimetric	On site lab
11	T.Coliform	0.45 μ filter, Filtration apparatus, Incubator.	Membrane Filtration	On site lab
12	F.Coliform	0.45 μ filter, Filtration apparatus, Incubator.	Membrane Filtration	On site lab
13	T. Hardness	-	Titrimetric	On site lab
14	Ca-Hardness	-	Titrimetric	On site lab
15	Chloride	-	Titrimetric	On site lab
16	Nitrate	Hach DR 4000	Cadmium Reduction	On site lab
17	Fluoride	Hach DR 4000	SPADNS	On site lab
18	Ammonia	Hach DR 4000	Nessler	On site lab
19	Sulphate	Hach DR 4000	SulfaVer 4	On site lab
20	Phosphate	Hach DR 4000	PhosVer 3	On site lab
21	Iron	Hach DR 4000	FerroVer	On site lab
22	Zinc	Hach DR 4000	Zincon	On site lab
23	Copper	Hach DR 4000	Bicinchoninate	On site lab
24	Manganese	Hach DR 4000	PAN	On site lab
25	Chromium	iCE 3000 AAS	Spectroscopic	BCSIR Lab
26	Lead	iCE 3000 AAS	Spectroscopic	BCSIR Lab
27	Cadmium	iCE 3000 AAS	Spectroscopic	BCSIR Lab
28	Mercury	iCE 3000 AAS	Spectroscopic	BCSIR Lab

Table 3.2: Instrumental detection limit of iCE 3000 series AA

Sl. No.	Element	Wave length nm	Instrumental detection limit	
			Flame mg/L	Vapor μg/L
1	Chromium	357.9	0.0054	
2	Cadmium	228.8	0.0028	
3	Lead	217.0	0.013	
4	Mercury	253.7	-	0.06

3.3. Plant Efficiency Evaluation Method:

The extent to which pollutants have been eliminated from raw water and treated for production water is denoted by removal efficiency, expressed as a percentage. Water suppliers employ a range of treatment methods to eliminate impurities from the source water, according to Angreni (2009). To determine the efficacy of removal, the concentration of contaminants in the untreated water is compared to that of the treated water, in relation to the concentration of pollutants in the untreated water. The formula for calculating efficiency can be expressed mathematically in the following manner:

$Eff = (C_{raw\ water} - C_{treated\ water})/(C_{raw\ water}) * 100$ -------------------- (Eq. 3.1)

Eff = Efficiency (%)

$C_{raw\ water}$ = Concentration of pollutant in raw water (mg/L)

$C_{treated\ water}$ = Concentration of pollutant in treated water (mg/L)

3.4. Water Quality Assessment

Both the raw water (Halda river water) and the treated water were analyzed for about 26 water quality parameters namely-TDS, Turbidity, EC, Temperature, TSS, Total Coliform, Fecal Coliform, pH, Total Hardness, Ca- Hardness, Chloride, Nitrate, Flouride, Ammonia, Sulphate, Phosphate, Arsenic, Chromium, Iron, Zinc, Copper, Manganese, Lead, Cadmium, Mercury, DO, BOD, COD. The obtained outcomes were evaluated against the benchmarks established by Bangladesh Standard and Testing Institution (BSTI), Environmental Conservation Rules-1997 (ECR-97) and World Health Organization (WHO) guidelines in terms of drinking water quality.

CHAPTER IV

RESULTS AND DISCUSSION

4.1. Efficiency of the Water Treatment Plants

Chattogram WASA's Mohara water treatment facility has the capability to purify and process 100000 cubic meters of Halda River's untreated water every day, with 90000 cubic meters of clean water being distributed following the treatment. The standard treatment procedure executed at the water treatment facility comprises the application of coagulant (alum and lime) and pre-treatment with chlorine, as deemed necessary, to the raw water that has been through sedimentation basins. Following the process of flocculation in the clarifiers, the resulting water is then conveyed for filtration to the sand bed filter. Following filtration, a chlorine solution is applied to disinfect the water and maintain residual chlorine levels at the plant in the range of 0.8 to 1.0 mg/L, leaving a residual trace in the customer's end. Performance of the MWTP was evaluated in this study through the efficiency of the WTP based on the removal efficiency of some selected parameters such as Turbidity, Chloride, Ammonia, TSS, Total Coliform, Fecal Coliform and COD. Removal efficiency of these selected parameters such as turbidity, chloride, ammonia, TSS, total coliform, fecal coliform and COD were expressed as percentage.

4.1.2 Turbidity

The success of disinfection following the sedimentation and filtration process of a water treatment plant solely relies on the extent to which turbidity is effectively eliminated. It signifies that the plant is operating flawlessly. In Figure 4.1, there is a visual comparison displayed between the untreated water and treated water of the Mohara Water Treatment Plant. This report presents data on the turbidity levels in raw water observed during high and low tides between December, 2020 and October, 2021. The turbidity levels began to decline from January , 2021 and reached their lowest point in April, 2021, with readings of 142 ± 1.63 NTU during high tide and 91 ± 0.82 NTU during low tide. However, the levels increased again and peaked at 403.67 ± 2.62 NTU during high tide in May 2021 and 392.33 ± 2.05 NTU during low tide in June, 2021. Then the turbidity of the rest of the months found fluctuating for both in high tide and low tide condition. The rise in turbidity levels could be attributed to an elevated amount of clay, dissolved organic and inorganic substances in the untreated water source, as stated by Jachimowski (2018). Additionally, the occurrence of rainfall in May and June of 2021 may have resulted in water influxes carrying numerous impurities into the river.

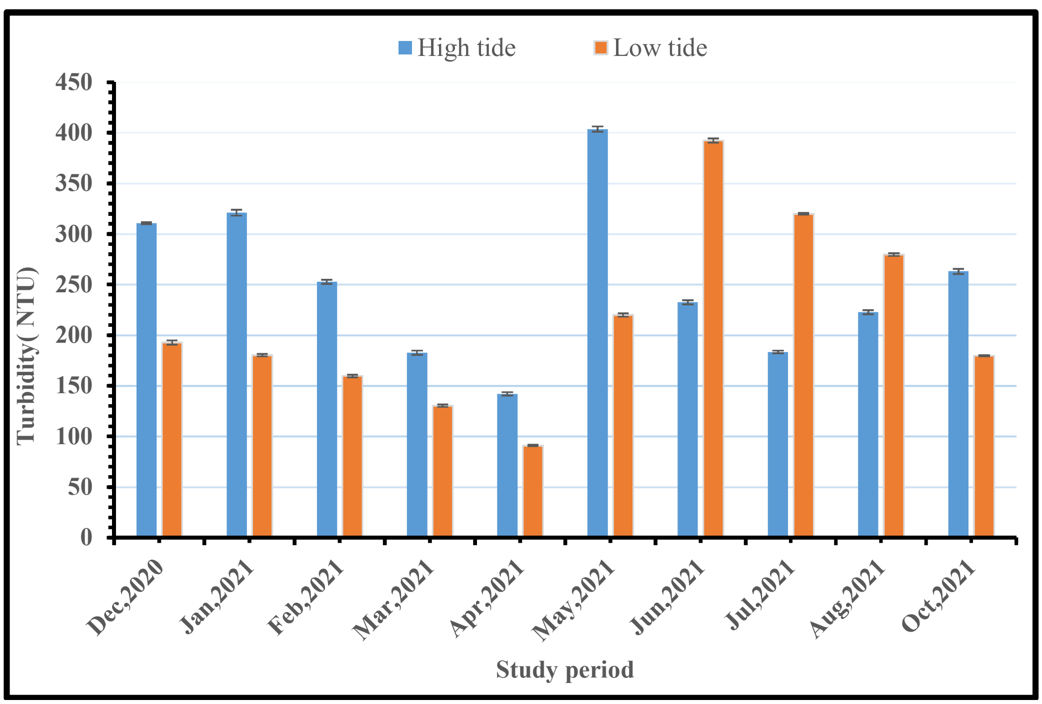

Figure 4.1: Comparison of raw water Turbidity during high tide and low tide

Hossen & Jishan (2018) also revealed the variation of turbidity in Halda river. In the period of heavy rainfall, the influx of mud and silt into rivers and streams can cause rapid rise in turbidity levels, thereby obstructing the efficient functioning of filters. Excessive turbidity has the potential to clog tanks and pipes with sediment, leading to the impairment of valves and faucets. The ideal level of turbidity for drinking water is 5 NTU or lower. The Turbidity levels in MWTP's raw water are inconsistent during both high and low tide, and do not adhere to the standards set by WHO, BSTI, or ECR-97. The formation of small flocs through coagulation and larger flocs through flocculation has been identified as an efficient method for the removal of turbidity and solubilized organic compounds from water, as per research of Ashery et al., 2010.

Figure 4.2 shows the concentration of Turbidity of treated water during high tide and low tide from December, 2020 to October, 2021. It is seen that the treated water turbidity of MWTP during this period fluctuates between the lowest value of 0.37 ± 0.01 NTU in July, 2021 to highest value of 0.63 ± 0.01 NTU in May, 2021 during high tide. During low tide the minimum turbidity was recorded 0.31 ± 0.01 NTU in April, 2021 and the maximum value was 0.65 ± 0.01 NTU in May, 2021. However the treated water turbidity of MWTP conform to WHO standard of 5 NTU.

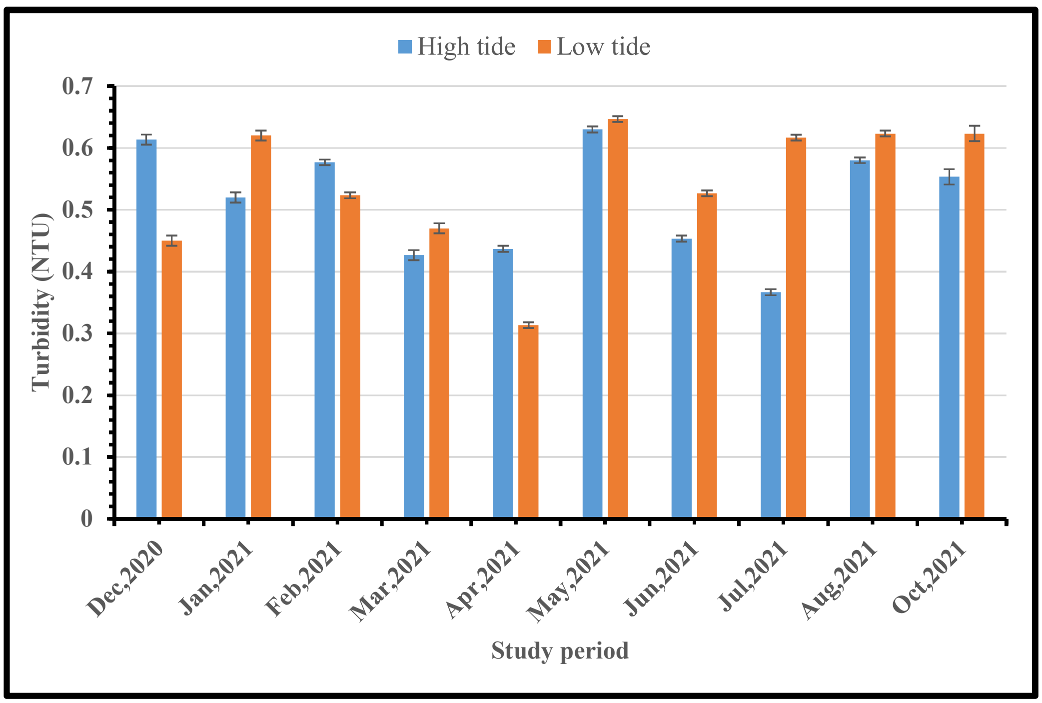

Figure 4.2: Comparison of treated water Turbidity during high tide and low tide

Figure 4.3 demonstrates the concentration of Turbidity (average) at various units of MWTP from December, 2020 to October 2021. Water enter into the treatment plant through the intake pump to the sedimentation basin. In December, 2020 the primary sedimentation basins remained stop for cleaning purpose. From the Figure 4.3 it is seen that for each month mean high turbid (116.5 ± 27.97 NTU – 312.5 ± 87.48 NTU) raw water enter into the sedimentation basins. After sedimentation raw water turbidity somehow decreased to reach the value of (95.17 ± 24.72 NTU – 260.83 ± 76.88 NTU).

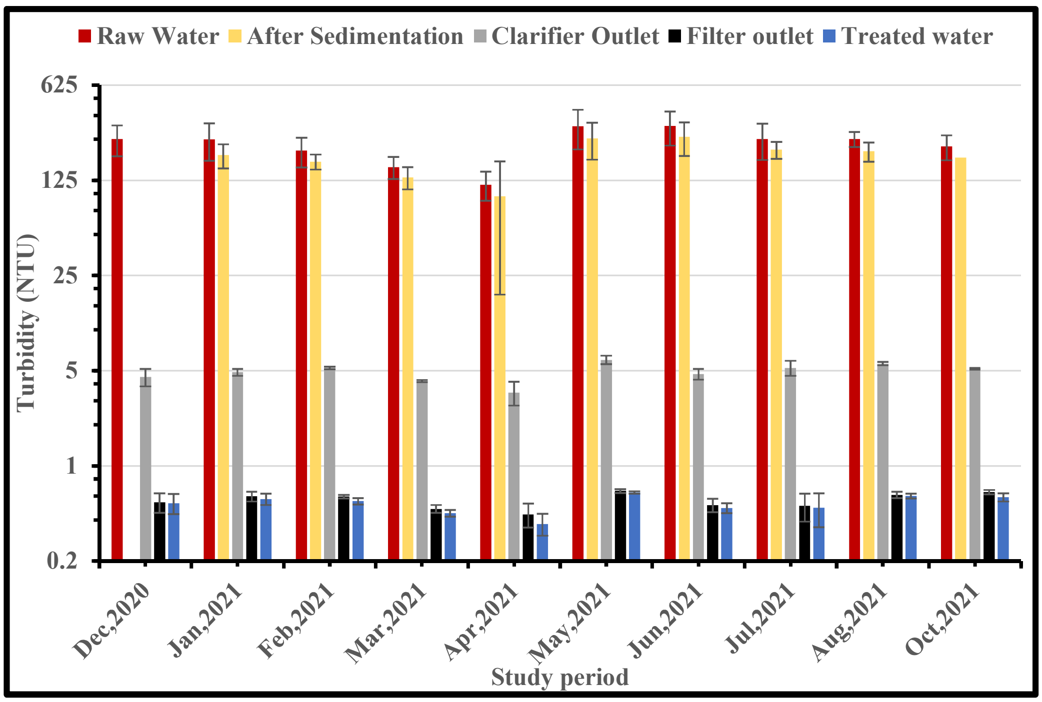

Figure 4.3: Concentration of monthly mean Turbidity at various units of MWTP

It is because the detention time in the sedimentation basins of MWTP is 2 hours. Within this time heavy silt, sand and mud become deposited as sediment and hence raw water turbidity gets reduced. On the other hand turbidity of the clarifier outlet recorded between 3.46 ± 0.68 NTU to 6.02 ± 0.44 NTU. It is seen that the water of the clarifier outlet remained below 6 NTU. This is because after the primary sedimentation basin the raw water comes to the rapid mixing chamber where proper dosage of alum, lime and polymer are added to start coagulation. During coagulation the suspended particle in the water react with the alum, lime and polymer and make flocs. These flocs bond together to form a big floc and get settled in the bottom of the clarifier. As a result clear water come out of the clarifier where turbidity becomes very low. Then the clarifier outlet water goes to the filtration chamber. There are rapid gravity sand filters in MWTP. After the filtration the outlet water turbidity recorded between 0.44 ± 0.09 NTU to 0.65 ± 0.02 NTU and finally after disinfection with Chlorine the treated water turbidity recorded between 0.38 ± 0.07 NTU to 0.64 ± 0.01 NTU. The fact that the treatment process units cause significant reduction in turbidity levels can be attributed to the settlement of flocs formed during the coagulation/flocculation process. The higher level of cloudiness in the incoming source of water directly impacts the cloudy level in the processed water. In instances of turbid conditions, the treated water experienced an upsurge in the concentration of suspended particles as stated by Gauthier et al. (2003). The most likely reason for elevated turbidity levels in treated water is the incorrect amount of coagulant, particularly if the optimal dosage is not administered. Figure 4.4 exhibits the MWTP's effectiveness in eliminating turbidity levels as a whole. It is seen that the turbidity removal efficiency gradually decreased from December, 2020 to April, 2021. Then it increased again to achieve the highest efficiency of 99.84 ± 0.03 % in June, 2021 which is much higher than the Turbidity removal efficiency found for the Angereb water treatment plant of Ethiopia (94.4%) in the study of Desye et al. (2021). The lowest efficiency was recorded 99.67 ± 0.02 % in April, 2021. In summary, it can be inferred that the MWTP exhibits a notable effectiveness in eliminating Turbidity from the untreated water source.

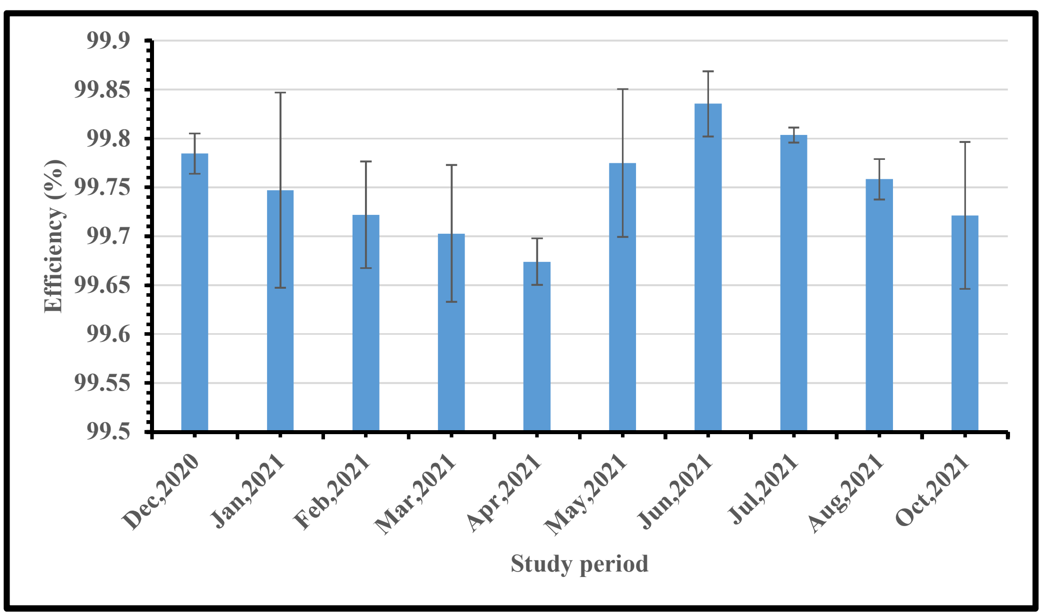

Figure 4.4: The Turbidity removal efficiency of MWTP

4.1.3 Total Suspended Solid (TSS)

The effective elimination of solids is a critical factor in ensuring the efficient operation of a primary treatment system, as stated by McGhee in 1991. Figure 4.5 illustrates the concentration of TSS of raw water during high tide and low tide from December, 2020 to October, 2021. Observations indicate a decline in TSS levels beginning in January 2021, with a low point of 187 ± 2 mg/L recorded during periods of high tide and 134.33 ± 1.15 mg/L during low tide in April of that year. This is because during this period the rain is almost no longer happening and water is almost stable. Then increase again to reach a highest of 540.67 ± 1.15 mg/L in May, 2021 during high tide and also a highest of 506.67 ± 1.53 mg/L in June, 2021 during low tide.

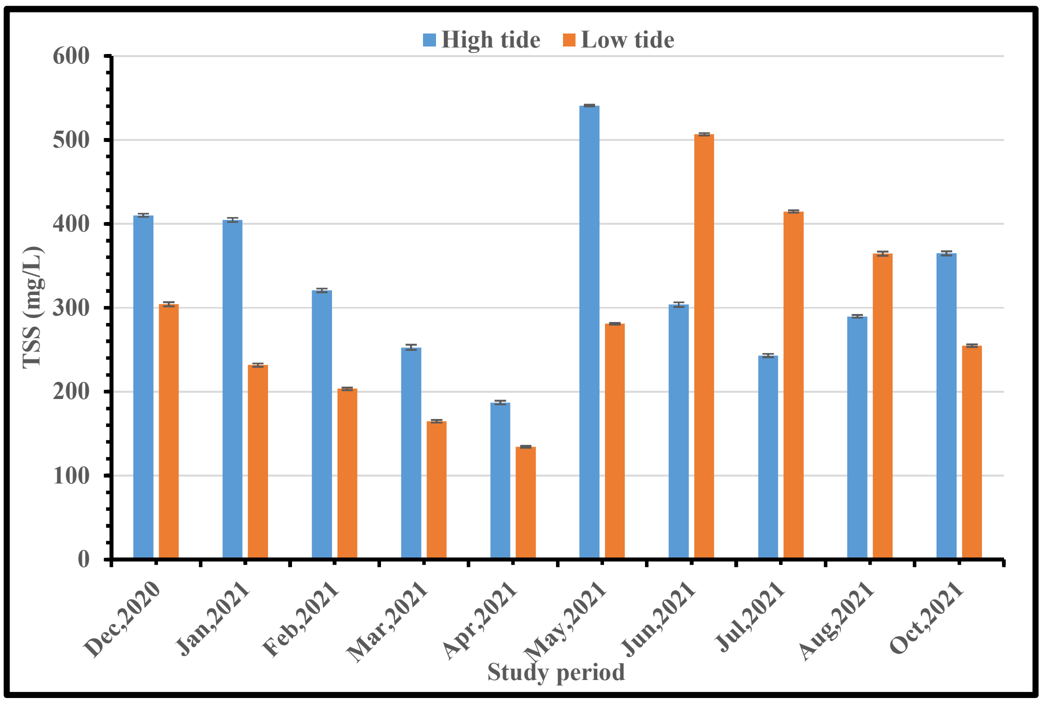

Figure 4.5: Comparison of raw water TSS during high tide and low tide

The rise in TSS levels can possibly be attributed to the presence of abundant sediments, nutrients, metals, and algae in the raw water. This can be attributed to the occurrence of heavy rainfall throughout May and June of 2021. According to the Michigan DEQ in 2001, a rise in TSS concentrations results in a decline in the general water quality of a body of water. Water clarity is diminished by increased levels of suspended particles. The aesthetics and recreational activities in freshwater bodies are negatively impacted by this. Figure 4.6 shows the concentration of TSS of treated water during high tide and low tide from December, 2020 to October, 2021. It is seen that the treated water TSS of MWTP during this period fluctuates between the lowest value of 0.54 ± 0.01 mg/L in July, 2021 to highest value of 1.23 ± 0.06 mg/L in June, 2021 during high tide. The lowest level of TSS, at 0.53 ± 0.02 mg/L, was observed during March of 2021, while the highest level, reaching 0.99 ± 0.01 mg/L, was recorded in May of the same year during low tide. However the treated water turbidity of MWTP conform to ECR-97 standard of 10 mg/L.

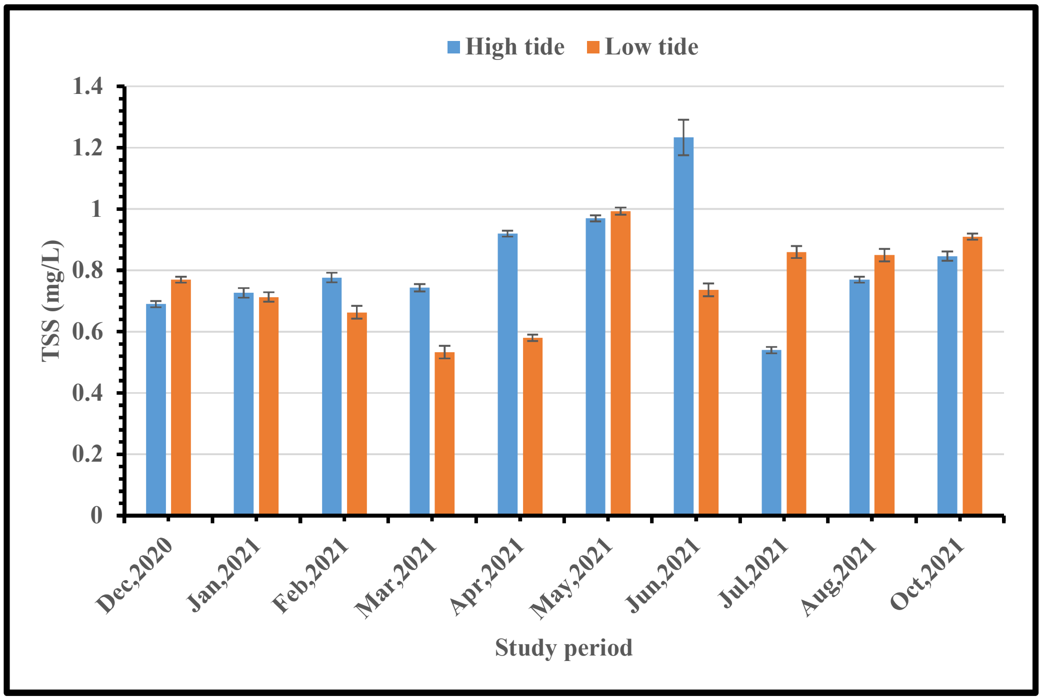

Figure 4.6: Comparison of Treated Water TSS during High Tide and Low Tide

Figure 4.7 shows the mean concentration of TSS at various units of MWTP from December, 2020 to October, 2021. Water is transferred to the sedimentation basin at the treatment plant via the intake pump. In December, 2020 the primary sedimentation basins remained stop for cleaning purpose. From the Figure 4.7 it is seen that for each month high TSS (160.67 ± 28.88 mg/L – 410.83 ± 142.23 mg/L) raw water enter into the sedimentation basins. After sedimentation raw water TSS somehow decreased to reach the value of 133.33 ± 21.95 mg/L – 337.83 ± 114.85 mg/L. It is because the detention time in the pre-sedimentation basins of MWTP is 2 hours. Within this time heavy silt, sand and mud become deposited as sediment and hence raw water TSS gets reduced. On the other hand TSS of the clarifier outlet recorded between 5.98 ± 0.76 mg/L to 9.85 ± 0.75 mg/L. It has been observed that the TSS present in the water exiting the clarifier remained at or below 10 mg/L. This is because after the primary sedimentation basin the raw water comes to the rapid mixing chamber where proper dosage of alum, lime and polymer are added to start coagulation.

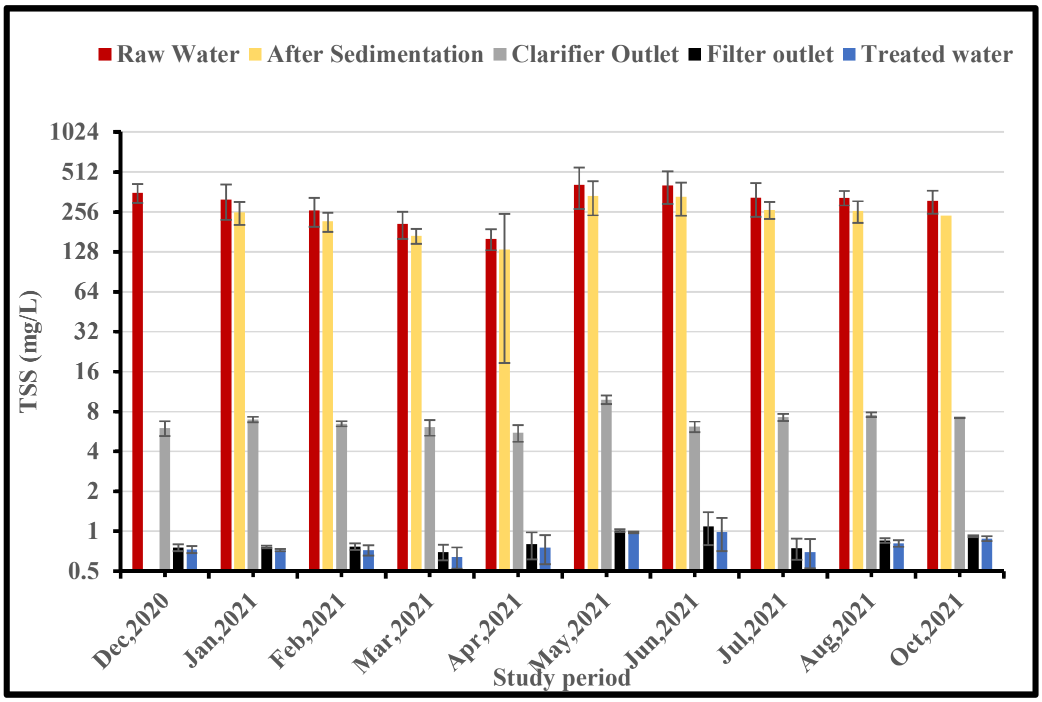

Figure 4.7: Concentration of monthly mean TSS at various units of MWTP

During coagulation the suspended particle in the water react with the Alum Lime and polymer and make flocs. These flocs bond together to form a big floc and get settled in the bottom of the clarifier. As a result clear water come out of the clarifier where TSS becomes very low. Then the clarifier outlet water goes to the filtration chamber. There are rapid gravity sand filters in MWTP. Following the filtration process, the TSS level of the discharged water ranged from 0.70 ± 0.09 mg/L to 1.09 ± 0.30 mg/L, and subsequently after Chlorine disinfection, the treated water TSS level was measured to be between 0.64 ± 0.1 mg/L to 0.99 ± 0.03 mg/L as chlorination can reduce TSS by reacting with the suspended organic matter. Hasmi et al. (1999) also stated that chlorination has a modest impact on TSS, BOD, COD and Ammonia and offers certain treatment benefits. It is clear that TSS levels significantly decrease throughout the treatment units as flocs formed during coagulation/flocculation process settle. The TSS levels of treated water are directly impacted by the elevated TSS of the unprocessed water that enters the system. If the coagulant is not used in the right amount, it is likely that the treated water will have elevated TSS levels. This is particularly true if the coagulant is not optimally dosed. The efficiency of the coagulation process greatly relies on the ideal coagulant dosage, and achieving proper coagulation is vital for obtaining the desired quality of treated water as stated by Mbaeze et al. (2017). Figure 4.8 shows the overall effectiveness of removing TSS in the MWTP. It is seen that the TSS removal efficiency gradually decreased from December, 2020 (99.79 ± 0.05%) to April, 2021. The lowest efficiency was recorded 99.54 ± 0.03% in April, 2021.Then it increased again. Meghana et al. (2017) found the TSS removal efficiency of the Water Treatment Plant of Bhadravathi in Karnataka, India ranging from 43% to 52% which is far much lower than the value found for MWTP in this study. So it can be said that the TSS removal efficiency of MWTP is to its best level which indicates that the plant is running satisfactorily.

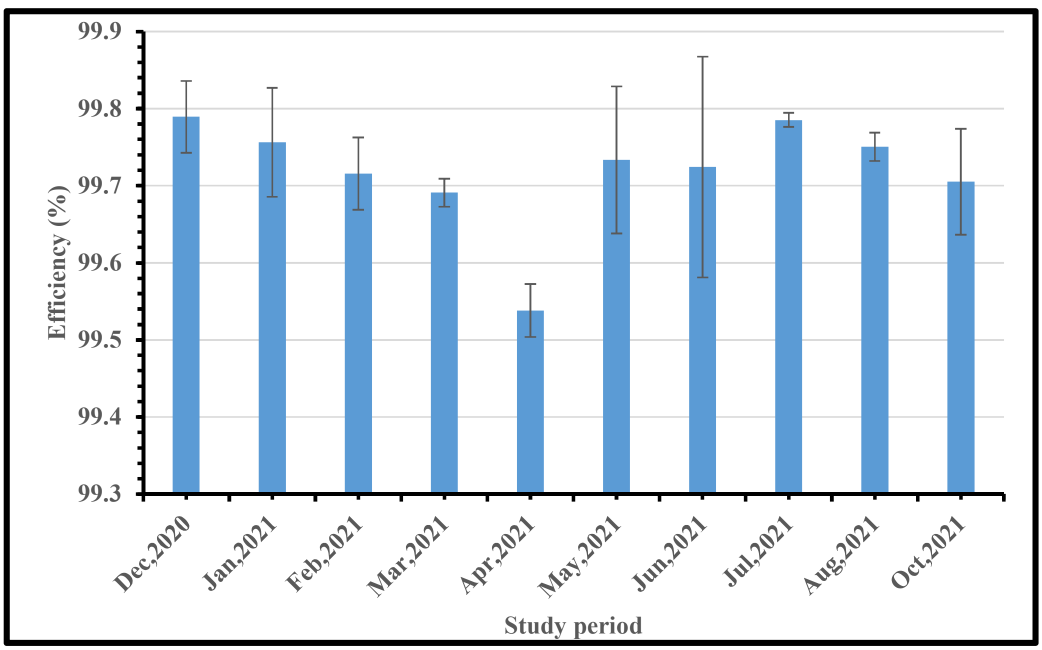

Figure 4.8: The TSS removal efficiency of MWTP

4.1.4 Chloride (Cl^-):

Chlorides are safe for human consumption in moderate amounts, however exceeding the WHO threshold of 250 mg/L may lead to an unpleasant, salty flavor in water (Jiwa, et al., 1991). Figure 4.9 visualizes the levels of Chloride in untreated water at both high and low tide, spanning from December, 2020 to October, 2021. It is seen that Chloride concentration fluctuates from December, 2020 to May, 2021 and reach a maximum of (1405 ± 5 mg/L) during high tide and then it starts to decrease gradually and reach a minimum of (13.33 ± 1.53 mg/L) during high tide in August, 2021. Conversely, it has been observed that the amount of Chloride present in raw water during low tide tends to vary, with the highest level of Chloride (50 ± 2 mg/L) measured in May, 2021 and the lowest levels (8.33 ± 0.58 mg/L) recorded in August, 2021.

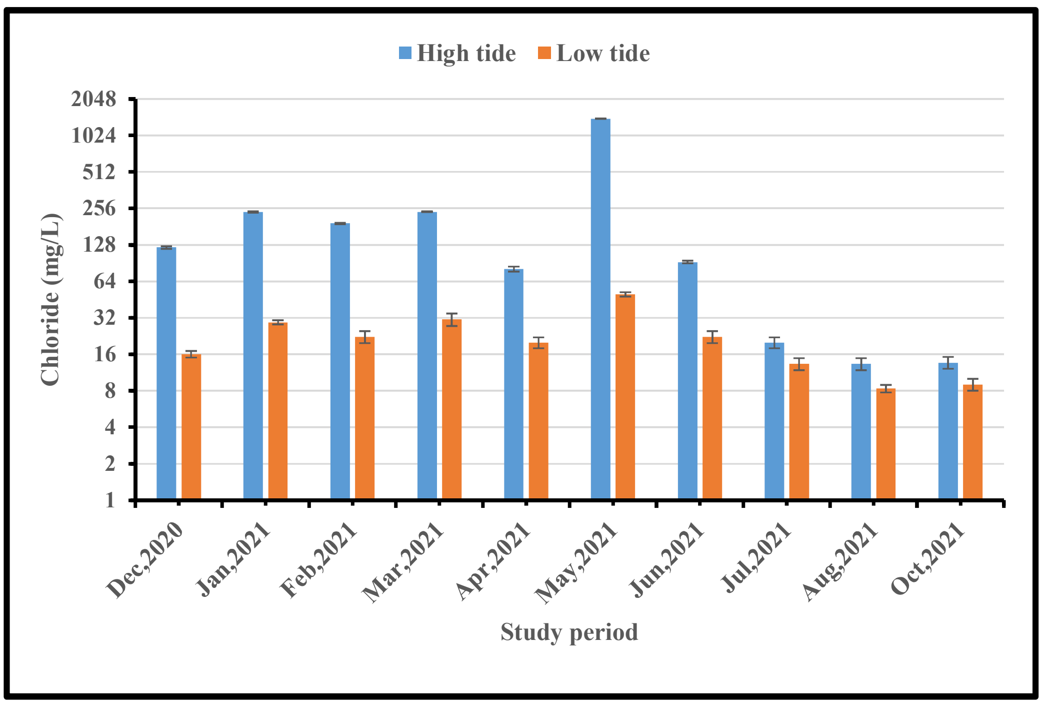

Figure 4.9: Comparison of raw water Chloride during high tide and low tide

From Figure 4.9 it has been observed that the raw water source contains a higher chloride level beyond both the ECR-97 permissible limit of 600 mg/L and the WHO standard limit of 250mg/L. The presence of a high concentration of Chloride in freshwater is generally regarded as a measure of pollution and can be found in both sanitation and industrial water sources, as stated by Florescu et al. (2010) in their study. The reason behind the high concentration of Chloride in raw water of Halda river during high tide is due to reduced water flow in the river during the dry season (November–May) which results in the intrusion of saline water from the Bay of Bengal through Karnafuly. This infiltration of salt water is influenced during the full moon and new moon when river level rises during high tide. Conversely during low tide the Chloride concentration in raw remained low as saline water goes back to the river Karnafuly during this time and available water is the upstream water of Halda river which is low in Chloride concentration. Releasing of adequate amount of water from Kaptai lake during dry season can mitigate this saline water intrusion in the Halda river as well as decreasing the Chloride concentration. Many experts acknowledge that the maintenance of estuarine salinity levels is heavily reliant on the implementation of flushing flows as affirmed by Arthington et al. in 1992 and Kelly in 1996. Arthington et al. (1992) established a logical connection between the level of water movement and the concentration of dissolved salts. According to their research, it is necessary to release flows during periods of high irrigation demand and when the salinity level exceeds 1000 μmhos/cm. During a recent dry season, the concentration of Chloride was measured at 20 times the acceptable level, as reported by Ahmad (2009). Another study by Islam et al. (2017) found maximum amount of Chloride (69.30 mg/L) during post-monsoon and minimum value of Chloride (8.4 mg/L) during winter in Halda river Figure 4.10 shows the concentration of Chloride in treated water during high tide and low tide from December, 2020 to October, 2021. It is seen that the treated water Chloride of MWTP during this period fluctuates between the lowest value of 9 ± 1 mg/L in both August, 2021 and October, 2021 to highest value of 597.67 ± 2.52 mg/L in May, 2021 during high tide. During low tide the minimum Chloride was recorded 6.33 ± 0.58 mg/L in June, 2021 and the maximum value was 20.67 ± 3.06 mg/L in May, 2021. An investigation carried out by Fahmida et al. (2013) found the maximum and minimum Chloride concentrations of 550 mg/L and 72 mg/L in Khulna City Corporation area supplied by Khulna WASA and they stated that the presence of elevated levels of Chloride in drinking water can be attributed to the recurrent issue of saline water intrusion, which is a common occurrence in the KCC area.

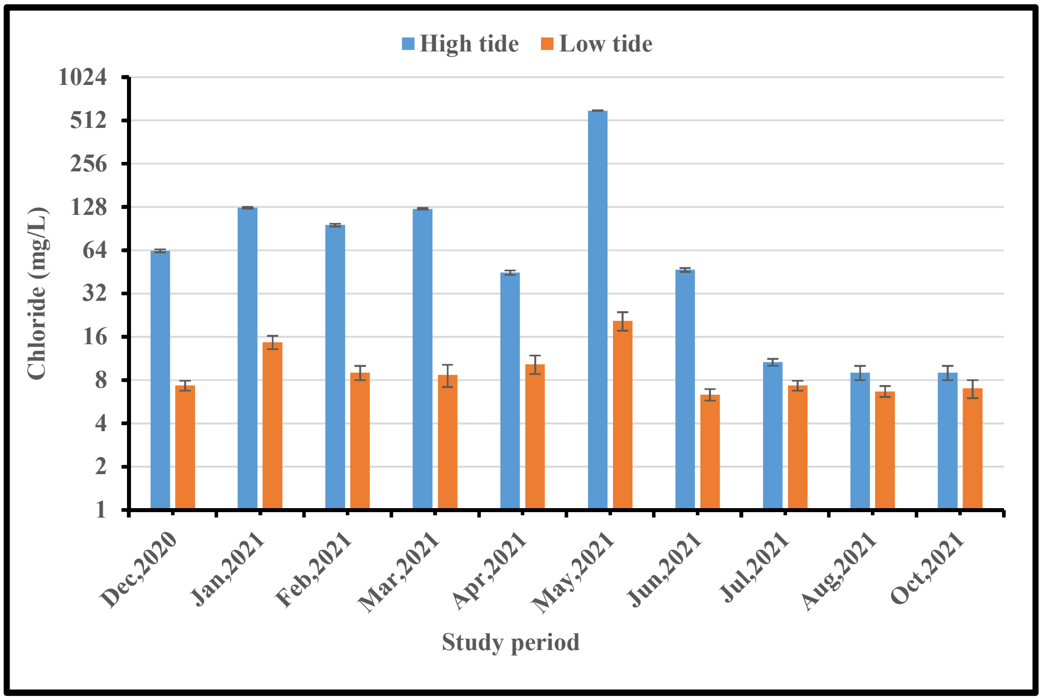

Figure 4.10: Comparison of treated water Chloride during high tide and low tide

Another study by Zuthi et al. (2009) found high Chloride concentration in CWASA supplied water and they stated that the reason for this could be attributed to the occurrence of the common issue of saline water infiltration in CWASA's current sources of water supply. Figure 4.11 shows the concentration of mean Chloride at various units of MWTP from December, 2020 to October, 2021.Water enter into the treatment plant through the intake pump to the sedimentation basin. In December, 2020 the primary sedimentation basins remained stop for cleaning purpose. From the Figure 4.11 it is seen during this period raw water from Halda river having Chloride content of a minimum value of 10.5 ± 3.27 mg/L during August, 2021 and the highest value of 727.5 ± 742.17 mg/L during May, 2021 enter into the sedimentation basins.

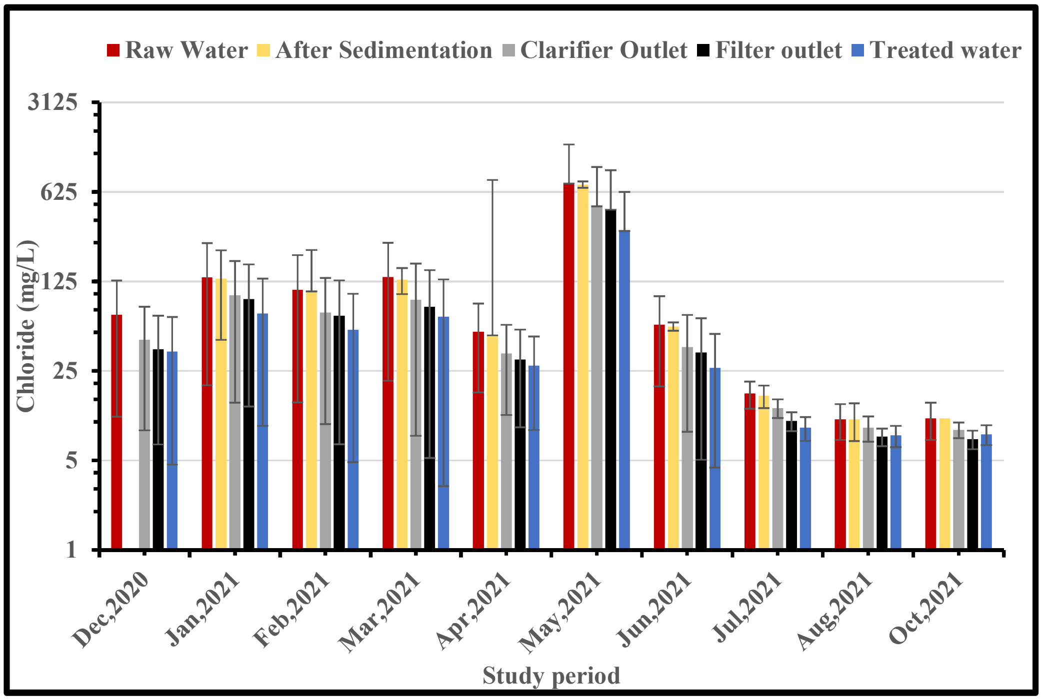

Fig. 4.11: Concentration of monthly mean Chloride at various units of MWTP

After sedimentation raw water Chloride somehow decreased due to the dilution with the previous water and the value was recorded from (10.5 ± 3.21 mg/L– 712.17 ± 729.02 mg/L). On the other hand Chloride content of the clarifier outlet recorded between 8.67 ± 1.21 mg/L to 482.83 ± 495.33 mg/L. It is seen that the Chloride content of the clarifier outlet water decreased than the sedimentation basin outlet water. Since MWTP is a conventional water treatment plant it cannot fully remove the Chloride content of the source water. But when water from the rapid mixing chamber enter into the clarifier it gets diluted with the previously entered water and hence the chloride content in the clarifier outlet get decreased. Then the clarifier outlet water goes to the filtration chamber. There are rapid gravity sand filters in MWTP. Same thing happens in the filtration chamber as it is in clarifier chamber. After the filtration the outlet water Chloride was recorded between 7.33 ± 1.21 mg/L to 453 ± 470.68 mg/L and finally after disinfection with Chlorine the treated water Chloride was recorded between 7.83 ± 1.47 mg/L to 309.17 ± 316.05 mg/L.

Figure 4.12 shows the Chloride removal efficiency of the MWTP. The study period demonstrated varying levels of Chloride elimination effectiveness, ranging from 25.80

± 11.28% to 60.34 ± 12.51%. The lowest Chloride removal efficiency of MWTP was recorded 25.80 ± 11.28% in August, 2021 and the highest Chloride removal efficiency was recorded 60.34 ± 12.51% in June, 2021.

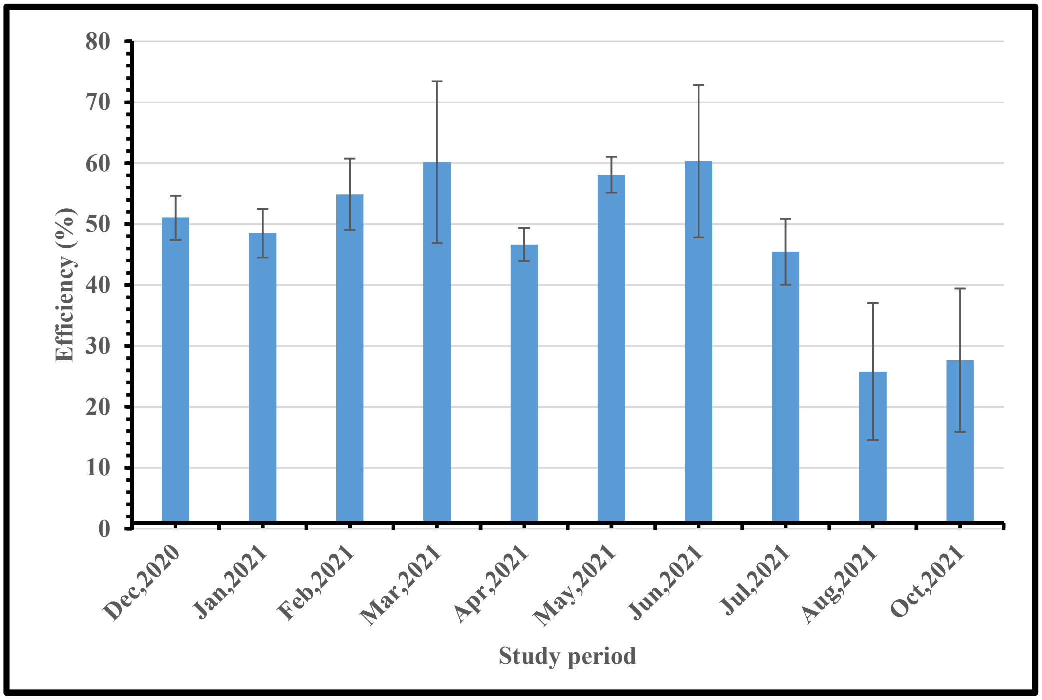

Figure 4.12: The Chloride removal efficiency of MWTP

Meghana et al. (2017) found the Chloride removal efficiency of the water treatment plant of Bhadravathi in Karnataka, India ranging from 36% to 58% which is almost same as the efficiency found in this study for MWTP. It has been observed that the MWTP is not very effective at removing chlorides, with the 60% efficiency rate which is because of using the conventional water treatment method including coagulation, sedimentation, and filtration which are not effective at removing chloride ions from water as Chlorides are negatively charged and highly soluble in water.

4.1.5 Ammonia

An essential factor in determining water pollution is the presence of Ammonia. Aquatic organisms struggle to eliminate high amounts of ammonia from water, causing the toxic substance to accumulate in their internal tissues and bloodstream, which may lead to fatality (Nion et al., 2020). Figure 4.13 shows the concentration of Ammonia present in raw water during the period of high tide and low tide from December, 2020 to October, 2021. It is seen that Ammonia concentration gradually decreased from December, 2020 to February, 2021 and reach a minimum value of 0.09 ± 0.01 mg/L during high tide and then it starts to increase and reach a maximum value of 0.25 ± 0.02 mg/L during high tide in June, 2021 and again starts to decrease in the rest of the month. Conversely, fluctuations in Ammonia concentration have been observed in raw water during low tide and a maximum Ammonia concentration was recorded 0.17 ± 0.02 mg/L in May, 2021 and minimum Ammonia concentration was recorded 0.10 ± 0.01 mg/L in October, 2021.

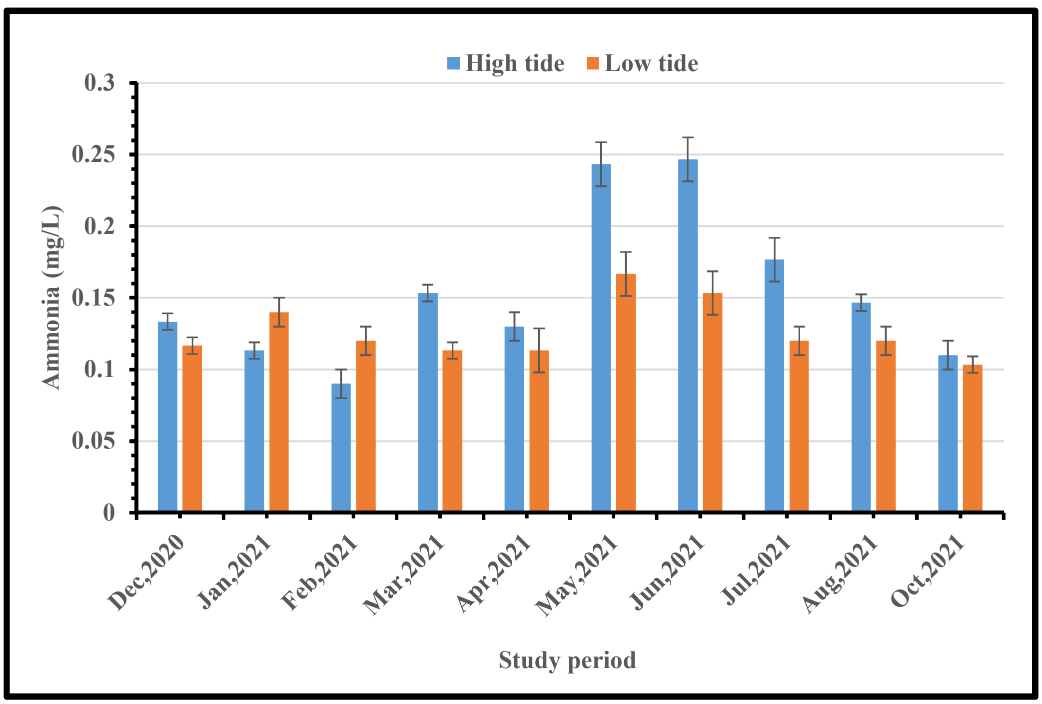

Figure 4.13: Comparison of raw water Ammonia during high tide and low tide

Aysha & Ali (2012) surveyed that the average level of Ammonia in the Halda river exceeded the safe limit for fish by tenfold year-round and also stated that the elevated levels of Ammonia in the river may be attributed to a higher pH. Ahmed et al. (2001) found the Ammonia content in their study as 0.4 mg/L in Kaptai lake which is comparatively higher than the present findings of this study. The high values of Ammonia in raw water of MWTP was may be due to sewage contamination from surrounding areas during the rainy season in May, 2021 and June, 2021. According to Environment Canada (1997), At 25ºC temperature and pH 7.5, maximum allowable limit of Ammonia for the protection of aquatic life is 0.89 mg/L and the toxicity increases with pH and temperature. From Figure 4.13 the Ammonia level in the untreated water source was observed to comply with the acceptable limit of 0.5 mg/L as per ECR-97 guidelines.

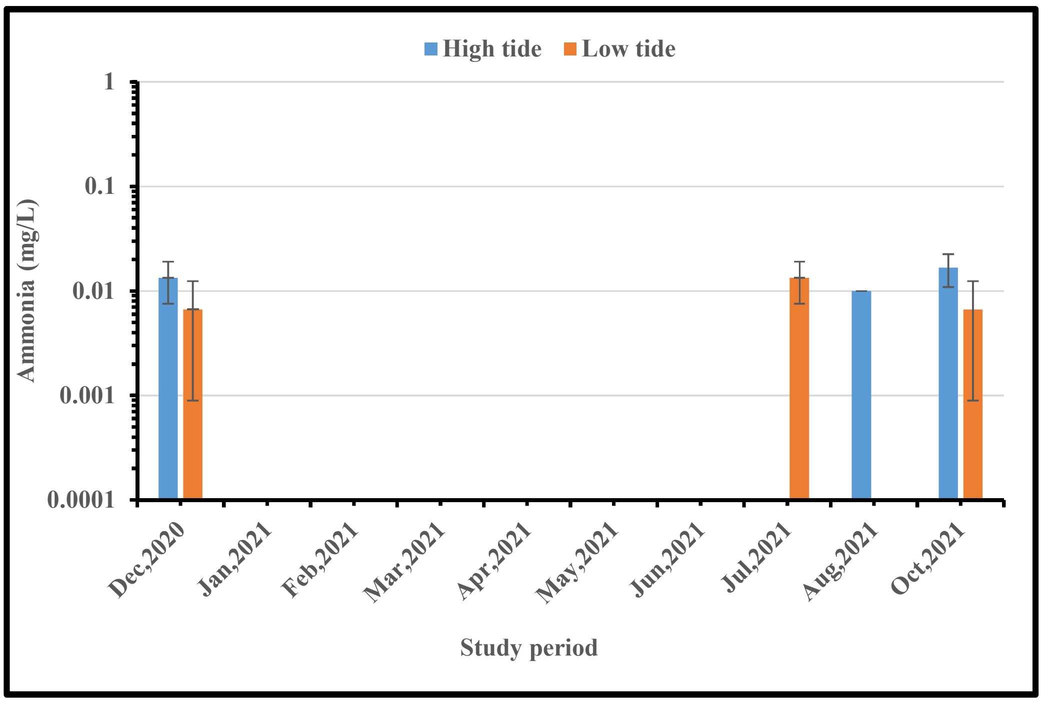

Figure 4.14: Comparison of treated water Ammonia during high tide and low

Figure 4.14 presents the level of Ammonia in treated water during high tide and low tide from December, 2020 to October, 2021. It is seen that the treated water Ammonia of MWTP during most of the months remained zero and the reading for the smallest amount 0. 01 mg/L was observed in August, 2021 during the period of high tide and also in October, 2021, the maximum concentration of (0.017 ± 0.01 mg/L) was measured. During low tide the maximum Ammonia was recorded (0.013 ± 0.06 mg/L) in July, 2021 and minimum Ammonia concentration was recorded 0.007 ± 0.01 mg/L in both December, 2020 and October, 2021 and rest of the month remained zero. From Figure 4.14 it is seen that the Ammonia content in the Treated water was found to have Ammonia content meeting the ECR-97 allowable limit (0.5 mg/L). An investigation carried out by Hossain et.al (2006) found the Ammonia value in the treated water of Sayedabad Water Treatment Plant of DWASA was low (0.01-0.54 mg/L) during May through November, moderate (0.92 mg/L) in December, and high (2.57-6.08 mg/L) during January through April. They also stated that this elevated level of Ammonia value in the treated water is coincided with high level of Ammonia contamination in the water of the river Sitalakhya. Figure 4.15 shows the concentration of mean Ammonia at various units of MWTP from December, 2020 to October, 2021. Water enter into the treatment plant through the intake pump to the sedimentation basin. In December, 2020 the primary sedimentation basins remained stop for cleaning purpose. From the Figure 4.15 it is seen during this period raw water from Halda river having Ammonia content of a minimum value of 0.105 ± 0.02 mg/L in February, 2021 and a maximum value of 0.21 ± 0.04 mg/L in May, 2021 enter into the sedimentation basins. After sedimentation raw water Ammonia concentration somehow decreased due to the settling down of the heavy silt and organic substances as sediment and the value was recorded from (0.08 ± 0.01 mg/L– 0.15 ± 0.04 mg/L). On the other hand Ammonia content of the clarifier outlet recorded between 0.03 ± 0.01 mg/L to 0.05 ± 0.01 mg/L. It is seen that the Ammonia content of the clarifier outlet water decreased than the sedimentation basin outlet water. This is because after the primary sedimentation basin the raw water comes to the rapid mixing chamber where proper dosage of alum, lime and polymer are added to start coagulation. During coagulation the suspended particle in the water react with the alum, lime and polymer and make sweep flocs. These sweep flocs bond together to form a big floc. The organic compound having Ammonia also be trapped within these flocs and get settled in the lowermost part of the clarifier. The water that is discharged from the clarifier is directed to the filtration chamber. There are rapid gravity sand filters in MWTP. The Ammonia levels were measured between

0.011 ± 0.01 mg/L and 0.03 ± 0.01 mg/L in the water that passed through the filtration process and finally following the use of Chlorine as a disinfectant, the levels of Ammonia in the treated water were observed to range from 0.01 ± 0.01 mg/L to 0.01± 0.01 mg/L.

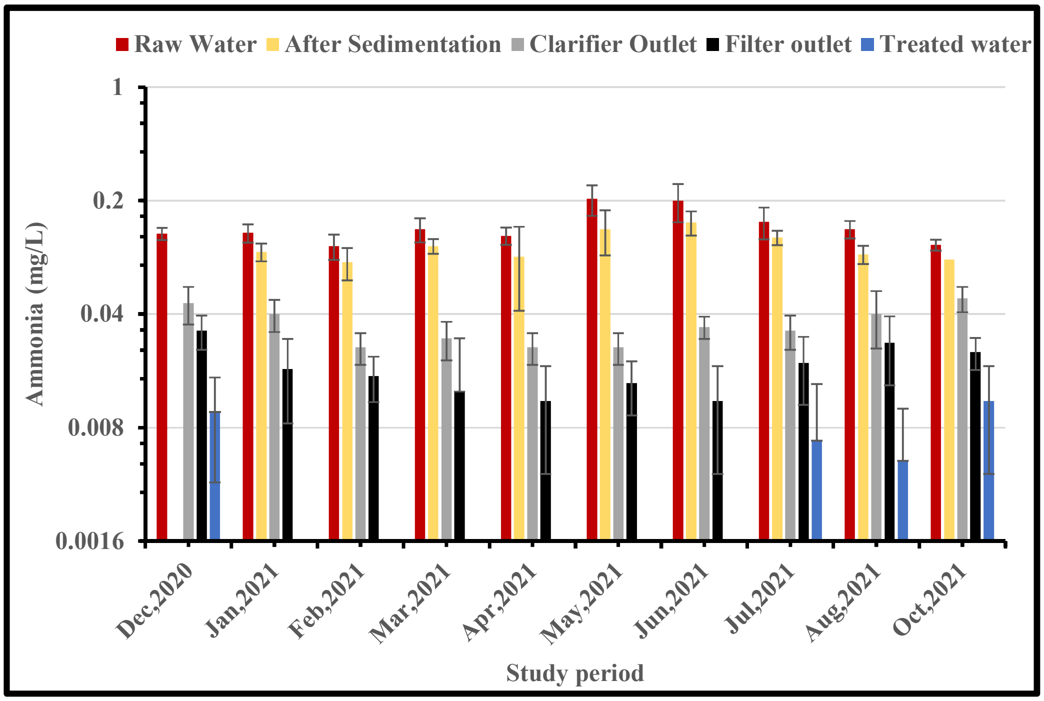

Figure 4.15: Concentration of monthly mean Ammonia at various units of MWTP

It is seen that Ammonia after the disinfection is decreased. This is because Ammonia, when in contact with chlorine, will react rapidly to form chloramines such as: monochloramine (NH_2Cl), dichloramine ($NHCl_2$), or trichloramine (NCl_3) following the reactions below-

<u>Monochloramine (NH_2Cl)</u>

$NH_4^+ + HOCl \Leftrightarrow NH_2Cl + H_2O + H^+$ ----------------- (Eq. 4.1)

<u>Dichloramine ($NHCl_2$)</u>

$NH_2Cl + HOCl \Leftrightarrow NHCl_2 + H_2O$ ----------------- (Eq. 4.2)

Trichloramine (NCl_3)

$NHCl_2 + HOCl \Leftrightarrow NCl_3 + H_2O$ ---------------- (Eq. 4.3)

Figure 4.16 shows the overall Ammonia removal efficiency of the MWTP. It is seen that the Ammonia removal efficiency during the study period fluctuates within 89.07 ± 7.28% and 100%. The Ammonia removal efficiency of MWTP was remained 100% in most of the month of the study period (January, 2021 - June, 2021). Rest of the month the Ammonia removal efficiency fluctuates and the lowest Ammonia removal efficiency was recorded 89.07 ± 7.28% in October, 2021. Lassoued (2017) found the Ammonia removal efficiency of Ngagel Water Treatment Plants ranging from 26.82% to 100% in their study in which the lowest value is much lower than the value found for the MWTP in this study. In summary, based on the preceding conversation, it can be inferred that the MWTP is highly effective in eliminating Ammonia from untreated water.

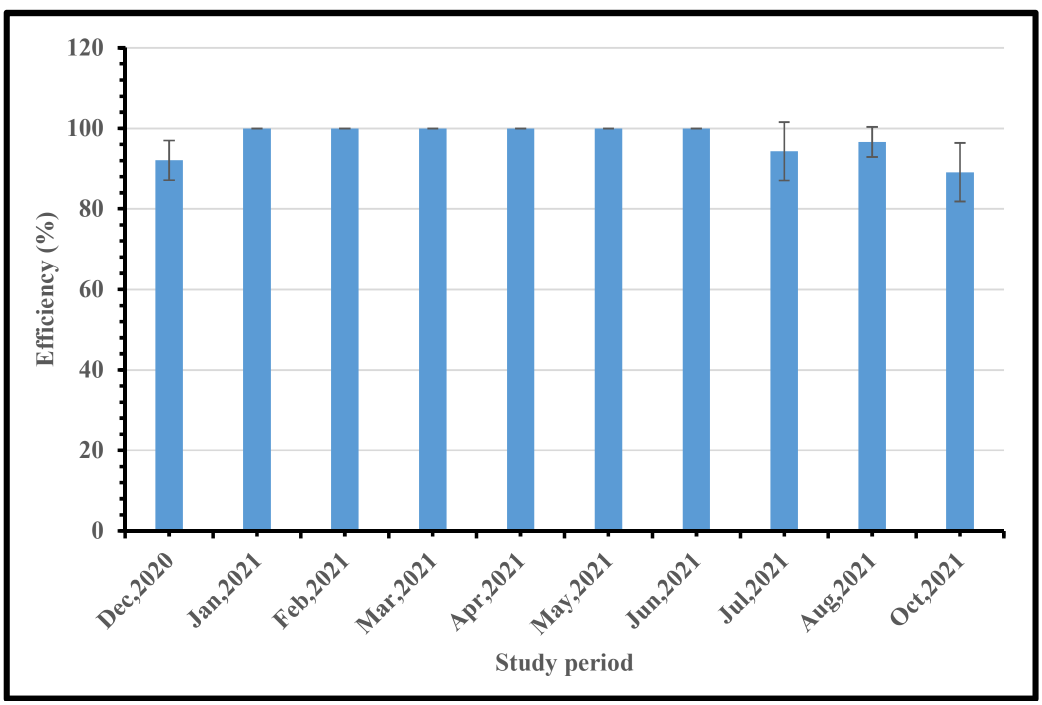

Figure 4.16: The Ammonia removal efficiency of MWTP

4.1.6 Chemical Oxygen Demand (COD)

Assessment of water pollution levels can be accurately determined by using Chemical Oxygen Demand (COD) as stated by Loomer & Cooke (2011). Water that contains over 200 mg/L of COD is categorized as contaminated, while pure water should have a COD concentration of under 20 mg/L, according to Effendi et al's findings in 2015. Excessive COD poses a threat to the survival of aquatic creatures and exacerbates water pollution, as noted by Nian et al. (2007). Figure 4.17 shows the level of COD in untreated water during high tide and low tide from December, 2020 to October, 2021. The concentration of COD varied between December of 2020 and October of 2021, with the lowest value of 20 ± 2 mg/L observed in August of 2021 and the highest values of 32 ± 2 mg/L occurring in January, 2021 during the period of high tide. On the other hand it has been observed that COD concentration in raw water during low tide also fluctuates and a minimum COD concentration was recorded 19.33 ± 1.15 mg/L in October, 2021 and maximum COD concentration was recorded 38.33 ± 1.53 mg/L in July, 2021.

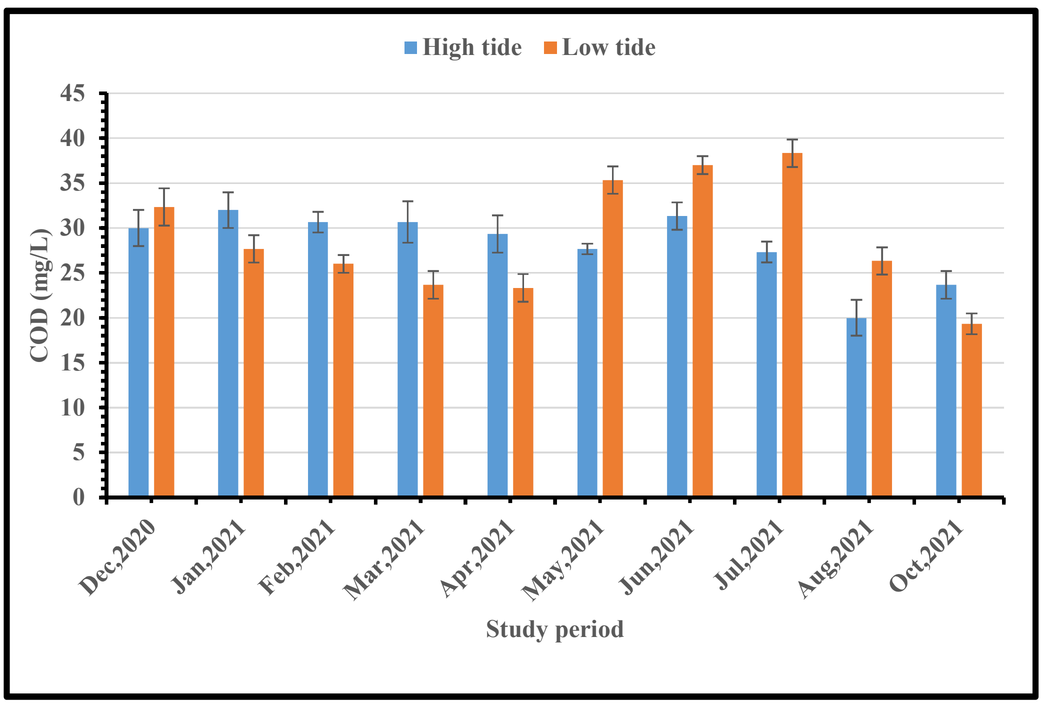

Figure 4.17: Comparison of raw water COD during high tide and low tide

Karim et al. (2019) found COD value ranging between 54.1 mg/L to 96 mg/L in their study which is far above from the result of the present study. The elevated COD level suggests an increase in microbial activity within the river, which is constantly receiving organic and inorganic matter that is being decomposed (Scen, et al., 2008). In their research, Bakar & Bhuyan (2017) observed the presence of COD levels between 2 mg/L and 983 mg/L in the Halda river. The COD level is influenced by the widespread application of chemical and organic fertilizers as well as the release of sewage. The discharge of municipal effluent is deemed responsible for the high COD level, which serves as an indicator of declining water quality as stated by Eisakhani & Malakahmad (2009). The high values of COD in raw water of MWTP was may be due to intrusion of organic compound from surrounding areas during the rainy season. From Figure 4.17 the recorded COD concentration of the untreated water source has been observed to surpass the permitted limit of 4 mg/L outlined in ECR-97. Figure 4.18 shows the concentration of COD in treated water during high tide and low tide from December, 2020 to October, 2021.

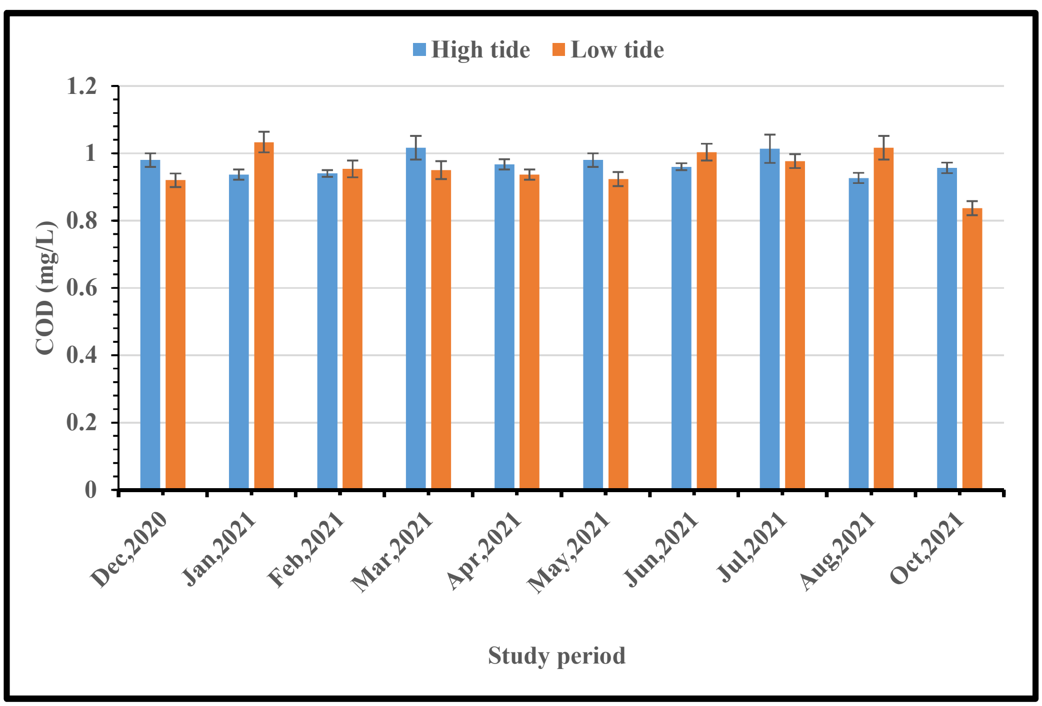

Figure 4.18: Comparison of Treated Water COD during high tide and low tide

It is seen that the lowest value of treated water COD of MWTP was recorded 0.93 ± 0.02 mg/L in August, 2021 and highest value of 1.02 ± 0.04 mg/L was recorded in March, 2021 during high tide. During low tide the maximum COD value was recorded (1.03 ± 0.03 mg/L) in January, 2021 and the lowest value of (0.84 ± 0.02 mg/L) was recorded in October, 2021 during the low tide. Siddhartha et al. (2017) found the COD value in the drinking water of Jessore was (3.0 – 6.3 mg/L) higher than the ECR-97 allowable limit of 4 mg/L. From fig. 4.18 it is seen that the COD content in the treated water of MWTP was found to have COD content meets the ECR-97 allowable limit (4 mg/L). Figure 4.19 shows the mean concentration of COD at various units of MWTP from December, 2020 to October, 2021. Water enters into the treatment plant through the intake pump to the sedimentation basin. In December, 2020 the primary sedimentation basins remained stop for cleaning purpose. From the Figure 4.19 it has been observed that during this time frame, the sedimentation basins receive unrefined water from the Halda river with a minimum COD concentration of 21.5 ± 2.66 mg/L in October, 2021 and a maximum of 34.17 ± 3.31 mg/L in June of the same year.

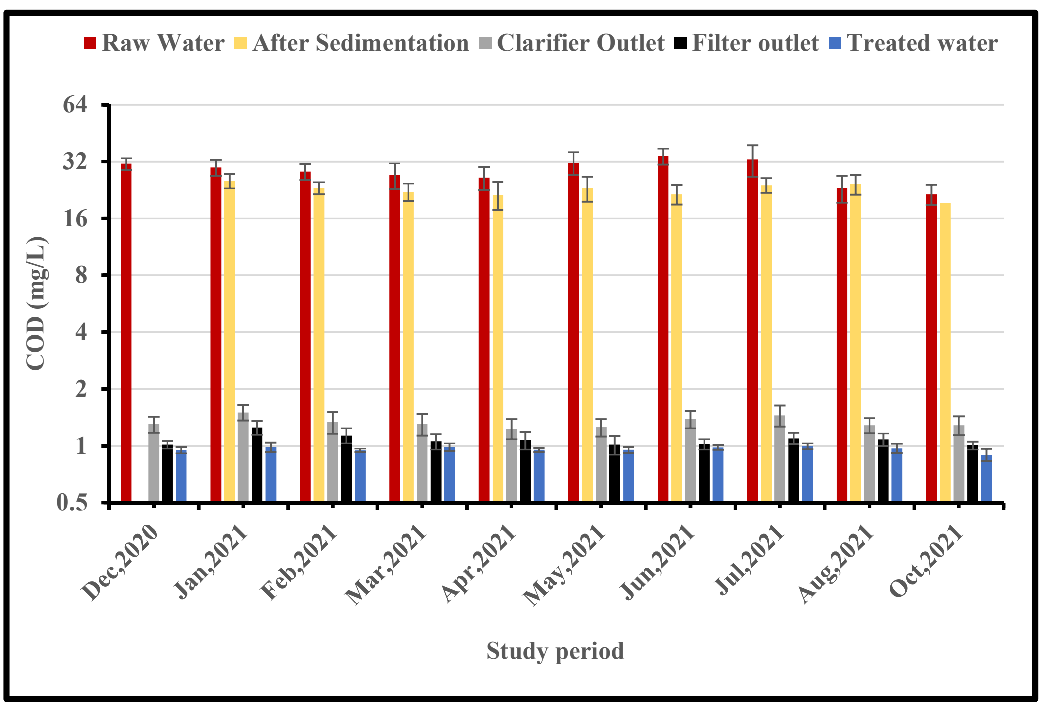

Figure 4.19: Concentration of monthly mean COD at various units of MWTP

The concentration of COD in raw water was observed to decrease after undergoing sedimentation, likely because of the settling of organic materials and heavy silt as sediment. The recorded values for COD ranged from 19.33 ± 2.94 mg/L to 25.33 ± 1.03 mg/L. On the other hand COD content of the clarifier outlet recorded between 1.23 ± 0.15 mg/L to 1.5 ± 0.14 mg/L. It is seen that the COD content of the clarifier outlet water decreased than the sedimentation basin outlet water. This is because after the primary sedimentation basin the raw water comes to the rapid mixing chamber where proper dosage of alum, lime and polymer are added to start coagulation. During coagulation the suspended particle in the water react with the alum, lime and polymer and make sweep flocs. These sweep flocs bond together to form a big floc. The flocs gather and contain not only organic compounds but also other suspended particles, which eventually settle as sludge at the base of the clarifier. Subsequently, the water that has exited the clarifier is directed towards the filtration chamber.

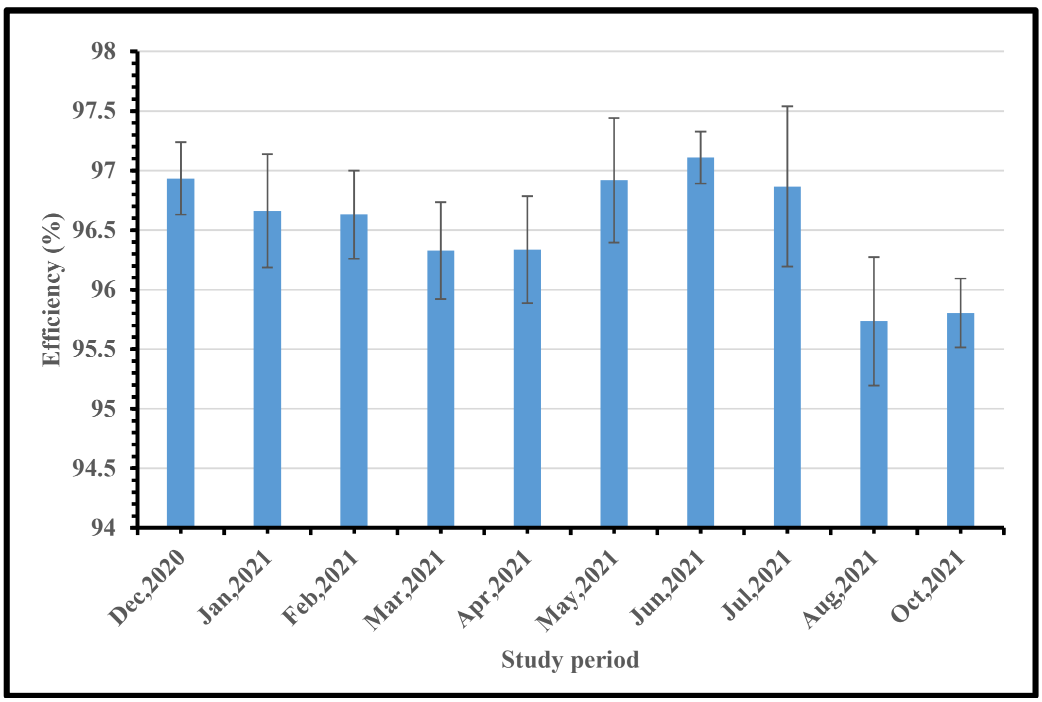

Figure 4.20: The COD removal efficiency of MWTP

There are rapid gravity sand filters in MWTP. After the filtration the outlet water COD was recorded between 1.00 ± 0.05 mg/L to 1.25 ± 0.10 mg/L and finally after disinfection with chlorine the treated water COD was recorded between 0.89 ± 0.07 mg/L to 0.99 ± 0.04 mg/L. It is seen that COD after the disinfection is decreased. This is because when in contact with chlorine, some organic compound will react rapidly and hence get reduced. Figure 4.20 shows the overall COD removal efficiency of the MWTP. It is seen that the COD removal efficiency during the study period fluctuates within 95.73 ± 0.54% and 97.11 ± 0.22%. The lowest COD removal efficiency of MWTP was recorded 95.73 ± 0.54% in August, 2021 and the highest COD removal efficiency was recorded 97.11 ± 0.22% in June, 2021.

4.1.7 Total Coliform

Coliform bacteria are a collective of microorganisms that are frequently detected in natural surroundings. Coliform bacteria pose no threat to human health. However, it is a challenge to identify this as a potential carrier of diseases. *E coli*, a type of bacteria, is exclusive to the coli form group and is typically located in the intestinal tracts of mammals, including humans, as mentioned by Metcafe & Eddy (1979). Figure 4.21 shows the population of Total Coliform in raw water during high tide and low tide from December, 2020 to October, 2021. It is seen that a maximum value of Total Coliform was recorded 551.67 ± 7.64 CFU/100 mL in December, 2020 and a minimum value of 170 ± 10 CFU/100 mL in July, 2021 during high tide. On the other hand a maximum value of Total Coliform in the raw water was recorded 425 CFU/100 mL in October, 2021 and a minimum value of 181.67 ± 7.64 CFU/100 mL was recorded in August, 2021 during low tide. This indicates that the raw water is highly contaminated by the coliform bacteria.

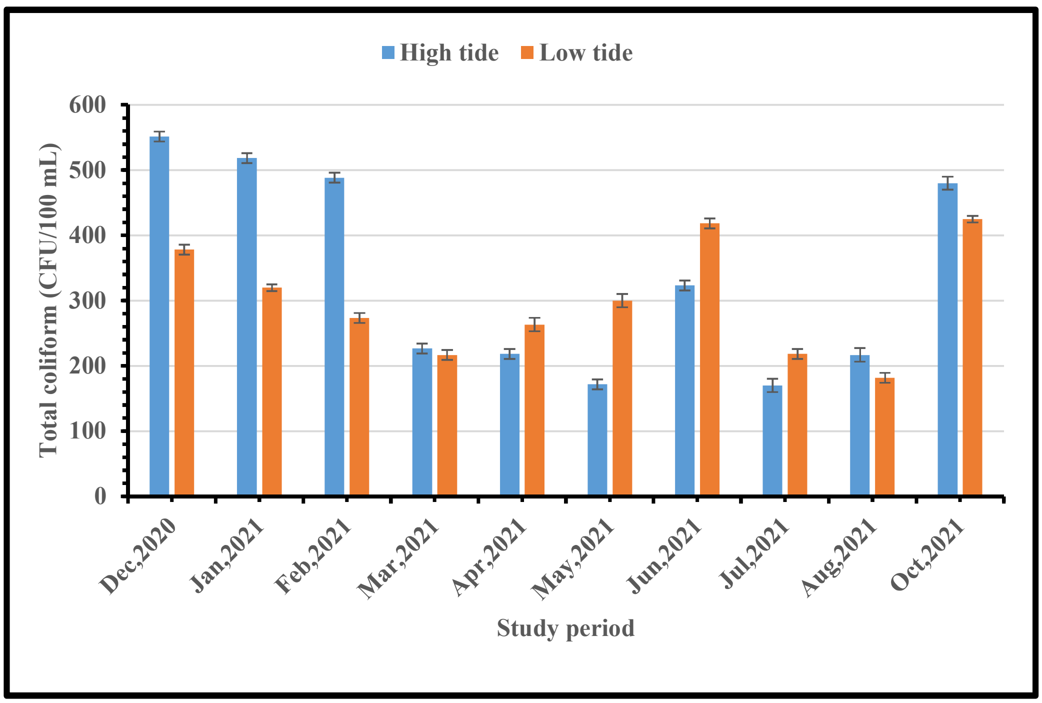

Figure 4.21: Comparison of raw water Total Coliform during high tide and low tide

If *Ecoli* is detected in water, it signals the likelihood of fecal contamination in the area, and could potentially suggest the presence of harmful microorganisms such as viruses, bacteria, and parasites (Divya & Solomon, 2016). Figure 4.22 shows the mean concentration of Total Coliform at various units of MWTP from December, 2020 to October, 2021. Water enter into the treatment plant through the intake pump to the sedimentation basin. In December, 2020 the primary sedimentation basins remained stop for cleaning purpose. From the Figure 4.22 it is seen that during this period raw water from Halda river having Total Coliform population of a maximum value of 465 ± 95.18 CFU/100 mL in December, 2020 and a minimum value of 195 ± 26.83 CFU/100 mL in July, 2021 enter into the sedimentation basins.

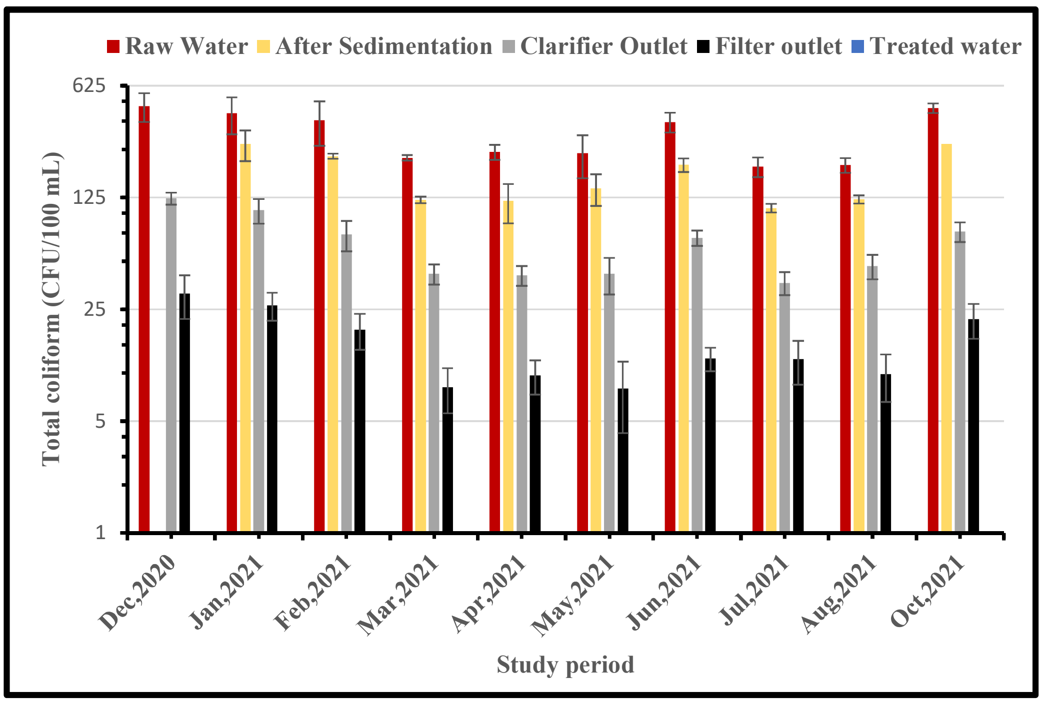

Figure 4.22: Concentration of monthly mean Total Coliform at various units of MWTP

After sedimentation raw water Total Coliform concentration somehow decreased due to the settling down of the heavy silt and organic or inorganic suspended particles as sediment. This is because bacteria in the water use heavy silt and organic or inorganic suspended particles as their shelter. The value was recorded from (107.5 ± 19.69

CFU/100 mL – 270 ± 7.07 CFU/100 mL). On the other hand Total coliform content of the clarifier outlet recorded between 36.67 ± 6.06 CFU/100 mL to 123.33 ± 10.80 CFU/100 mL. It is seen that the Total Coliform content of the clarifier outlet water decreased than the sedimentation basin outlet water. This is because after the primary sedimentation basin the raw water comes to the rapid mixing chamber where proper dosage of alum, lime and polymer are added to start coagulation. During coagulation the suspended particle in the water react with the alum, lime and polymer and make sweep flocs. These sweep flocs bond together to form a big floc. The flocs in the clarifier trap not only total coliform bacteria but also suspended particles and organic compounds, causing them to settle at the bottom of the tank as sludge. The next stage involves directing the water from the clarifier outlet to the filtration chamber. There are rapid gravity sand filters in MWTP.

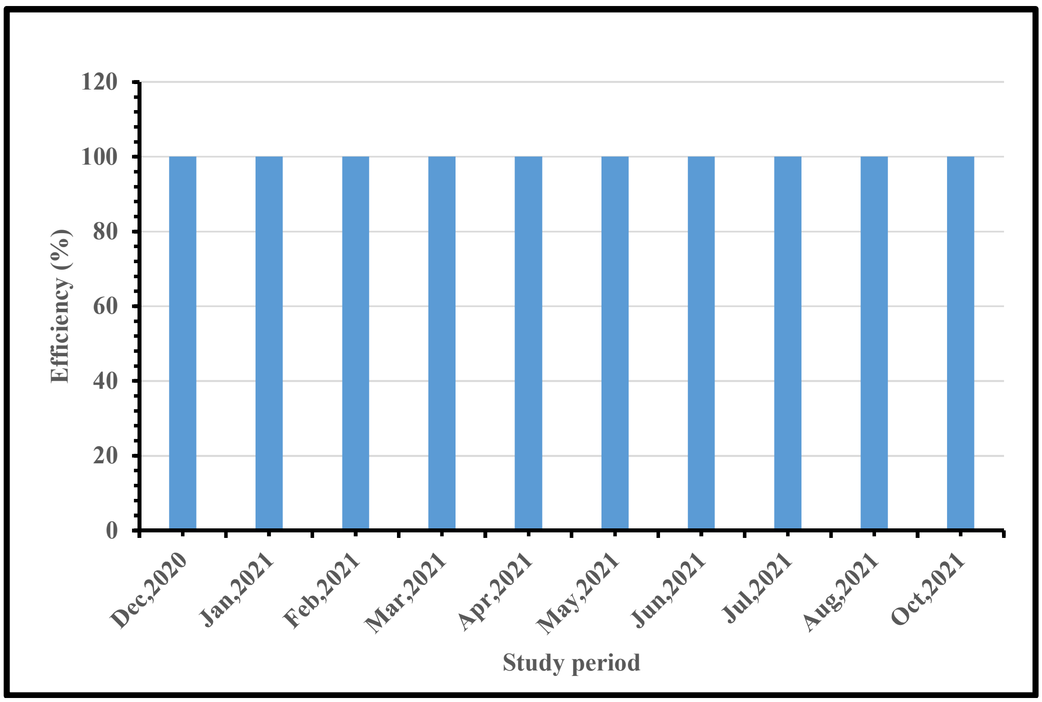

Figure 4.23: The Total Coliform removal efficiency of MWTP

After the filtration the outlet water Total Coliform content was recorded between 8 ± 3.79 CFU/100 mL to 31.33 ± 9.52 CFU/100 mL and finally after disinfection with chlorine the Total Coliform content in the treated water recorded nil. It is because when in contact with chlorine all bacteria get killed. Figure 4.23 shows the overall Total Coliform removal efficiency of the MWTP. It is seen that the Total Coliform removal efficiency during the study period remained 100% which is much higher than the Total Coliform removal efficiency found for the Angereb water treatment plant of Ethiopia (91.6 %) in the study of Desye et al. (2021). It indicates that MWTP has a very good efficiency to remove all the Total Coliform from the raw water and also proves the effective disinfection of MWTP.

4.1.8 Fecal Coliform

Fecal coliforms are bacteria of rod shape that lack spores and are classified as gram-negative. This microorganism has the ability to function without oxygen and can undergo lactose fermentation resulting in the production of acid and gases at a temperature of 44± 0.5^{0}C within a timeframe of 48 hours. It does not have the capability to produce oxidase and is unable to withstand high temperatures. Heat levels used in pasteurization alone are sufficient to eradicate this bacterium. *Ecoli* is a pioneering microbial marker utilized for detecting the presence of fecal contamination in food, drinking water, and water supply. The existence of the bacterium known as *E.Coli* indicating the contamination of waste from humans and animals in food and water, the presence of coli in water is a significant factor, according to Atlas' findings in 1993. Figure 4.24 shows the population of Fecal Coliform in raw water during high tide and low tide from December, 2020 to October, 2021. It is seen that a maximum value of Fecal Coliform was recorded 85 ± 5 CFU/100 mL in December, 2020 and a minimum value of 25 ± 5 CFU/100 mL in July, 2021 during high tide.

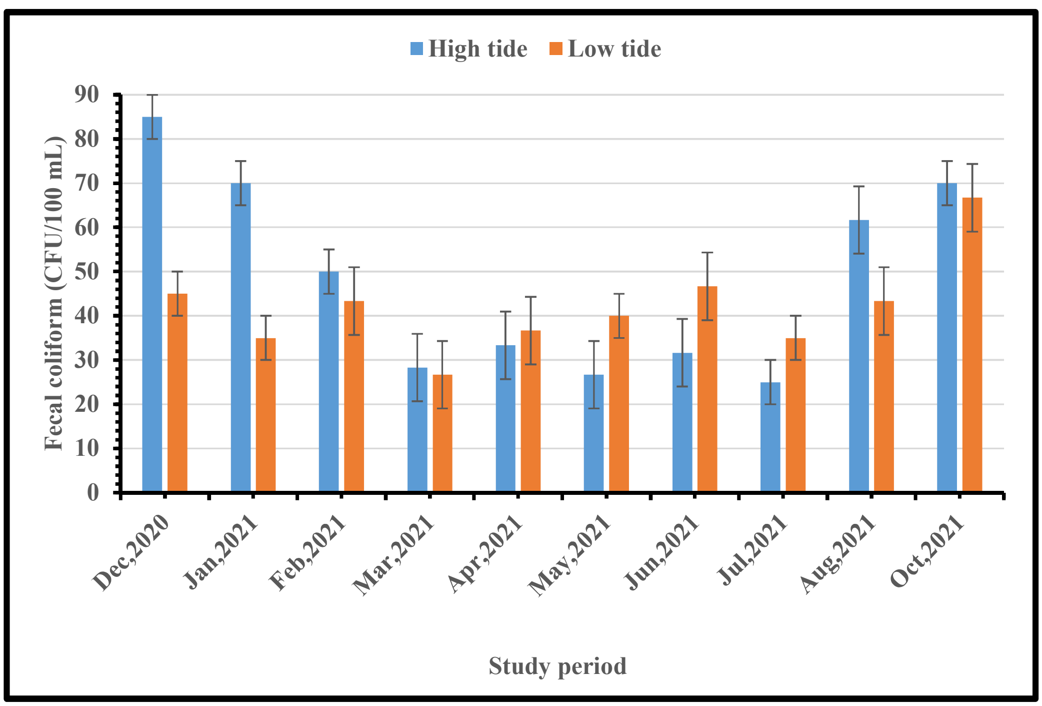

Figure 4.24: Comparison of raw water Fecal Coliform during high tide and low tide

On the other hand a maximum value of Fecal Coliform in the raw water was recorded 66.67 ± 7.64 CFU/100 mL in October, 2021 and a minimum value of 26.67 ± 7.64 CFU/100 mL was recorded in March, 2021 during low tide. This indicates that the raw water is highly contaminated by the Fecal coliform bacteria. If *E.coli* is detected in water, it signals the likelihood of fecal contamination in the area, and could potentially suggest the presence of harmful microorganisms such as viruses, bacteria, and parasites (Divya & Solomon, 2016). Figure 4.25 shows the mean concentration of Fecal Coliform at various units of MWTP from December, 2020 to October, 2021. Water enter into the treatment plant through the intake pump to the sedimentation basin. In December, 2020 the primary sedimentation basins remained stop for cleaning purpose. From the Figure 4.25 it is seen that during this period raw water from Halda river having Fecal Coliform population of a maximum value of 68.33 ± 6.06 CFU/100 mL in October, 2021 and a minimum value of 27.5 ± 6.89 CFU/100 mL in March, 2021 enter into the sedimentation basins.

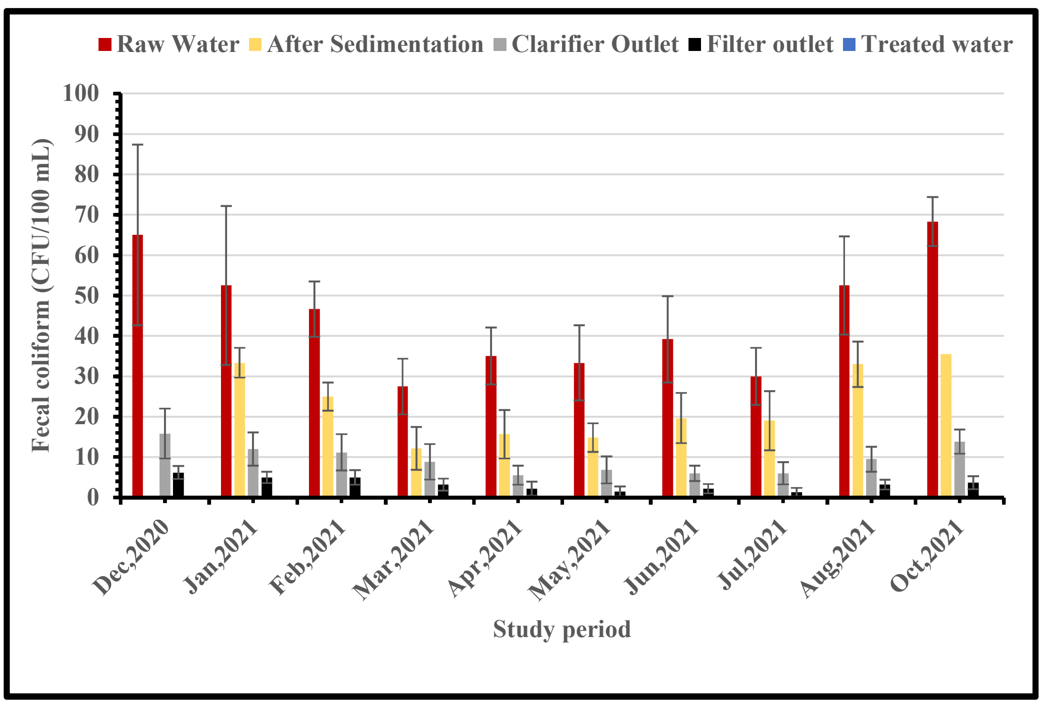

Figure 4.25: Concentration of monthly mean Fecal Coliform at various units of MWTP

After sedimentation raw water Fecal Coliform concentration somehow decreased due to the settling down of the heavy silt and organic or inorganic suspended particles as sediment. This is because bacteria in the water use heavy silt and organic or inorganic suspended particles as their shelter. The value was recorded from (12.17 ± 3.49 CFU/100 mL – 35.5 ± 5.61 CFU/100 mL). On the other hand Fecal coliform content of the clarifier outlet recorded between 5.5 ± 2.35 CFU/100 mL to 15.83 ± 6.15 CFU/100 mL. It is seen that the Fecal Coliform content of the clarifier outlet water decreased than the sedimentation basin outlet water. This is because after the primary sedimentation basin the raw water comes to the rapid mixing chamber where proper dosage of alum, lime and polymer are added to start coagulation. During coagulation the suspended particle in the water react with the alum, lime and polymer and make sweep flocs. These sweep flocs bond together to form a big floc. The flocs in the clarifier are effective in capturing organic compounds, suspended particles, and Fecal coliform bacteria, which then settle at the bottom as sludge. Subsequently, the water that has exited the clarifier is channeled into the filtration chamber.

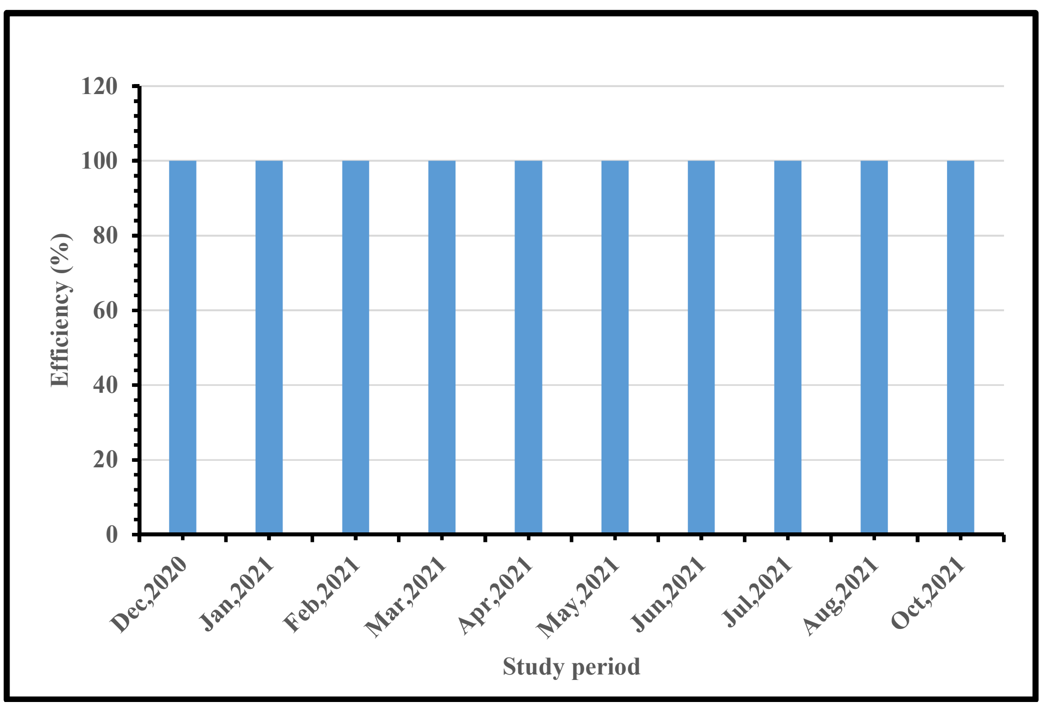

Figure 4.26: The Fecal Coliform removal efficiency of MWTP

There are rapid gravity sand filters in MWTP. After the filtration the outlet water Fecal Coliform content was recorded between 1.33 ± 1.03 CFU/100 mL to 6.17 ± 1.60 CFU/100 mL and finally after disinfection with chlorine the Fecal Coliform content in the treated water recorded nil. It is because when in contact with chlorine all bacteria get killed. Figure 4.26 shows the overall efficiency in eliminating Fecal coliform of the MWTP. It is seen that the Fecal Coliform removal efficiency during the study period remained 100% which is higher than the Fecal Coliform removal efficiency found for the Angereb water treatment plant of Ethiopia (99 %) in the study of Desye et al. (2021) It indicates that MWTP has a very good efficiency to remove all the Fecal Coliform from the raw water and also proves the effective disinfection of MWTP.

4.2 Water Quality Assessment

The idea of 'Water quality' pertains to the attributes of water concerning its chemical, biological, and physical aspects. Severe health and economic ramifications arise when the permissible limits for the various uses of water components are surpassed, resulting in an increase in their values. The instructions laid out in Table 4. 1 outline the upper thresholds for organic and inorganic elements as well as biological characteristics such as those present in drinking water, and were issued jointly by the World Health Organization (WHO), Bangladesh Standard Testing Institute (BSTI), and Department of Environment (DoE). When the values surpass the limit that is allowed, the water becomes contaminated, leading to adverse health and economic effects on individuals. A total sum of 26 nos. of water quality parameters namely-TDS, Turbidity, EC, Temperature, TSS, Total Coliform, Fecal Coliform, pH, Total Hardness, Ca-Hardness, Chloride, Nitrate, Fluoride, Ammonia, Sulphate, Phosphate, Arsenic, Chromium, Iron, Zinc, Copper, Manganese, Lead, Cadmium, Mercury, DO, BOD and COD were tested for both the raw water and treated water of MWTP. The test results obtained were then compared with the available drinking water quality guideline issued by WHO, BSTI and ECR-97.

Table: 4.1: Drinking Water Quality Standard

SL. NO.	Parameters	Unit	BSTI 1240:2001	WHO Guidelines	ECR 1997
1	Color	Hazen	Max. 5.0	NP	15
2	Odor	---	Unobjectionable		Odorless
3	Taste	---	Agreeable		
4	Turbidity	NTU	Max. 5.0		10
5	pH	---	6.4-7.4	6.5-8.5	6.5-8.5
6	T. Hardness (as $CaCO_3$)	mg/L	300.0	NP	200-500
7	Iron (as Fe)	mg/L	Max. 0.3	NP	0.3-1.0
8	Chlorides (as Cl)	mg/L	Max. 250.0	NP	150-600
9	TDS	mg/L	Max. 500.0	NP	1000
10	Calcium (as Ca)	mg/L	Max. 75.0	NP	75
11	Sodium (as Na)	mg/L	Max. 200.0	NP	200
12	Copper(as Cu)	mg/L	Max. 1.0	2.0	1
13	Manganese (as Mn)	mg/L	Max. 0.5	0.4	0.1
14	Nitrate(as NO_3)	mg/L	Max. 4.5	50	10
15	Nitrite(as NO_2)	mg/L	Nil	3	<1
16	Fluoride(as F)	mg/L	Max. 1.0	1.5	1
17	Mercury (as Hg)	mg/L	Max. 0.001	0.006	0.001
18	Cadmium (as Cd)	mg/L	Max. 0.003	0.003	0.005
19	Arsenic(as As)	mg/L	Max. 0.01	0.01	0.05
20	Cyanide(as CN)	mg/L	Max. 0.01	NP	0.1
21	Lead(as Pb)	mg/L	Max. 0.01	0.01	0.05
22	Zinc(as Zn)	mg/L	Max. 3.0	NP	5.0
23	Chromium (as Cr)	mg/L	Max. 0.05	0.05	0.05
24	Barium	mg/L	Max. 1.0	Max. 0.7	
25	Borate	mg/L	Max. 5.0	Max. 0.5	
26	Nickel	mg/L	Max. 0.02	0.07	0.1
27	Hydrogen Sulphide	mg/L	Max. 0.05	NP	
28	T. Coliform	cfu/100mL	Nil	Nil	Nil
29	Fecal Coliform	cfu/100mL		Nil	Nil
30	Plate Count	pc/1 mL	Max. 1000.0		
31	Residual Chlorine	mg/L	----	0.2 - 5	0.2
32	Ammonia	mg/L		NP	0.5
33	Aluminium	mg/L		0.1	0.2
34	Phosphate	mg/L			6
35	BOD_5	mg/L			0.2
36	COD	mg/L			4
37	DO	mg/L		NP	6
38	TSS	mg/L			10
39	Sulphate	mg/L		NP	400
40	Temperature	^0C			20-30

4.2.1 Turbidity

Figure 4.27 shows that the raw water of MWTP has the highest Turbidity of 312.5 ± 87.48 NTU in June, 2021 and the lowest Turbidity of 116.5 ± 27.97 NTU in April, 2021. Highest turbidity is the result of mixing of heavy silt and mud which are washed into the Halda river during heavy rainfall in described period. Lowest Turbidity in the Halda river achieved in times of minimal water flow, particularly in the dry season. Barua et al. (2019) found Turbidity in the Halda river ranging from 117 NTU to 130 NTU during the study period of their study which is much lower than the value found in this study. The turbidity level of drinking water is advisable to not exceed 5 NTU. The Turbidity levels in the untreated water at MWTP have been observed to be inconsistent and do not meet the Turbidity standards prescribed by the WHO for potable water. However, the data displayed in Figure 4.27 reveals that the turbidity levels for the water treated at MWTP range from 0.38 ± 0.07 NTU to 0.64 ± 0.01 NTU. Molla et al. (2014) also found Turbidity below 5 NTU in the majority of the CWASA supply water samples in their study. So from the above discussion it can be inferred that turbidity of the treated water of MWTP complies entirely with the WHO drinking water regulations throughout the study period.

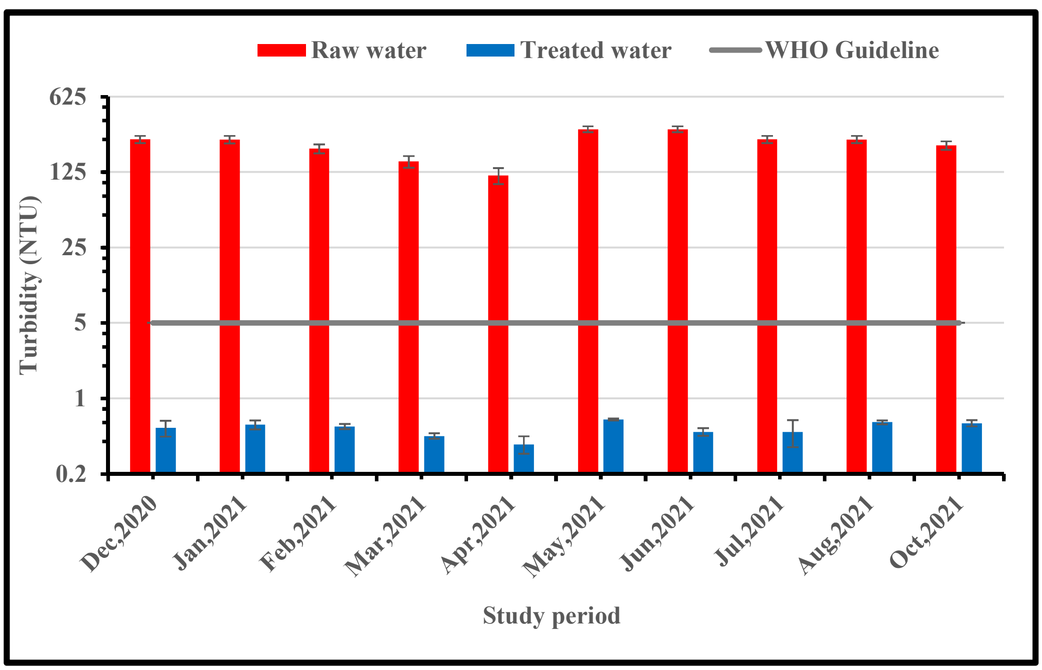

Figure 4.27: Comparison of Turbidity concentration of MWTP with WHO standard

4.2.2 Total Dissolved Solids (TDS)

Figure 4.28 shows that the raw water of MWTP has the highest TDS of 1205 ± 1225.81 mg/L in May, 2021 and the lowest TDS of 39.83 ± 4.36 mg/L in August, 2021. Highest TDS is the result of intrusion of saline water from the Bay of Bengal via the Karnafuly river into the Halda river during dry season in the described period. Lowest TDS in the Halda river achieved when there is no intrusion of saline water and immediately after the rainy season. Barua et al. (2019) found TDS in the Halda river ranging from 45.5 mg/L to 104.1 mg/L during the study period of their study which is much lower than the value found in this study. Drinking water should have a TDS value of maximum 1000 mg/L according to WHO guideline. Interestingly, it has been observed that the TDS level in the untreated water at MWTP is conform to WHO guideline for TDS in drinking water except for the month of May, 2021. However, Figure 4.28 shows that TDS value of treated water of MWTP is ranged between 33.33 ± 1.21 mg/L to 767.67 ± 783.25 mg/L. Zannat et al. (2020) found TDS values in the supply water of CWASA ranging from 220 mg/L to 260 mg/L in their study which is much lower than the upper limit of the value fund in this study. So from the above discussion it can be concluded that TDS of the treated water of MWTP is totally conform to WHO guideline for drinking water during all the months of the study period.

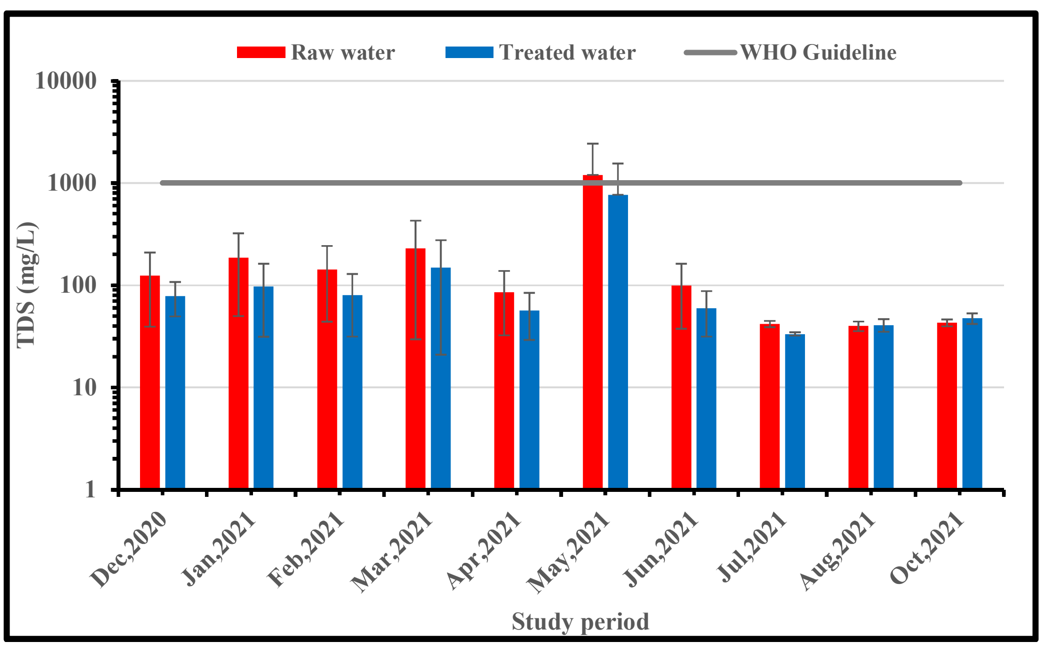

Figure 4.28: Comparison of TDS concentration of MWTP with WHO standard

4.2.3 Electrical Conductivity (EC)

Figure 4.29 shows that the raw water of MWTP has the highest Electrical Conductivity (EC) of 2409.33 ± 2449.05 μS/cm in May, 2021 and the lowest EC of 69.67 ± 31.20 μS/cm in August, 2021. Highest EC is the result of intrusion of saline water from the Bay of Bengal via the Karnafuly river into the Halda river during dry season in described period. Lowest EC in the Halda river achieved when there is no intrusion of saline water and immediately after the rainy season. Islam et al. (2020) recorded EC value ranging from 29 μS/cm to 196 μS/cm in the Halda river during their study which is far lower than the value found in this study. Drinking water should have an EC value of maximum 2000 μS/cm according to WHO guideline. The EC level of untreated water at the MWTP adheres to the WHO standard for EC in potable water, with the exception of May, 2021. However, Figure 4.29 also shows that EC value of treated water of MWTP is ranged between 65.5 ± 1.52 μS/cm to 1323.3 ± 1325.49 μS/cm. Zannat et al. (2020) recorded EC values in the supply water of CWASA ranging from 320 μS/cm to 460 μS/cm in their study which is much lower than the upper limit of the value fund in this study. Whatever, from the above discussion it can be said that EC value of treated water of MWTP is totally conform to WHO guideline for drinking water during all the months of the study period.

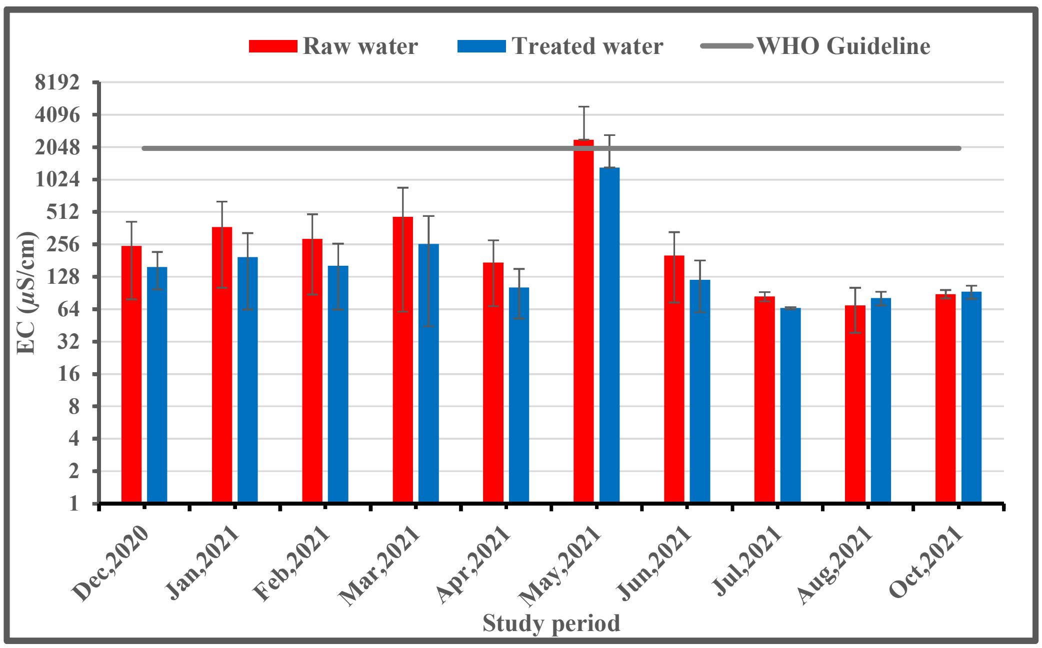

Fig. 4.29: Comparison of EC concentration of MWTP with WHO standard

4.2.4 Temperature

Figure 4.30 shows that the raw water of MWTP has the highest Temperature of 26.45 ± 0.10 ^{0}C in May, 2021 and the lowest Temperature of 21.12 ± 0.76 ^{0}C in December, 2020. Temperature variation is due to the weather change during the described period. Drinking water should have a Temperature value of maximum 30^{0}C according to ECR-97 guideline. The Temperature reading of the untreated water in MWTP aligns with the Temperature standards outlined in ECR-97 for potable water. However, Figure 4.30 also shows that Temperature value of treated water of MWTP is ranged between 23.03 ± 0.52^{0}C to 27.4 ± 0.09 ^{0}C which is totally conform to WHO guideline for drinking water during all the months of the study period.

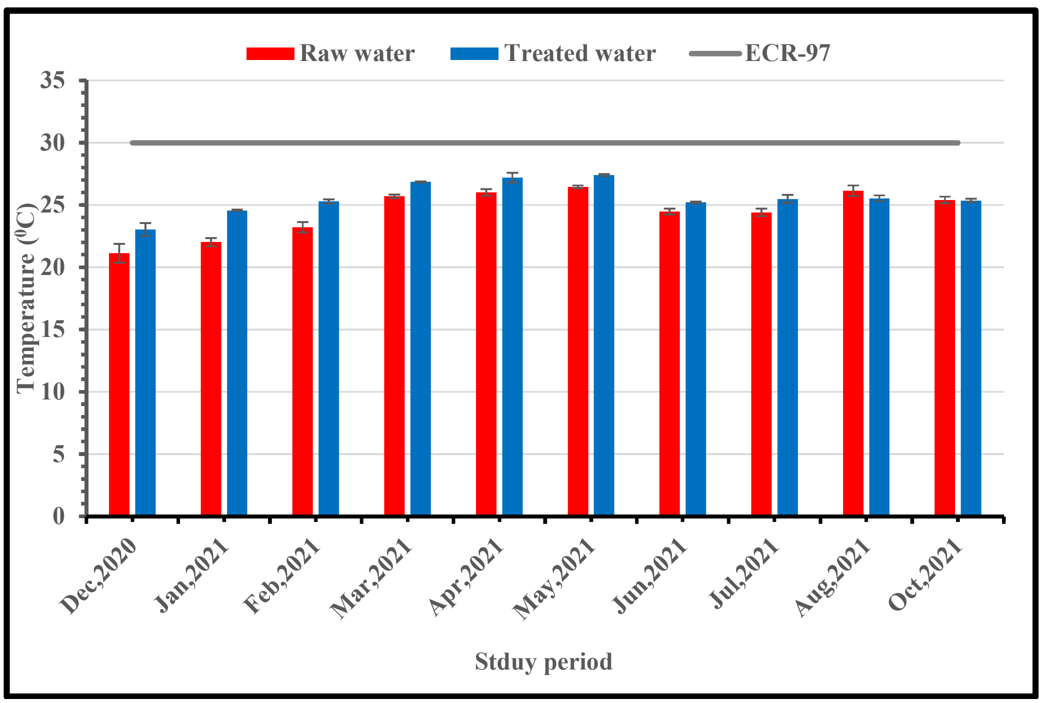

Figure 4.30: Comparison of Temperature of MWTP with ECR-97

4.2.5 Total Suspended Solids (TSS)

Figure 4.31 shows that the raw water of MWTP has the highest TSS of 410.83 ± 142.23 mg/L in May, 2021 and the lowest TSS of 160.67 ± 28.88 mg/L in April, 2021. Highest TSS is the result of mixing of heavy silt and mud which are washed into the Halda river during heavy rainfall in described period. Lowest TSS in the Halda river achieved during the dry season when there is little water flow in the Halda river. According to ECR-97 guideline, drinking water should have a maximum TSS of 10 mg/L. The TSS levels in the untreated water at MWTP are not consistent and do not meet the ECR-97 standard for TSS in drinking water. However, Figure 4.31 also shows that TSS of treated water of MWTP is ranged between 0.64 ± 0.12 mg/L to 0.99 ± 0.27 mg/L. which is totally conform to ECR-97 guideline for drinking water during all the months of the study period.

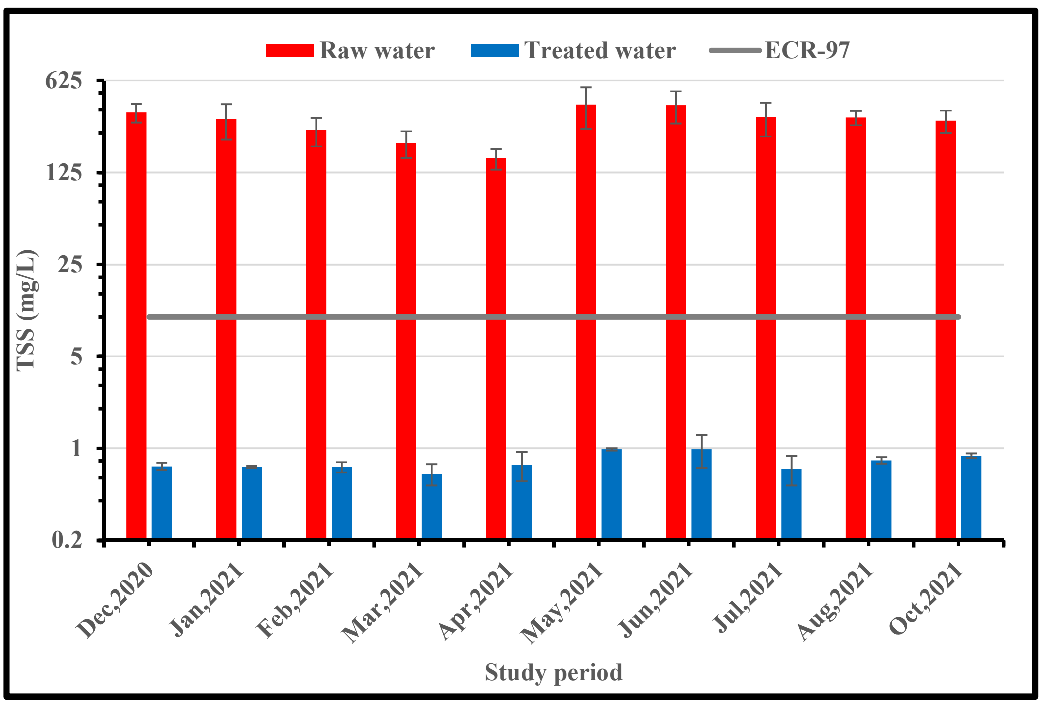

Figure 4.31: Comparison of TSS concentration of MWTP with ECR-97

4.2.6 pH

Figure 4.32 shows that the raw water of MWTP has the highest pH of 7.17 ± 0.05 in February, 2021 and the lowest pH of 6.73 ± 0.05 in July, 2021. Highest pH is achieved during the dry season when there is less presence of high decomposed organic matter in the Halda river. Lowest pH in the Halda river achieved during the rainy season when acidic rain water got mixed with the River water and might be due to presence of high decomposed organic matter in rainy season. Islam et al. (2017) recorded pH ranging from 7.1 to 8.8 in their study in the Halda river. According to WHO guideline, drinking water should have a pH value ranging between 6.5 to 8.5. It has been observed that the pH of untreated water in MWTP is stable and also conform to the WHO guideline for pH in drinking water. However, Figure 4.32 also shows that pH of treated water of MWTP is ranged between 6.86 ± 0.02 to 6.97 ± 0.05. Zuthi et al. (2009) found somehow higher value of pH ranging from 6.6 to 8.2 in the CWASA supply water in their study. It is seen that pH of treated water of MWTP is totally conform to WHO guideline for drinking water during all the months of the study period.

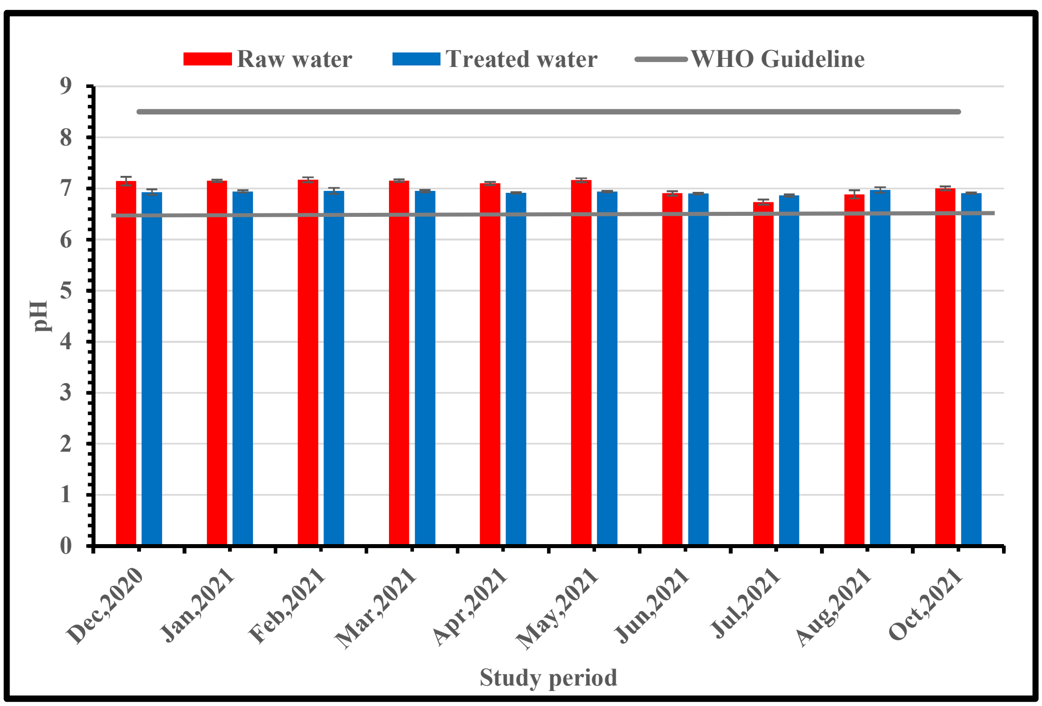

Figure 4.32: Comparison of pH concentration of MWTP with WHO

4.2.7 Total Hardness

Figure 4.33 shows that the raw water of MWTP has the highest Total Hardness value of 48.17 ± 3.60 mg/L in January, 2021 and the lowest Total Hardness of 34.83 ± 0.75 mg/L in October, 2021. It is seen that there is no massive change in the Total Hardness value of raw water in the source water throughout the study period. According to drinking water standard of Bangladesh, drinking water should have a maximum Total Hardness value of 300 mg/L. So the Total Hardness value of raw water in MWTP is stable and also conform BSTI guideline for Total Hardness in drinking water. However, Figure 4.33 shows that Total hardness value of treated water of MWTP is ranged between 30.67 ± 0.82 mg/L to 43.17 ± 2.48 mg/L which is so much lower than that of a study (20-384 mg/L) conducted by Zuthi et al. (2009). It is also seen that the Total Hardness value of treated water in MWTP is conform BSTI guideline for Total Hardness in drinking water.

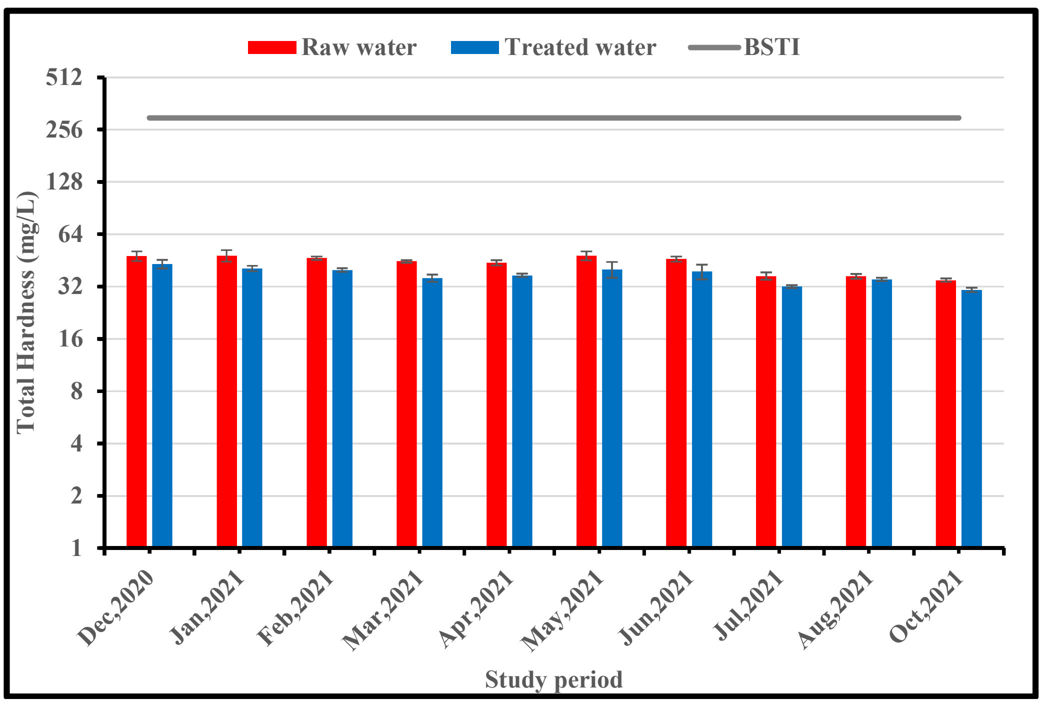

Figure 4.33: Comparison of Total Hardness concentration of MWTP with BSTI

4.2.8 Ca-Hardness

Figure 4.34 shows that the raw water of MWTP has the highest Ca Hardness value of 29.33 ± 2.42 mg/L in January, 2021 and the lowest Ca Hardness of 13.33 ± 1.03 mg/L in October, 2021. Bakar & Bhuyan (2017) discovered significantly elevated levels of Ca-Hardness, which were observed to fluctuate between 38 mg/L and 121 mg/L. Throughout the period of this study, the value of Ca-Hardness in the raw water was observed to vary. The Drinking water standard in Bangladesh as per BSTI sets a limit of 70 mg/L as the maximum acceptable level of Ca-Hardness in drinking water. However Figure 4.34. also shows that Ca-Hardness value of treated water of MWTP is ranged between 10.5 ± 0.55 mg/L to 24 ± 1.67 mg/L which is conform to the BSTI guideline for Ca-Hardness in drinking water.

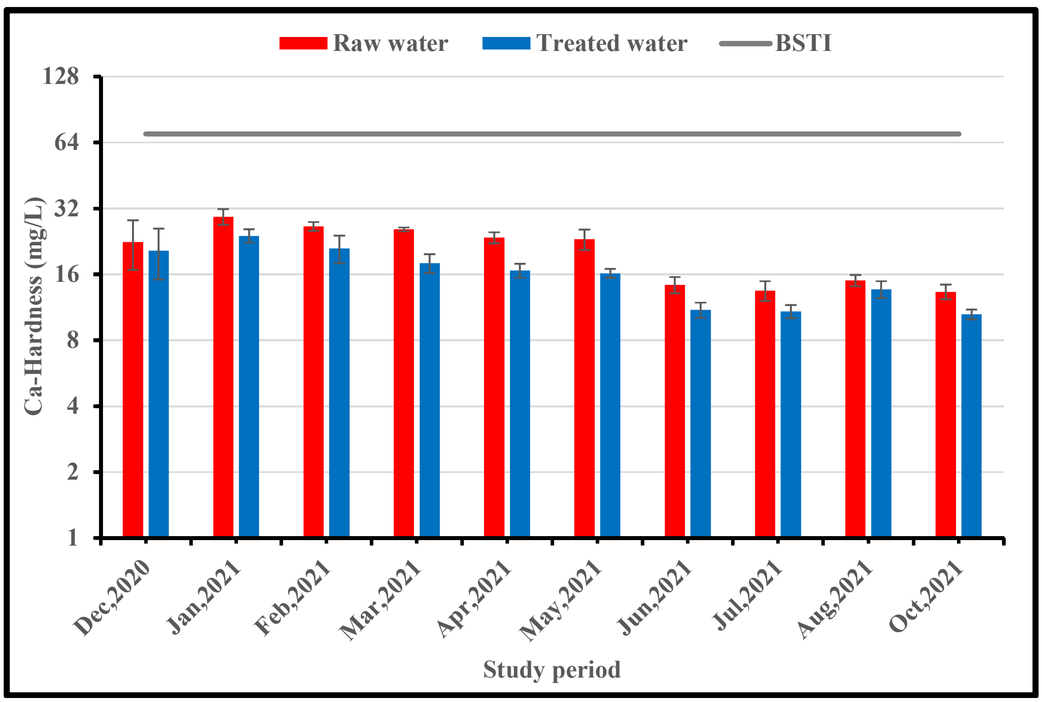

Figure 4.34: Comparison of Ca-Hardness concentration of MWTP with BSTI

4.2.9 Chloride (Cl^-)

Figure 4.35 shows that the raw water of MWTP has the highest Chloride value of 727.5 ± 742.17 mg/L in May, 2021 and the lowest Chloride of 10.83 ± 2.93 mg/L in August, 2021. It is seen that Chloride value of raw water fluctuates throughout the study period. The maximum value achieved during the dry season when saline water from the Bay of Bengal enter into the Halda river through Karnafuly river. A study conducted by Islam et al. (2017) recorded Chloride values between 8.4-69.30 mg/L in the Halda river which is much lower than this study. As per ECR-97 standards, the highest permissible chloride content in potable water is limited to 600 mg/L. Accordingly, it appears that the Chloride level found in untreated water at MWTP does not meet the Chloride standards specified in the ECR-97 regulations for potable drinking water. However, Figure 4.35 also shows that Chloride value of treated water of MWTP is ranged between 7.83 ± 1.47 mg/L to 309.17 ± 316.05 mg/L. Zuthi et al. (2009) found Chloride value ranging from 82 mg/L to 1300 mg/L in the CWASA supplied water in their study which is far higher than the value found in this study. After analyzing the aforementioned discussion, it can be concluded that the Chloride level of processed water in MWTP meets the Chloride standard for drinking water as outlined in the ECR-97 guideline.

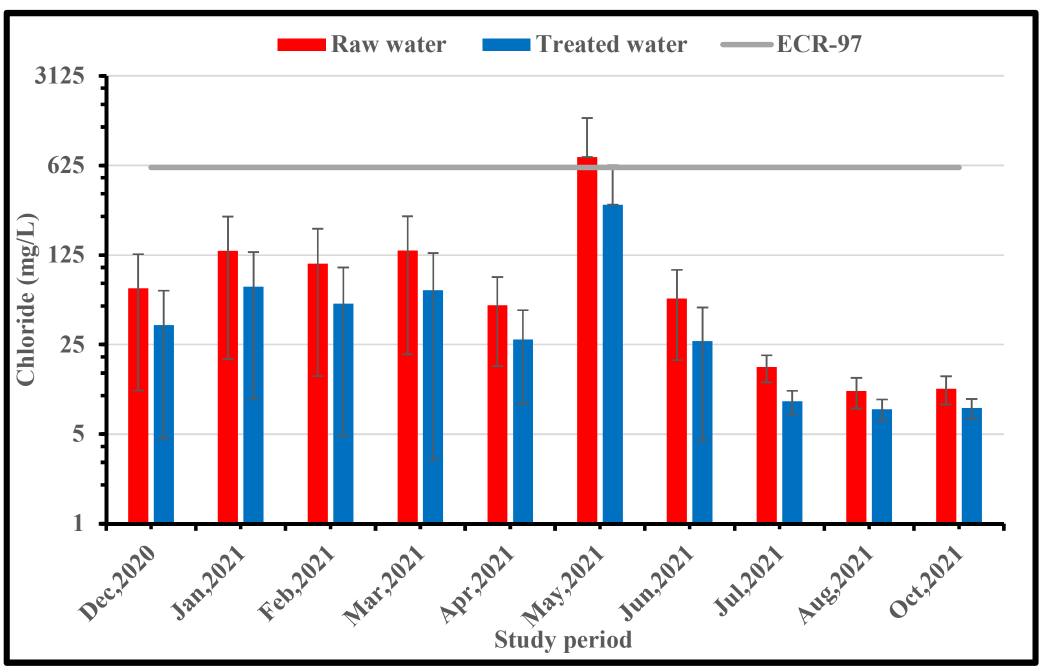

Figure 4.35: Comparison of Chloride concentration of MWTP with ECR-97

4.2.10 Nitrate (NO_3)

Figure 4.36 shows that the raw water of MWTP has the highest Nitrate value of 2.97 ± 1.32 mg/L in July, 2021 and the lowest Nitrate of 1.38 ± 0.39 mg/L in June, 2021. Throughout the study period, the Nitrate value of untreated water was observed to vary. A study conducted by Islam et al. (2017) recorded Nitrate between 0.12-3.1 mg/L in the Halda river which is higher than this study. The WHO recommends that the Nitrate concentration in drinking water should not exceed 50 mg/L. So it seen that the Nitrate value of raw water in MWTP is conform to the WHO guideline for Nitrate in drinking water. However, Figure 4.36 also shows that Nitrate value of treated water of MWTP varied from 0.29 ± 0.06 mg/L to 0.93 ± 0.06 mg/L. Molla et al. (2014) found Nitrate in drinking water of Chittagong City below 60 mg/L in their study which is far higher than the value found in this study. Whatever, from above discussion it can be deduced that the level of Nitrate in the purified water at MWTP complies with the WHO standard for potable water.

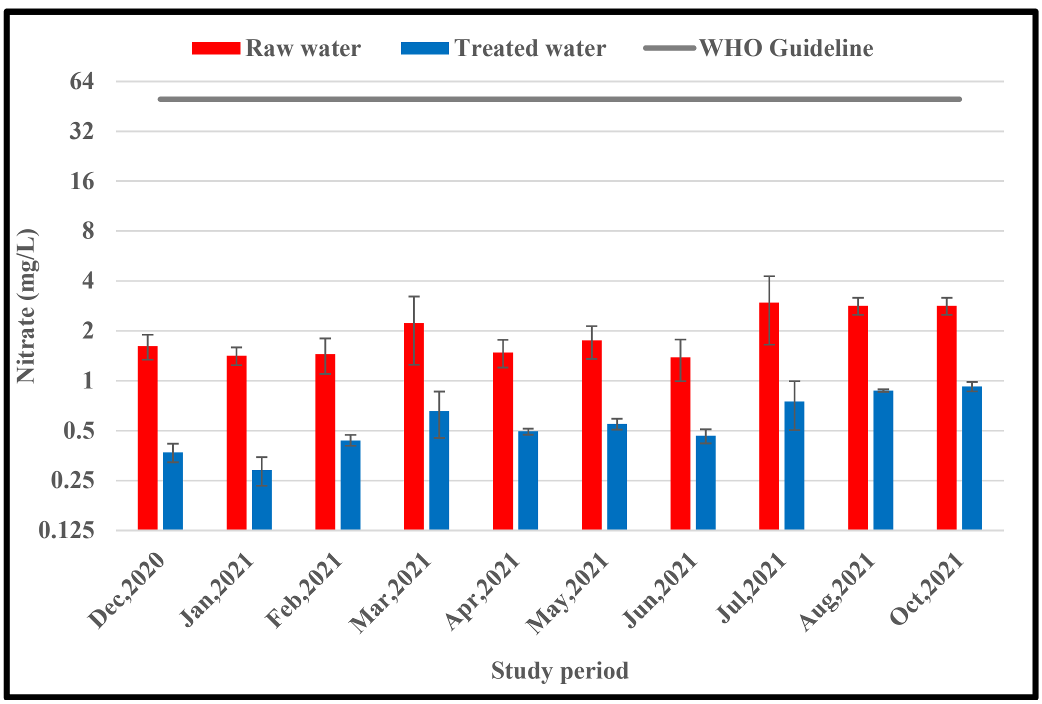

Figure 4.36: Comparison of Nitrate concentration of MWTP with WHO standard

4.2.11 Fluoride (F^-)

Figure 4.37 shows that the raw water of MWTP has the highest Fluoride value of 0.79 ± 0.48 mg/L in June, 2021 and the lowest Fluoride of 0.20 ± 0.08 mg/L in April, 2021. It is seen that Fluoride value of raw water fluctuates throughout the study period. A study conducted by Rakib et al. (2021) recorded Fluoride values between 0.07 - 0.29 mg/L in the Halda river which is lower than this study. According to WHO, drinking water should have a maximum Fluoride value of 1.5 mg/L. So it seen that the Fluoride value of raw water in MWTP is conform to the WHO guideline for Fluoride in drinking water. However, Figure 4.37 also shows that Fluoride value of treated water of MWTP is in the range of 0.04 ± 0.01 mg/L to 0.18 ± 0.10 mg/L. Biswas et al. (2012) recorded Fluoride in drinking water of Dhaka WASA ranging between 0.11 mg/L to 0.80 mg/L in their study which is relatively higher than the value found in this study. Whatever, from above discussion it has been observed that the Fluoride content in the processed water at MWTP satisfies the recommended standard by the WHO for fluoride levels in potable water.

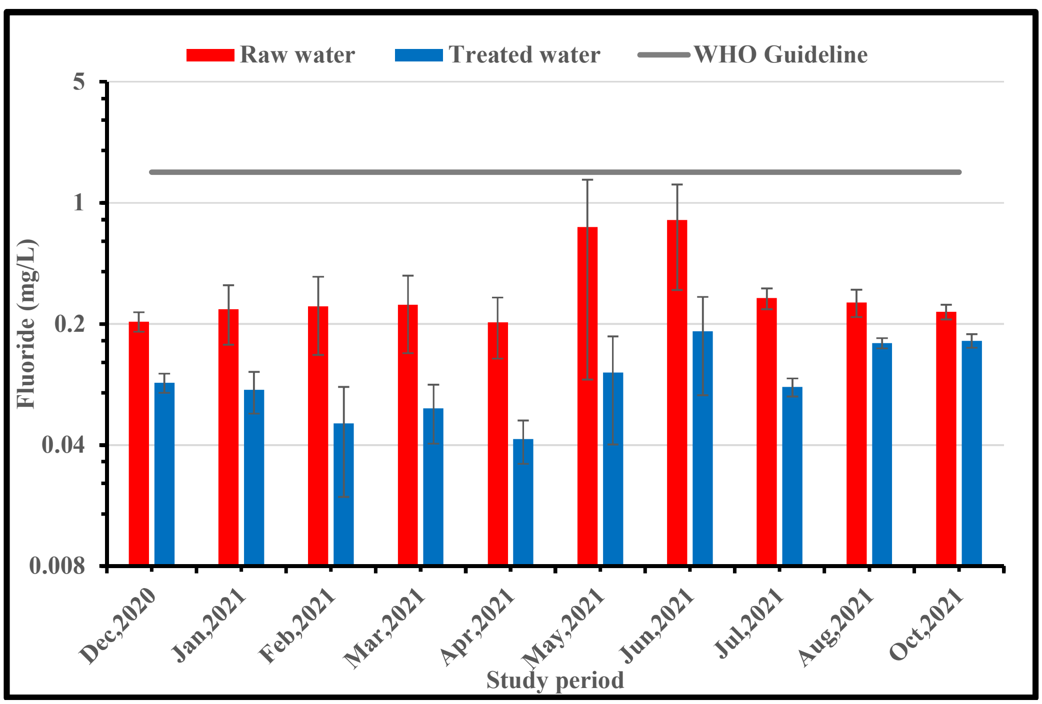

Figure 4.37: Comparison of Fluoride concentration of MWTP with WHO standard

4.2.12 Ammonia

The graph depicted in Figure 4. 38 illustrates that in May 2021, the MWTP's raw water contained the highest amount of Ammonia, with a value of 0.21 ± 0.04 mg/L, while in February 2021, it had the lowest value of Ammonia at 0.10 ± 0.02 mg/L. It is seen that Ammonia value of raw water fluctuates throughout the study period. A study conducted by Rakib et al. (2021) recorded Ammonia values between 0.28 - 0.47 mg/L in the Halda river which is comparatively higher than this study. According to ECR-97, drinking water should have a maximum Ammonia value of 0.5 mg/L. So it seen that the Ammonia value of raw water in MWTP is conform to the ECR-97 guideline for Ammonia in drinking water. However, Figure 4.38 also shows that the level of Ammonia in the treated water from MWTP falls within the range of 0.0 mg/L to 0.01 ± 0.01 mg/L. Hossain et al. (2006) found Ammonia in treated water of Saidabad Water Treatment Plant of Dhaka WASA ranging between 0.01 mg/L to 6.08 mg/L in their study which is far higher than the value found in this study. Whatever, from the above discussion it has been observed that the Ammonia value of purified water in MWTP fully complies with the ECR-97 guideline for Ammonia in drinking water.

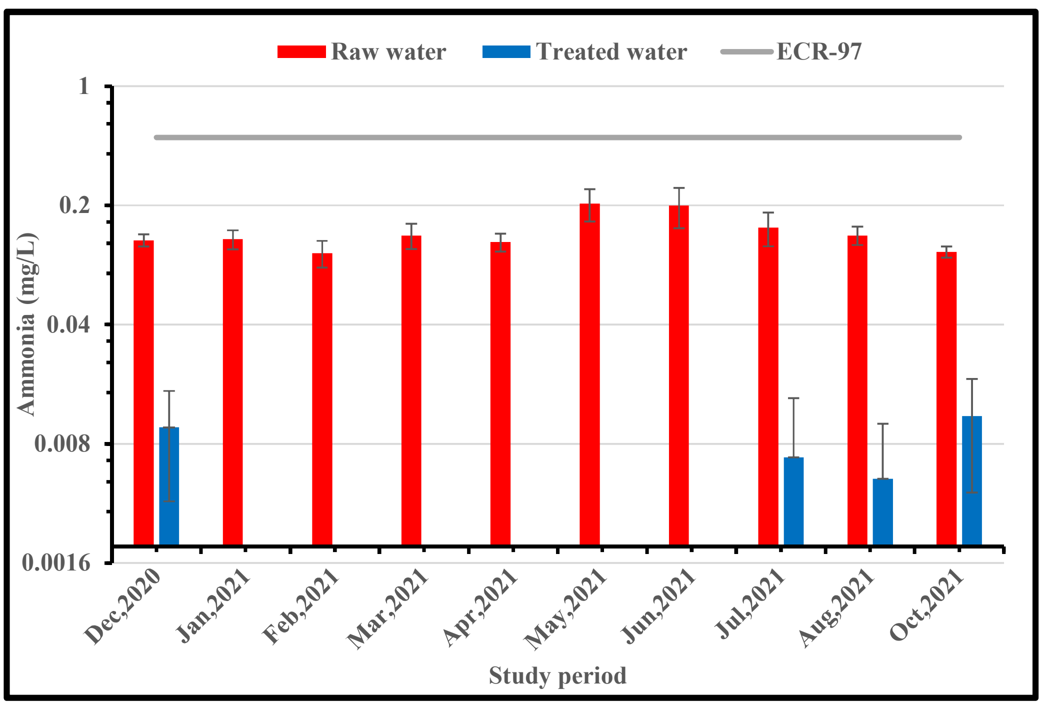

Figure 4.38: Comparison of Ammonia concentration of MWTP with ECR-97

4.2.13 Sulphate

Figure 4.39 shows that the raw water of MWTP has the highest Sulphate value of 27 ± 4.47 mg/L in June, 2021 and the lowest Sulphate of 12.67 ± 1.21 mg/L in January, 2021. Observations indicate that the level of Sulphate in the untreated water varies throughout the duration of the analysis. A study conducted by Karim et al. (2019) recorded Sulphate values between 17-24 mg/L in the different points of Halda river which is comparatively closer to this study. According to ECR-97, drinking water should have a maximum Sulphate value of 400 mg/L. So it seen that the Sulphate value of raw water in MWTP is conform to the ECR-97 guideline for in drinking water. However, Figure 4.39 also shows that Sulphate value of treated water of MWTP is ranged between 17.33 ± 1.51 mg/L to 30.83 ± 4.67 mg/L. Hossain et al. (2020) found the highest Sulphate value in household water of Gazipur (0.69 mg/L) the lowest value was recorded 0.09 mg/L in household water of Mymensingh in their study which is much lower than the value found in this study. Based on the preceding discussion, it is evident that the Sulphate level of processed water at MWTP adheres to the ECR-97 standard for Sulphate in potable water.

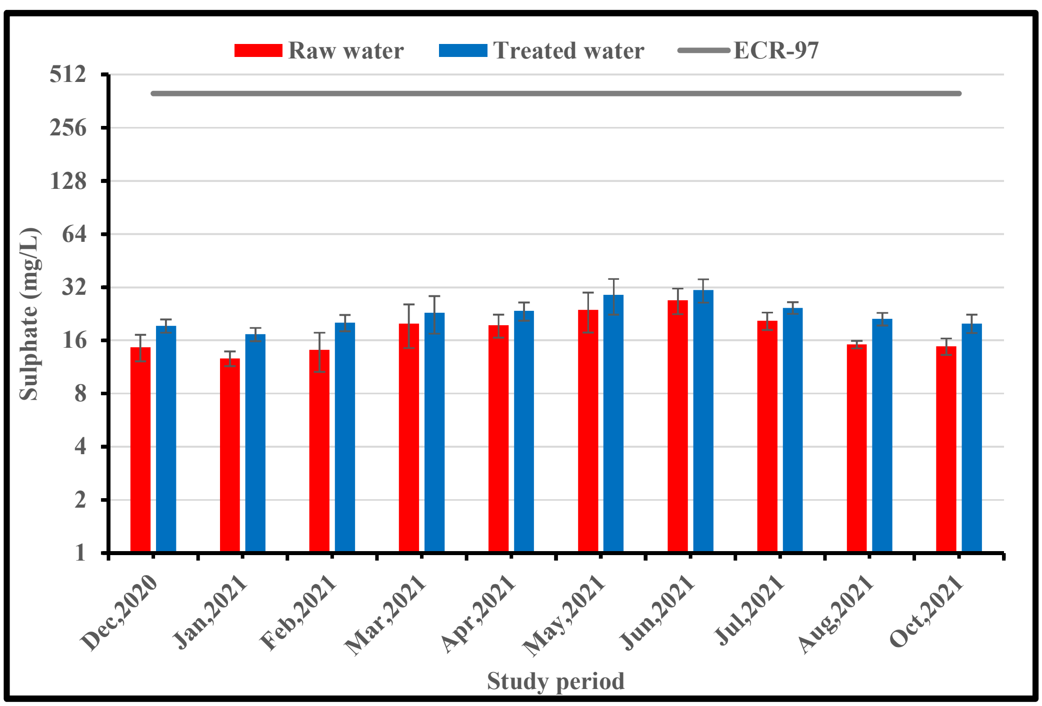

Figure 4.39: Comparison of Sulphate concentration of MWTP with ECR-97

4.2.14 Phosphate

In August 2021, the MWTP's raw water had the highest level of Phosphate, measuring 0.37 ± 0.10 mg/L as shown in Figure 4.40. Conversely, in April 2021, the lowest Phosphate value of 0.13 ± 0.02 mg/L was recorded. During the entire study period, the Phosphate level in the raw water was observed to vary. A study conducted by Karim et al. (2019) recorded the highest Phosphate values ranging between 0.33 and 0.38 mg/L in the intake point of MWTP of Halda river which is comparatively closer to this study. According to ECR-97, drinking water should have a maximum Phosphate value of 6 mg/L. So it seen that the Phosphate value of raw water in MWTP is conform to the ECR-97 guideline for in drinking water. However, Figure 4.40 also shows that Phosphate value of treated water of MWTP is ranged between 0.03 ± 0.01 mg/L to 0.09 ± 0.02 mg/L. Hossain et al. (2020) found the highest Phosphate value in household water of Dhaka (0.46mg/L) and the lowest value was recorded 0.04 mg/L in household water of Rangpur in their study which is somehow higher than the value found in this study. Whatever from the above discussion, it has been observed that the Phosphate level in the processed water at MWTP adheres to the Phosphate standards outlined in ECR-97 for potable water.

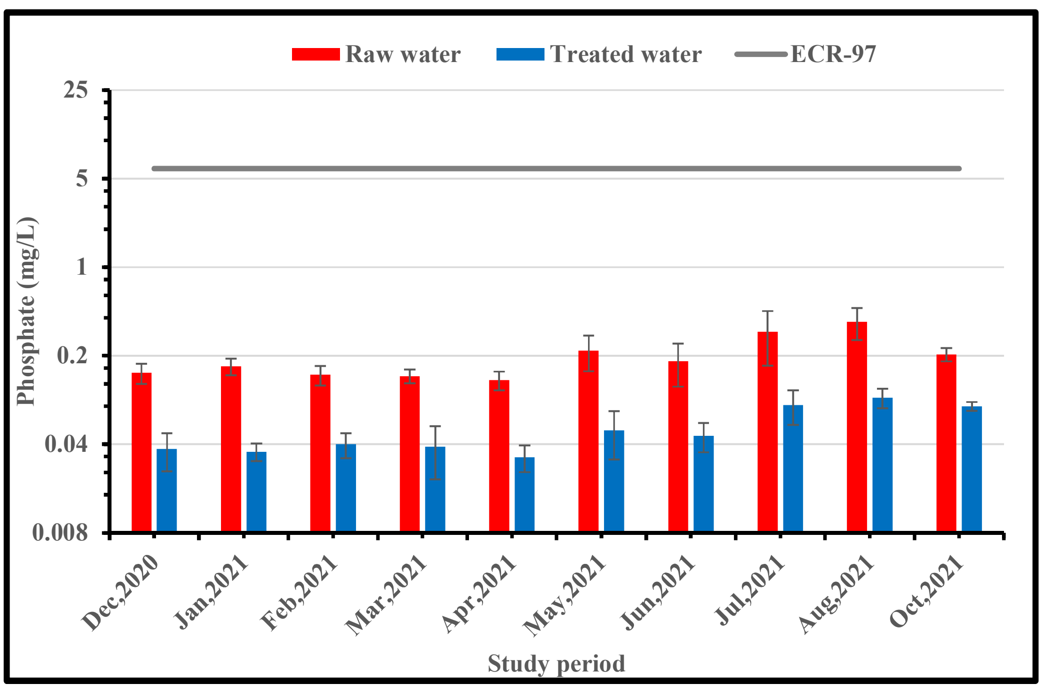

Figure 4.40: Comparison of Phosphate concentration of MWTP with ECR-97

4.2.15 Iron (Fe)

In August 2021, the graph in Figure 4. 41 indicates that the MWTP's untreated water contained the highest amount of Iron (Fe) at 0.83 ± 0.28 mg/L. Conversely, in January of 2021, the raw water had the lowest Fe level of 0.12 ± 0.01 mg/L. The fluctuation of the Fe composition in the raw water has been observed during the entire period of analysis. A study conducted by Dey et al. (2021) recorded the concentration of Fe in the Halda river ranged from 0.311 ± 0.05 mg/L to 0.49 ± 0.08 mg/L which is comparatively closer to this study. According to BSTI, drinking water should have a maximum Fe value of 0.3 mg/L. It appears that the level of Fe present in the MWTP's untreated water does not meet the standard set by BSTI for Fe in drinking water. However, Figure 4.41 also shows that Fe value of treated water of MWTP is ranged between 0.05 ± 0.01 mg/L to 0.12 ± 0.07 mg/L. Zannat et al. (2020) found the highest Fe value in CWASA supply water in Chattogram City (0.75mg/L) and the lowest value was 0.01 mg/L in their study. The highest value of Fe in their study is much higher than the highest value found in this study. Whatever, from the above discussion it has been inferred that the Fe content in the MWTP treated water meets the Fe standards set by BSTI for consumption.

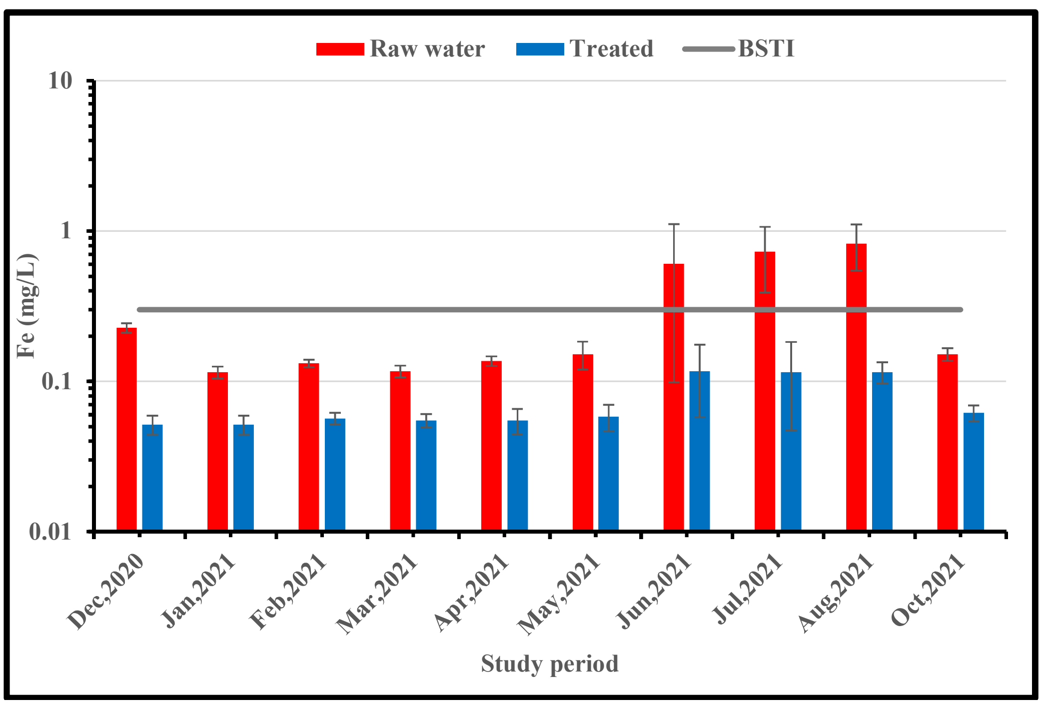

Figure 4.41: Comparison of Fe concentration of MWTP with BSTI

4.2.16 Zinc (Zn)

Figure 4.42 shows that the raw water of MWTP has the highest Zinc (Zn) value of 0.24 ± 0.03 mg/L in June, 2021 and the lowest Zn of 0.12 ± 0.02 mg/L in October, 2021. It is seen that Zn value of raw water fluctuates throughout the study period. A study conducted by Dey et al. (2021) recorded the average Zn concentration as 0.5494 mg/L in the Halda river which is completely higher than the value found in this study. According to BSTI, drinking water should have a maximum Zn value of 3 mg/L. So it seen that the Zn value of raw water in MWTP is conform to the BSTI standard for Zinc in drinking water. However, Figure 4.42 also shows that Zn value of treated water of MWTP is ranged between 0.03±0.0089 mg/L to 0.08 ± 0.01 mg/L. Molla et al. (2020) observed the highest Zn value in Dhaka WASA supply water in Dhaka City (0.57 mg/L) and the lowest value was less than 0.01 mg/L in their study. The highest value of Zn in their study is much higher than the highest value found in this study. Upon analysis of the previous exchange, it can be observed that the Zn level in processed water at MWTP adheres to the Zn guidelines established by the BSTI for consumption.

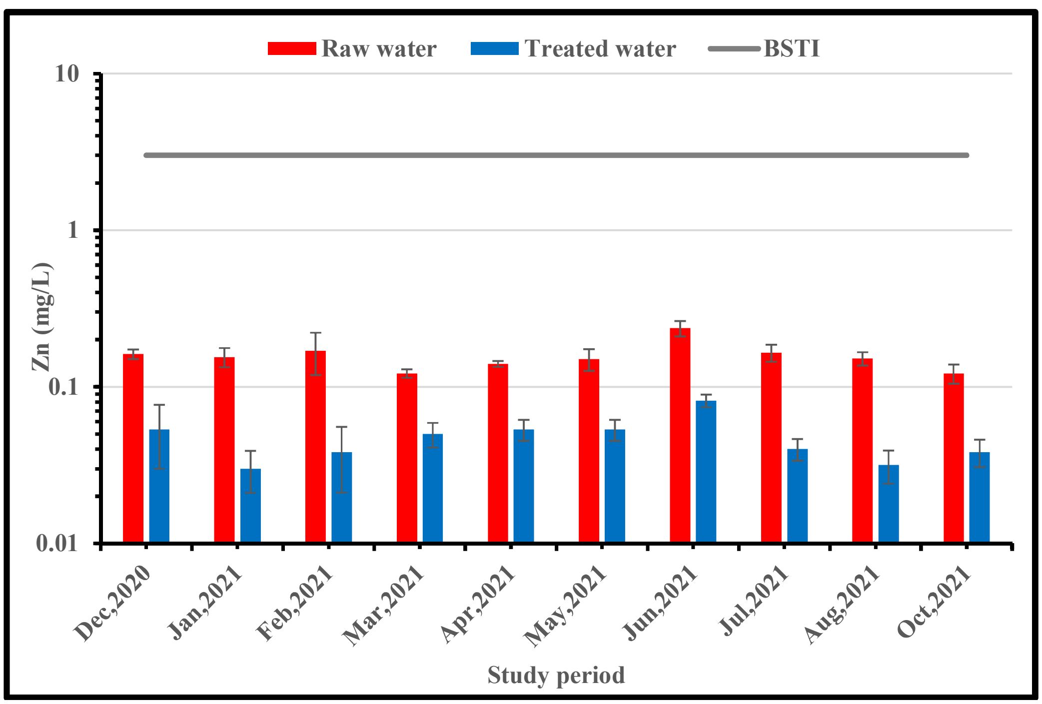

Figure 4.42: Comparison of Zn concentration of MWTP with BSTI

4.2.17 Copper (Cu)

Figure 4.43 shows that the raw water of MWTP has the highest Copper (Cu) value of 0.22 ± 0.10 mg/L in May, 2021 and the lowest Cu of 0.13 ± 0.02 mg/L in December, 2020. It is seen that Cu value of raw water fluctuates throughout the study period. A study conducted by Dey et al. (2021) recorded the lowest concentration of Cu as 0.1706 ± 0.0749 mg/L and the highest value as 0.57539 ± 0.02526 mg/L in the Halda river which is completely higher than the value found in this study. According to WHO guideline, drinking water should have a maximum Cu value of 2 mg/L. So it seen that the Cu value of raw water in MWTP is conform to the WHO guideline for Cu in drinking water. However, Figure 4.43 also shows that Cu value of treated water of MWTP is ranged between 0.03 ± 0.01 mg/L to 0.05 ± 0.01 mg/L. Choudhury (2011) observed Cu concentration in the drinking water samples of Dhaka city were in the range of 0.00274 - 0.0353 mg/L. It can be observed from the preceding discussion that the Cu levels present in treated water at MWTP are consistent with the Cu standards outlined by the WHO for safe drinking water.

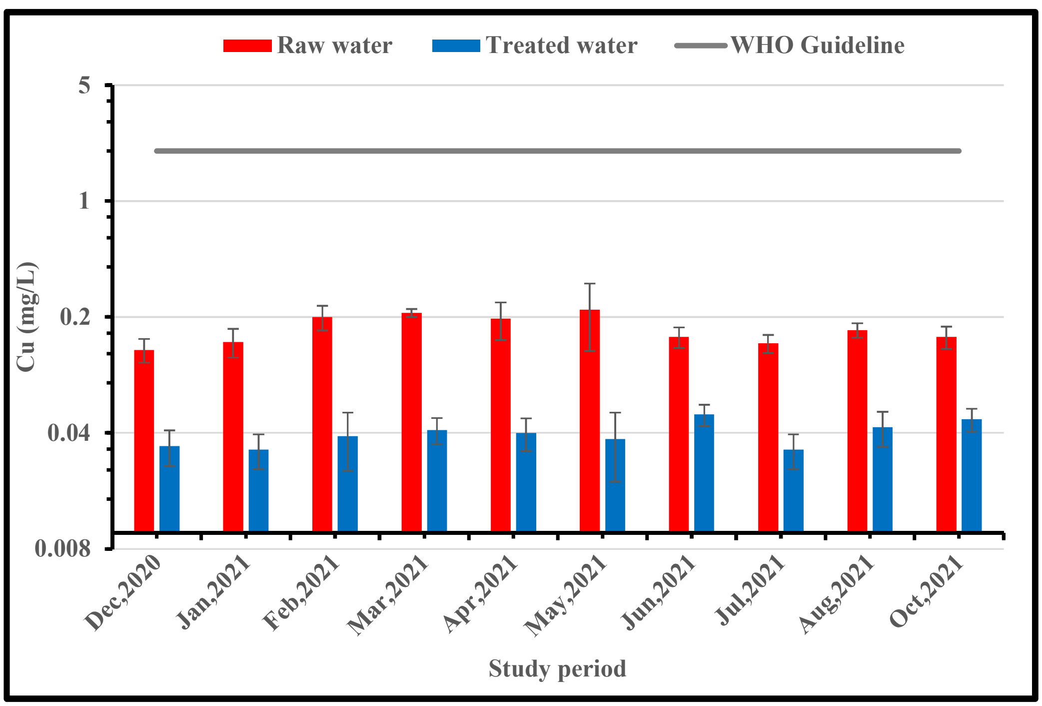

Figure 4.43: Comparison of Cu concentration of MWTP with WHO standard

4.2.18 Manganese (Mn)

Figure 4.44 shows that the raw water of MWTP has the highest Manganese (Mn) value of 0.13 ± 0.01 mg/L in July, 2021 and the lowest Mn of 0.08 ± 0.01 mg/L in April, 2021. It is seen that Mn value of raw water fluctuates throughout the study period. A study conducted by Dey et al. (2021) recorded the average concentration of Mn as 0.4695 mg/L in the Halda river which is completely higher than the value found in this study. According to WHO guideline, drinking water should have a maximum Mn value of 0.4 mg/L. So it seen that the Mn value of raw water in MWTP is conform to the WHO guideline for Mn in drinking water. However, Figure 4.44 also shows that Mn value of treated water of MWTP is ranged between 0.01 ± 0.01 mg/L to 0.04 ± 0.01 mg/L. Choudhury (2011) observed the highest Mn concentration in the drinking water samples of Dhaka city as 0.0879 ± 0.002 mg/L and the lowest value as 0.00536 ± 0.00055 mg/L. It has been established from the preceding conversation that the Mn level found in the water treated at MWTP is in accordance with the Mn regulations set forth by the WHO pertaining to potable water.

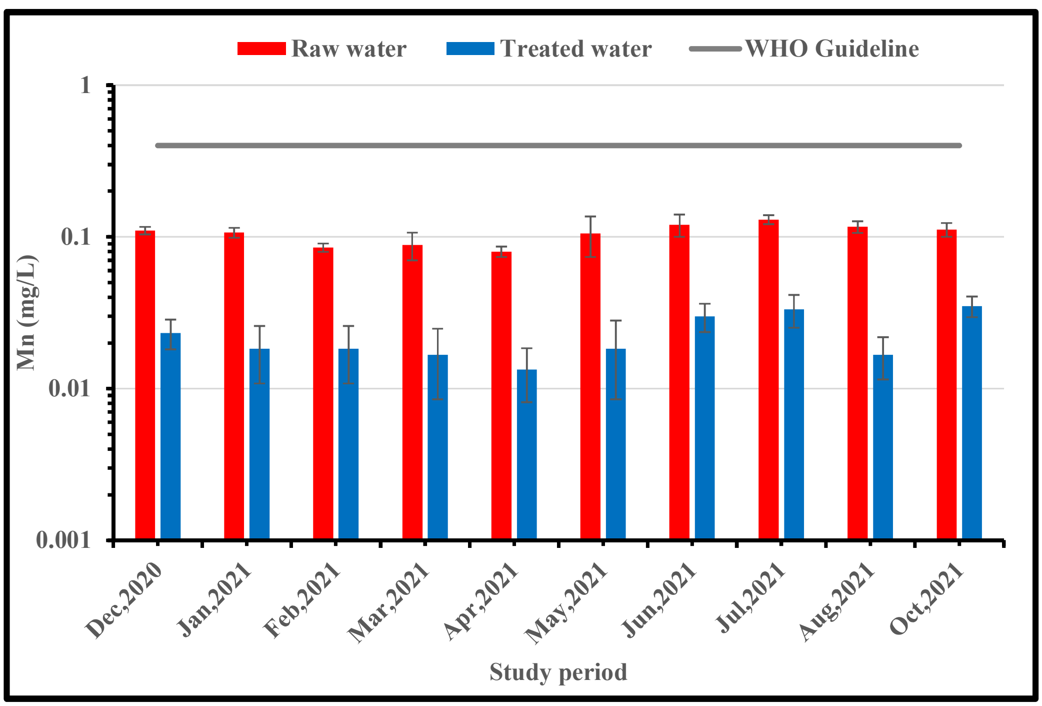

Figure 4.44: Comparison of Mn concentration of MWTP with WHO standard

4.2.19 Dissolved Oxygen (DO)

Figure 4.45 shows that the raw water of MWTP has the highest Dissolved Oxygen (DO) value of 7.72 ± 0.23 mg/L in December, 2020 and the lowest DO of 6.40 ± 0.13 mg/L in July, 2021. During the study, it was observed that the DO level in the untreated water exhibited variations. A study conducted by Karim et al. (2019) observed the DO of Halda river water ranged from 5.90 - 8.40 mg/L in the Halda river. According to ECR-97 guideline, drinking water should have a maximum DO value of 6 mg/L. So it seen that the DO value of raw water in MWTP is conform to the ECR-97 guideline for DO in drinking water. However, Figure 4.45 also shows that DO value of treated water of MWTP is ranged between 7.17 ± 0.04 mg/L to 8.11 ± 0.23 mg/L. Nitol et al. (2016) observed the DO concentration of the examined samples of Dakshin Khan in Dhaka City varied from 1.70 mg/L to 5.10 mg/L which is comparatively lower than the value of this study. It is evident from the preceding discourse that the DO levels in the processed water at MWTP are in adherence to the ECR-97 directive regarding DO in potable water.

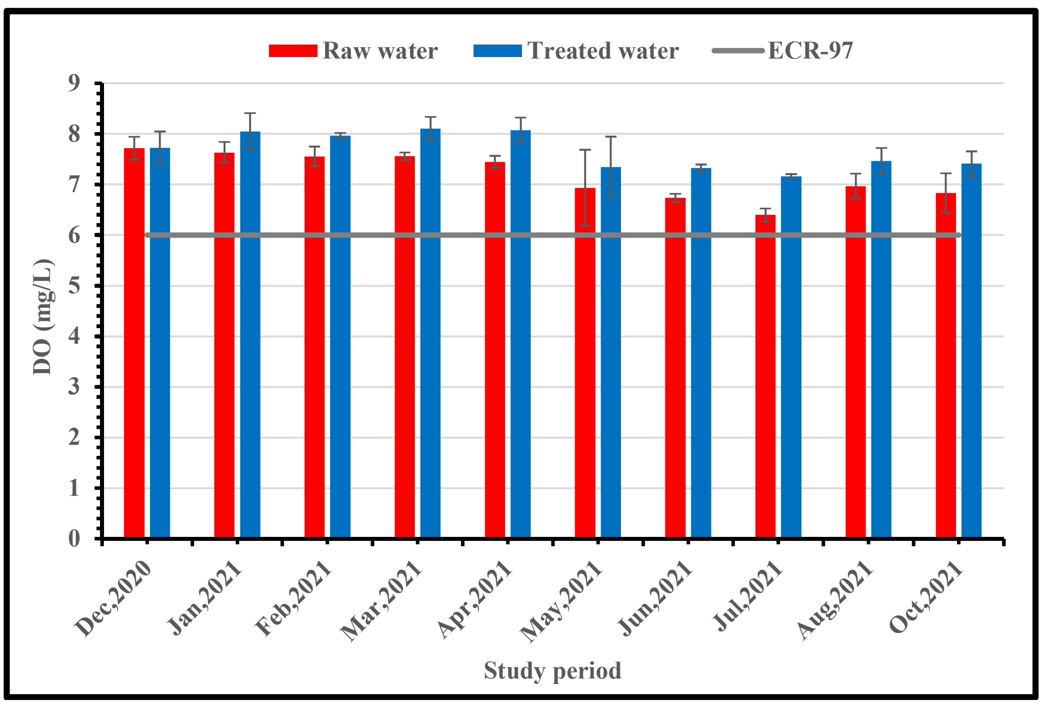

Figure 4.45: Comparison of DO concentration of MWTP with ECR-97

4.2.20 Biological Oxygen Demand (BOD)

Figure 4.46 shows that the raw water of MWTP has the highest Biological Oxygen Demand (BOD) value of 1.35 ± 0.20 mg/L in February, 2021 and the lowest BOD of 1.15 ± 0.03 mg/L in March, 2021. Throughout the study duration, there was observed variability in the BOD value of untreated water. A study conducted by Karim et al. (2019 observed the BOD of Halda river water ranged from 0.3 - 2.8 mg/L in the Halda river. According to ECR-97 guideline, drinking water should have a maximum BOD value of 0.2 mg/L. It appears that the BOD level found in the untreated water at MWTP does not meet the BOD standards established in the ECR-97 regulations for potable water. However, the data depicted in Figure 4.46 indicates that the MWTP's treated water has a BOD measurement that falls within the range of 0.09 ± 0.01 mg/L to 0.13 ± 0.02 mg/L. Zannat et al. (2020) observed the BOD concentration of the examined samples of supplied water of CWASA varied from 4.9 mg/L to 8.10 mg/L which is much higher than the value of this study. From the previous discussion, it can be concluded that the BOD level of the treated water in MWTP meets the BOD standard for drinking water set by ECR-97.

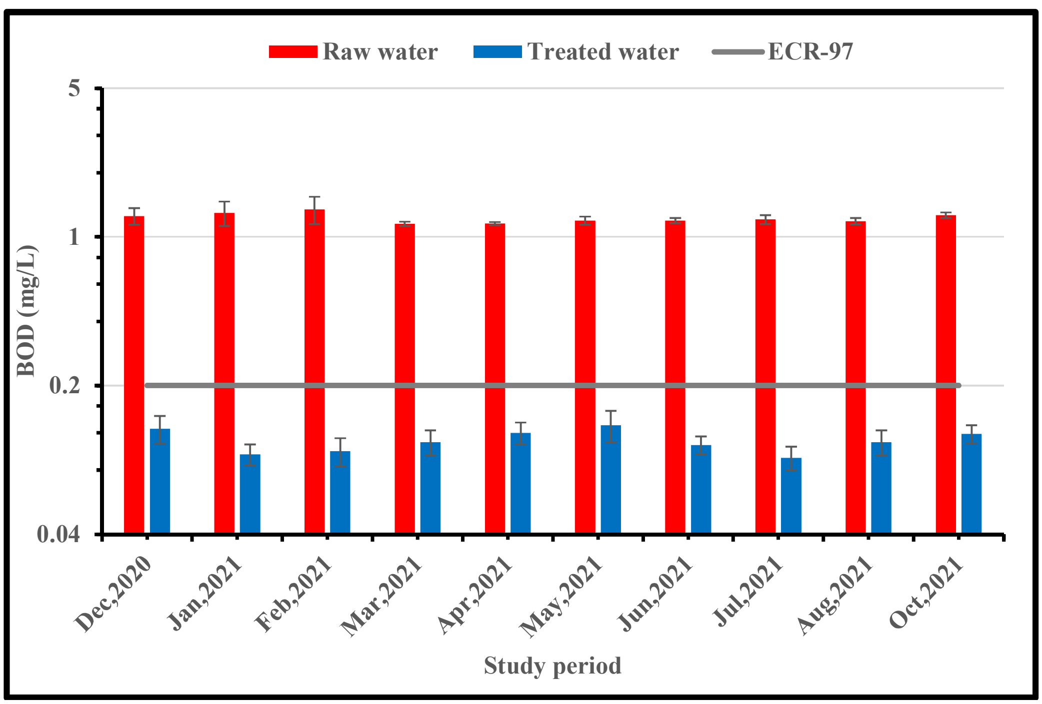

Figure 4.46: Comparison of BOD concentration of MWTP with ECR-97

4.2.21 Chemical Oxygen Demand (COD)

Figure 4.47 shows that the raw water of MWTP has the highest Chemical Oxygen Demand (COD) value of 34.17 ± 3.31 mg/L in June, 2021 and the lowest COD of 21.5 ± 2.67 mg/L in October, 2021. It is seen that COD value of raw water fluctuates throughout the study period. A study conducted by Karim et al. (2019) observed the average COD value found in Halda river is 54.1 mg/L. According to ECR-97 guideline, drinking water should have a maximum COD value of 4 mg/L. The COD level of untreated water in MWTP appears to deviate from the ECR-97 directive on acceptable COD levels in potable water. However, Figure 4.47 also shows that COD value of treated water of MWTP is ranged between 0.90 ± 0.07 mg/L to 1.0 ± 0.04 mg/L. Siddhartha (2017) observed the COD concentration of the examined samples varied from 3 mg/L to 6.3 mg/L which is much higher than the value of this study. The previously mentioned conversation indicates that the COD level in the purified water at MWTP meets the COD standard for drinking water given by the ECR-97 guideline.

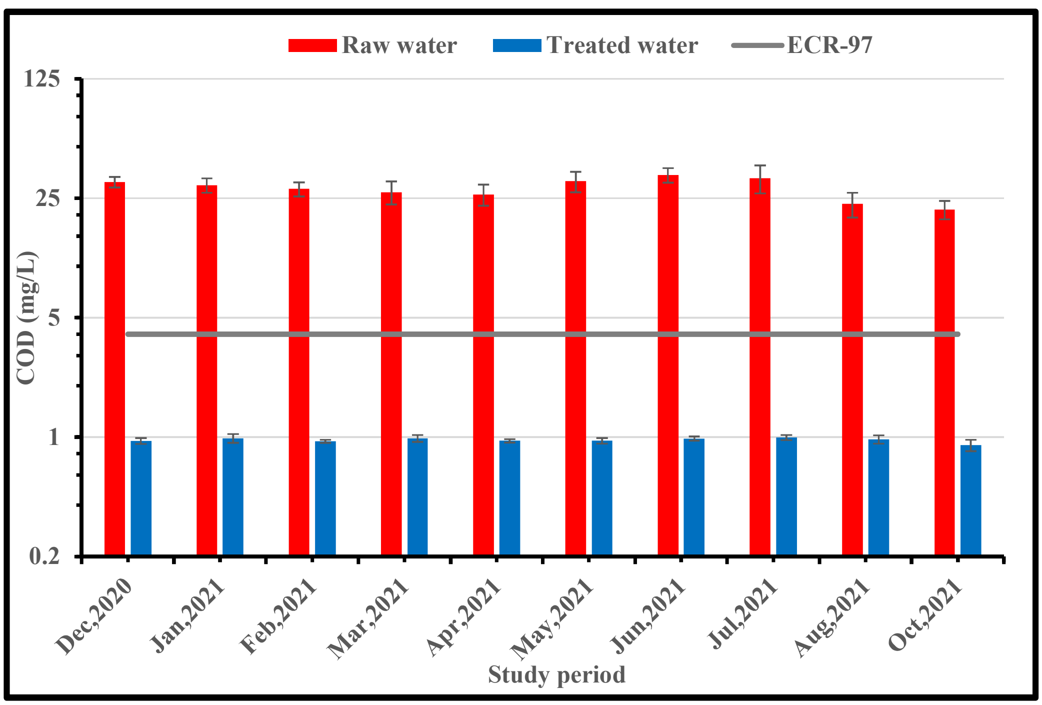

Figure 4.47: Comparison of COD concentration of MWTP with ECR-97

4.2.22 Lead (Pb)

Lead (Pb) was found below the instrumental detection limit of Flame AAS (0.013 mg/L) in both the raw water and the treated water of MWTP. Bakar & Bhuiya (2017) recorded the Pb concentration in the Halda river ranging between 0.1 and 0.01 mg/L in their study. Dey et al. (2021) also recorded the average Pb concentration in the Halda river as 1.28 mg/L in their study. The amount of Pb present in both the untreated and treated water at MWTP is observed to be compliant with the maximum allowed limit of 0. 01 mg/L established by WHO for Pb in potable water.

4.2.23 Cadmium (Cd)

Cadmium (Cd) in the both raw water and the treated water of MWTP was found below the instrumental detection limit of Flame AAS (0.0028 mg/L). Bakar & Bhuiya (2017) recorded the Cd concentration in the Halda river ranging between 0.03 and 0.2 mg/L in their study. Dey et al. (2021) also recorded the Cd concentration at different points of along the Halda river ranging from 10.0 ± 0.36 μg/L to 80.0 ± 2.85 μg/L in their study. So from the above discussion it can be said that Cd concentration in the both raw water and the treated water of MWTP is within the permissible limit of 0.003 mg/L set by WHO for Cd in drinking water.

4.2.24 Mercury (Hg)

Mercury (Hg) was found below the instrumental detection limit of AAS (0.06 mg/L) in both the raw water and the treated water of MWTP. Bakar & Bhuiya (2017) recorded the Hg concentration in the Halda river ranging between 0.001 and 0.01 mg/L in their study. Dey et al. (2021) couldn't detect Hg in none of the samples of Halda river in their study. From the above discussion it can be said that Hg concentration in the both raw water and the treated water of MWTP is within the permissible limit of 0.006 mg/L set by WHO for Hg in drinking water.

4.2.25 Arsenic (As)

Arsenic (As) was not detected in both the raw water and the treated water of MWTP. Karim et al. (2019) found in their study that Arsenic level was within the safe limit for aquatic life in the Halda river. Dey et al. (2021) recorded the average concentration of As in Halda river as 60.0 μg/L in their study. So it can be said that As concentration in the both raw water and the treated water of MWTP is within the permissible limit of 0.01 mg/L set WHO for As in drinking water.

4.2.26 Chromium (Cr)

Chromium (Cr) in both the raw water and the treated water of MWTP was found below the instrumental detection limit of Flame AAS (0.0054 mg/L). Bakar & Bhuiya (2017) recorded the Cr concentration in the Halda river ranging between 0.01 and 0.12 mg/L in their study. Dey et al. (2021) recorded the average concentration of Cr in the Halda river as 70.8 μg/L in their study. From the above discussion it can be said that Cr concentration in the both raw water and the treated water of MWTP is within the permissible limit of 0.05 mg/L set by WHO for Cr in drinking water.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The Mohara Water Treatment Plant (MWTP), operated by CWASA, is crucial for fulfilling Chattogram City's water demands. This study extensively examined its performance and treated water quality, revealing key insights. Utilizing conventional purification processes, the plant consistently provides safe and palatable water for various domestic purposes, including drinking and cooking. Beyond general knowledge, the study focused on precise details concerning efficiency and water quality. The evaluation confirmed the plant's ability to effectively treat water, meeting the community's needs. Treated water quality adhered to strict standards, ensuring immediate safety and public trust. Moreover, the study emphasized the plant's vital role in safeguarding public health by providing clean and safe drinking water, preventing waterborne diseases. The research also aimed to identify areas for potential improvement in overall plant efficiency, helping CWASA enhance performance and meet the city's growing water demand. Furthermore, by consistently meeting stringent standards, the plant maintains public trust in the water supply system. This study provides CWASA with valuable insights for informed decision-making regarding plant operations and future upgrades. In conclusion, the MWTP is indispensable for Chattogram City's water supply. Continuous monitoring and evaluation ensure efficiency and the provision of high-quality, safe drinking water, ultimately benefiting the residents. Based on the research findings, the following unique conclusions emerge:

1. The MWTP achieves an impressive 99.9% turbidity removal, showcasing its ability to consistently produce high-quality treated water through effective chemical dosing and optimal sand filter performance.
2. The MWTP has a chloride removal efficiency of less than 60%, indicating vulnerability. Being a conventional plant, it may struggle with chloride removal, necessitating adaptation for future climate change challenges.

3. The MWTP achieves 100% ammonia removal, affirming the excellent performance of coagulation and chlorination processes for effective ammonia elimination, ensuring water safety
4. The plant exhibits a remarkable 99.8% TSS removal efficiency, underscoring efficient solid particle removal through proper chemical dosing for coagulation, contributing to clear and clean water production.
5. With a perfect 100% removal efficiency for both Total Coliform and Fecal Coliform, the plant's successful disinfection practices guarantee the absence of disease-causing bacteria, ensuring public safety
6. The MWTP achieves an impressive 98% COD removal efficiency, indicating its effectiveness in removing chemical pollutants and maintaining low organic compound levels for overall water quality.
7. Compliance with drinking water quality guidelines from organizations like WHO, BSTI, and ECR-97 validates the MWTP's commitment to stringent standards and the provision of safe drinking water.
8. Effective elimination of biological contaminants aligns with WHO's drinking water guidelines, reinforcing the plant's role in safeguarding public health.
9. Heavy metals within permissible WHO limits ensure satisfactory water quality, vital for residents' well-being in Chattogram City.
11. The MWTP 's longevity since 1987 and good operational condition underscore the importance of continuous maintenance and analysis to ensure sustained efficiency and reliability.
12. Successful removal of biological contaminants and heavy metals within permissible limits highlights the plant's dedication to protecting public health.
13. The plant's efficient treatment processes play a critical role in maintaining CWASA's water supply capacity for sustainable city development.
14. The comprehensive evaluation of the MWTP's performance and treated water quality contributes to the broader understanding of water treatment processes.

15. The findings of this research highlight the critical role of the MWTP which aligns with sustainable development goals for clean
16. The research findings validate the importance of public-private partnerships and collaboration between CWASA and relevant stakeholders in ensuring the efficiency and success of the MWTP.
17. Despite being conventional, the plant consistently meets quality standards, reaffirming its reliability in supplying safe water.

5.2. Recommendations

The recommendations that can be provided from the outcomes of the study are the following:

1. It is crucial to implement comprehensive strategies to mitigate saline water intrusion into the source of the MWTP, including physical barriers, sustainable groundwater management, and exploring alternative water sources.
2. Prioritization of water quality preservation in the distribution system with advanced monitoring technologies to detect and address deviations in real-time is highly recommended.
3. Adhering to established conventional methods and operating procedures while considering technological advancements is crucial for improved plant efficiency.
4. Implementing a robust monitoring system is vital for continuous unit-by-unit performance evaluation to maintain optimal water quality.
5. Establish a systematic maintenance schedule for treatment units is essential to prevent potential breakdowns and degradation.
6. Implementation of a comprehensive water quality monitoring program is imperative that includes frequent sampling and adherence to regulatory guidelines.
7. Conducting regular performance evaluations of the treatment plant, leveraging insights gained from research for continuous improvement is highly recommended.

8. Providing comprehensive caretaker training programs to ensure effective plant operation, emphasizing adherence to guidelines and responsibility is crucial to ensure effective operation of the treatment plant.
9. Conducting thorough analyses of the feeding source water quality to identify pollution sources and implement appropriate treatment and pollution mitigation measures is essential.
10. Collaboration with local industries and businesses to implement pollution prevention measures, enforce environmental regulations, and reduce pollutant introduction into source water is highly recommended.

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APPENDICES

Appendix 1: Turbidity of raw water and treated water of MWTP during the study period.

Raw water turbidity (NTU)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	310	312	310.67	0.94	190	195	192.67	2.05	251.67	64.65
Jan-21	318	325	321	2.94	179	182	180.33	1.25	250.67	77.07
Feb-21	250	255	252.67	2.05	158	161	159.67	1.25	206.17	50.97
Mar-21	180	185	182.67	2.05	129	132	130.33	1.25	156.5	28.72
Apr-21	140	144	142	1.63	90	92	91	0.82	116.5	27.96
May-21	400	406	403.67	2.62	218	222	220	1.63	311.83	100.62
June-21	230	235	232.67	2.05	390	395	392.33	2.05	312.5	87.48
July-21	182	185	183.33	1.25	319	321	320	0.82	251.67	74.862
Aug-21	220	225	222.67	2.05	278	281	279.67	1.25	251.167	31.28
Oct-21	260	266	263	2.45	179	180	179.67	0.47	221.33	45.68

Treated water turbidity (NTU)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	310	312	310.67	0.94	190	195	192.67	2.05	251.67	64.65
Jan-21	318	325	321	2.94	179	182	180.33	1.25	250.67	77.07
Feb-21	250	255	252.67	2.05	158	161	159.67	1.25	206.17	50.97
Mar-21	180	185	182.67	2.05	129	132	130.33	1.25	156.5	28.72
Apr-21	140	144	142	1.63	90	92	91	0.82	116.5	27.96
May-21	400	406	403.67	2.62	218	222	220	1.63	311.83	100.62
June-21	230	235	232.67	2.05	390	395	392.33	2.05	312.5	87.48
July-21	182	185	183.33	1.25	319	321	320	0.82	251.67	74.862
Aug-21	220	225	222.67	2.05	278	281	279.67	1.25	251.167	31.28
Oct-21	260	266	263	2.45	179	180	179.67	0.47	221.33	45.68

Appendix 2: Turbidity at various units of MWTP during the study period.

Month	Turbidity (NTU) After sedimentation				Turbidity (NTU) Clarifier outlet				Turbidity (NTU) Filter outlet			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20					5.2	6.8	5.98	0.76	0.7	0.8	0.75	0.04
Jan-21	183	325	253.83	76.51	6.5	7.28	6.96	0.34	0.74	0.79	0.76	0.02
Feb-21	170	264	216.83	49.86	6.2	6.74	6.47	0.28	0.7	0.81	0.77	0.04
Mar-21	135	203	169.17	35.98	5.3	6.85	6.07	0.82	0.59	0.8	0.69	0.09
Apr-21	112	155	133.33	21.95	4.8	6.28	5.53	0.78	0.61	0.98	0.79	0.19
May-21	231	445	337.83	114.85	9.1	10.56	9.85	0.75	0.98	1.05	1.01	0.02
June-21	242	423	332.83	96.96	5.61	6.78	6.15	0.57	0.8	1.39	1.08	0.30
July-21	180	353	265.5	92.95	6.8	7.7	7.25	0.47	0.61	0.88	0.745	0.13
Aug-21	223	297	260	38.73	7.25	7.86	7.56	0.2	0.81	0.89	0.85	0.03
Oct-21	195	286	240.83	48.04	7.1	7.2	7.14	0.04	0.9	0.94	0.92	0.01

Appendix 3: TSS of raw water and treated water of MWTP during the study period.

Raw water TSS (mg/L)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	408	412	410	2	302	307	304.33	2.52	357.17	57.91
Jan-21	402	407	404.67	2.52	230	234	231.67	2.08	318.17	94.78
Feb-21	319	323	320.67	2.08	202	205	203.33	1.53	262	64.29
Mar-21	250	256	252.67	3.06	163	166	164.67	1.53	208.67	48.25
Apr-21	185	189	187	2	133	135	134.33	1.15	160.67	28.88
May-21	540	542	540.67	1.15	280	282	281	1	410.83	142.22
June-21	301	306	303.67	2.52	505	508	506.67	1.53	405.17	111.20
July-21	241	245	243	2	413	416	414.67	1.53	328.83	94.04
Aug-21	288	291	289.67	1.53	362	367	364.33	2.52	327	40.94
Oct-21	362	367	364.67	2.52	253	256	254.67	1.53	309.67	60.28

Treated water TSS (mg/L)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	0.68	0.7	0.69	0.01	0.76	0.78	0.77	0.01	0.73	0.04
Jan-21	0.71	0.74	0.73	0.02	0.7	0.73	0.71	0.02	0.72	0.02
Feb-21	0.76	0.79	0.78	0.02	0.64	0.68	0.66	0.02	0.72	0.06
Mar-21	0.73	0.75	0.74	0.01	0.51	0.55	0.53	0.02	0.64	0.12
Apr-21	0.91	0.93	0.92	0.01	0.57	0.59	0.58	0.01	0.75	0.19
May-21	0.96	0.98	0.97	0.01	0.98	1	0.99	0.011	0.98	0.02
June-21	1.2	1.3	1.23	0.06	0.72	0.76	0.74	0.02	0.98	0.27
July-21	0.53	0.55	0.54	0.01	0.84	0.88	0.86	0.02	0.7	0.18
Aug-21	0.76	0.78	0.77	0.01	0.83	0.87	0.85	0.02	0.81	0.05
Oct-21	0.83	0.86	0.85	0.02	0.9	0.92	0.91	0.01	0.88	0.04

Appendix 4: TSS at various units of MWTP during the study period.

Month	TSS (mg/L) After sedimentation				TSS (mg/L) Clarifier outlet				TSS (mg/L) Filter outlet			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20					5.2	6.8	5.98	0.76	0.7	0.8	0.75	0.04
Jan-21	183	325	253.83	76.51	6.5	7.28	6.96	0.34	0.74	0.79	0.76	0.02
Feb-21	170	264	216.83	49.86	6.2	6.74	6.47	0.28	0.7	0.81	0.77	0.04
Mar-21	135	203	169.17	35.99	5.3	6.85	6.07	0.82	0.59	0.8	0.70	0.09
Apr-21	112	155	133.33	21.95	4.8	6.28	5.53	0.78	0.61	0.98	0.80	0.19
May-21	231	445	337.83	114.85	9.1	10.56	9.85	0.75	0.98	1.05	1.01	0.02
June-21	242	423	332.83	96.96	5.61	6.78	6.15	0.57	0.8	1.39	1.09	0.3
July-21	180	353	265.5	92.95	6.8	7.7	7.25	0.47	0.61	0.88	0.75	0.13
Aug-21	223	297	260	38.73	7.25	7.86	7.56	0.29	0.81	0.89	0.85	0.03
Oct-21	195	286	240.83	48.04	7.1	7.2	7.15	0.04	0.9	0.94	0.92	0.01

Appendix 5: Chloride of raw water and treated water of MWTP during the study period.

Raw water chloride (mg/L)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	120	125	121.67	2.89	15	17	16	1	68.83	57.91
Jan-21	235	242	239	3.61	28	30	29.33	1.15	134.17	114.86
Feb-21	190	195	192.33	2.52	20	25	22.33	2.52	107.33	93.14
Mar-21	238	242	240	2	28	35	31	3.61	135.5	114.50
Apr-21	78	85	81	3.61	18	22	20	2	50.5	33.51
May-21	1400	1410	1405	5	48	52	50	2	727.5	742.17
June-21	90	95	92.33	2.52	20	25	22.33	2.52	57.33	38.41
July-21	18	22	20	2	12	15	13.33	1.53	16.67	3.98
Aug-21	12	15	13.33	1.53	8	9	8.33	0.58	10.833	2.93
Oct-21	12	15	13.67	1.53	8	10	9	1	11.33	2.80

Treated water chloride (mg/L)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	62	65	63.33	1.53	7	8	7.33	0.58	35.33	30.69
Jan-21	125	128	126.33	1.53	13	16	14.67	1.53	70.5	61.18
Feb-21	94	98	95.67	2.08	8	10	9	1	52.33	47.49
Mar-21	122	125	124	1.73	7	10	8.67	1.53	66.33	63.19
Apr-21	43	46	44.67	1.53	9	12	10.33	1.53	27.5	18.85
May-21	595	600	597.67	2.52	18	24	20.67	3.06	309.17	316.05
June-21	45	48	46.67	1.53	6	7	6.33	0.58	26.5	22.11
July-21	10	11	10.67	0.58	7	8	7.33	0.58	9	1.90
Aug-21	8	10	9	1	6	7	6.67	0.58	7.83	1.47
Oct-21	8	10	9	1	6	8	7	1	8	1.41

Appendix 6: Chloride at various units of MWTP during the study period.

Month	Chloride (mg/L) After sedimentation				Chloride (mg/L) Clarifier outlet				Chloride (mg/L) Filter outlet			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20					10	78	43.83	35.27	8	66	37	30.33
Jan-21	30	235	131.5	110.47	20	175	97	82.91	18	165	91.33	78.16
Feb-21	22	186	104.5	87.83	14	130	71.33	61.73	11	125	67.17	60.46
Mar-21	22	235	129.17	115.57	14	168	90.33	82.54	11	148	79	73.77
Apr-21	18	76	47.33	29.98	12	57	34.33	23.04	10	52	30.83	21.75
May-21	45	1380	712.17	729.02	30	936	482.83	495.32	22	885	453	470.68
June-21	18	95	55.5	40.39	10	68	38.33	29.98	7	64	34.83	29.79
July-21	11	21	16	4.24	10	15	12.83	2.14	8	12	10.17	1.72
Aug-21	7	14	10.5	3.21	7	12	9	2	6	9	7.67	1.21
Oct-21	7	15	10.67	3.44	7	10	8.67	1.21	6	9	7.33	1.21

Appendix 7: Ammonia of raw water and treated water of MWTP during the study period.

Raw water ammonia (mg/L)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	0.13	0.14	0.13	0.01	0.11	0.12	0.12	0.01	0.12	0.01
Jan-21	0.11	0.12	0.11	0.01	0.13	0.15	0.14	0.01	0.13	0.02
Feb-21	0.08	0.1	0.09	0.01	0.11	0.13	0.12	0.01	0.105	0.02
Mar-21	0.15	0.16	0.15	0.01	0.11	0.12	0.11	0.01	0.13	0.02
Apr-21	0.12	0.14	0.13	0.01	0.1	0.13	0.11	0.02	0.12	0.01
May-21	0.23	0.26	0.24	0.02	0.15	0.18	0.17	0.02	0.20	0.04
June-21	0.23	0.26	0.25	0.02	0.14	0.17	0.15	0.02	0.2	0.05
July-21	0.16	0.19	0.18	0.02	0.11	0.13	0.12	0.01	0.15	0.03
Aug-21	0.14	0.15	0.15	0.01	0.11	0.13	0.12	0.01	0.13	0.02
Oct-21	0.1	0.12	0.11	0.01	0.1	0.11	0.10	0.01	0.11	0.01
Treated water ammonia (mg/L)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	0.01	0.02	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01
Jan-21	0	0	0	0	0	0	0	0	0	0
Feb-21	0	0	0	0	0	0	0	0	0	0
Mar-21	0	0	0	0	0	0	0	0	0	0
Apr-21	0	0	0	0	0	0	0	0	0	0
May-21	0	0	0	0	0	0	0	0	0	0
June-21	0	0	0	0	0	0	0	0	0	0
July-21	0	0	0	0	0.01	0.02	0.01	0.01	0.01	0.01
Aug-21	0.01	0.01	0.01	0	0	0	0	0	0.01	0.01
Oct-21	0.01	0.02	0.01	0.01	0	0.01	0.01	0.01	0.011	0.01

Appendix 8: Ammonia at various units of MWTP during the study period.

Month	Ammonia (mg/L) After sedimentation				Ammonia (mg/L) Clarifier outlet				Ammonia (mg/L) Filter outlet			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20					0.03	0.06	0.047	0.01	0.02	0.04	0.03	0.01
Jan-21	0.08	0.12	0.10	0.02	0.03	0.05	0.04	0.01	0.01	0.03	0.02	0.01
Feb-21	0.07	0.1	0.08	0.01	0.02	0.03	0.025	0.01	0.01	0.02	0.02	0.01
Mar-21	0.08	0.13	0.105	0.02	0.02	0.04	0.03	0.01	0	0.03	0.01	0.02
Apr-21	0.07	0.1	0.09	0.01	0.02	0.03	0.025	0.01	0	0.02	0.01	0.01
May-21	0.08	0.18	0.13	0.05	0.02	0.03	0.025	0.01	0.01	0.02	0.01	0.01
June-21	0.1	0.19	0.15	0.04	0.03	0.04	0.03	0.01	0	0.02	0.01	0.01
July-21	0.09	0.15	0.12	0.02	0.02	0.04	0.03	0.01	0.01	0.03	0.02	0.01
Aug-21	0.08	0.11	0.091	0.011	0.02	0.06	0.04	0.015	0.01	0.04	0.03	0.01
Oct-21	0.07	0.1	0.07	0.01	0.04	0.06	0.05	0.01	0.02	0.03	0.02	0.01

Appendix 9: COD of raw water and treated water of MWTP during the study period

Raw water COD (mg/L)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	28	32	30	2	30	34	32.33	2.08	31.17	2.23
Jan-21	30	34	32	2	26	29	27.67	1.53	29.83	2.86
Feb-21	30	32	30.67	1.15	25	27	26	1	28.33	2.73
Mar-21	28	32	30.67	2.31	22	25	23.67	1.53	27.17	4.22
Apr-21	27	31	29.33	2.08	22	25	23.33	1.53	26.33	3.67
May-21	27	28	27.67	0.58	34	37	35.33	1.53	31.5	4.32
June-21	30	33	31.3	1.53	36	38	37	1	34.17	3.31
July-21	26	28	27.33	1.15	37	40	38.33	1.53	32.83	6.15
Aug-21	18	22	20	2	25	28	26.33	1.53	23.17	3.82
Oct-21	22	25	23.67	1.53	18	20	19.33	1.15	21.5	2.67
Treated water COD (mg/L)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	0.96	1	0.98	0.02	0.9	0.94	0.92	0.02	0.95	0.04
Jan-21	0.92	0.95	0.94	0.02	1	1.06	1.03	0.03	0.99	0.06
Feb-21	0.93	0.95	0.94	0.01	0.93	0.98	0.95	0.03	0.95	0.02
Mar-21	0.98	1.05	1.02	0.04	0.92	0.97	0.95	0.03	0.98	0.05
Apr-21	0.95	0.98	0.97	0.02	0.92	0.95	0.94	0.02	0.95	0.02
May-21	0.96	1	0.98	0.02	0.9	0.94	0.92	0.02	0.95	0.04
June-21	0.95	0.97	0.96	0.01	0.98	1.03	1.00	0.03	0.98	0.03
July-21	0.98	1.06	1.01	0.04	0.96	1	0.98	0.02	0.10	0.04
Aug-21	0.91	0.94	0.93	0.02	0.98	1.05	1.02	0.04	0.97	0.05
Oct-21	0.94	0.97	0.96	0.02	0.82	0.86	0.84	0.02	0.90	0.07

Appendix 10: COD at various units of MWTP during the study period.

Month	COD (mg/L) After sedimentation				COD (mg/L) Clarifier outlet				COD (mg/L) Filter outlet			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20					1.2	1.5	1.3	0.13	0.98	1.1	1.01	0.05
Jan-21	24	27	25.33	1.03	1.3	1.7	1.5	0.14	1.1	1.4	1.25	0.10
Feb-21	20	26	23.17	2.23	1.1	1.6	1.33	0.18	1	1.3	1.13	0.10
Mar-21	20	25	22.17	1.72	1.15	1.6	1.31	0.17	0.96	1.2	1.06	0.10
Apr-21	18	25	21.33	2.34	1.1	1.5	1.23	0.15	0.95	1.2	1.07	0.11
May-21	18	28	23.17	3.60	1.14	1.5	1.25	0.13	0.9	1.2	1.01	0.12
June-21	17	26	21.5	3.51	1.2	1.6	1.38	0.15	0.96	1.1	1.02	0.06
July-21	21	28	24	2.53	1.2	1.7	1.45	0.19	0.98	1.2	1.1	0.08
Aug-21	21	27	24.33	2.16	1.1	1.4	1.28	0.12	0.98	1.2	1.08	0.08
Oct-21	16	24	19.33	2.94	1.1	1.5	1.28	0.15	0.97	1.1	1.01	0.05

Appendix 11: Total coliform of raw water and treated water of MWTP during the study period.

Raw water total coliform (CFU/100 mL)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	545	560	551.67	7.64	370	385	378.33	7.64	465	95.18
Jan-21	510	525	518.33	7.64	315	325	320	5	419.17	108.79
Feb-21	480	495	488.33	7.64	265	280	273.33	7.64	380.83	117.96
Mar-21	220	235	226.67	7.64	210	225	216.67	7.64	221.67	8.76
Apr-21	210	225	218.33	7.64	255	275	263.33	10.41	240.83	25.96
May-21	165	180	171.67	7.64	290	310	300	10	235.83	70.74
June-21	315	330	323.33	7.64	410	425	418.33	7.64	370.83	52.48
July-21	160	180	170	10	210	225	218.33	7.64	194.17	27.64
Aug-21	205	225	216.67	10.40	175	190	181.67	7.64	199.17	20.84
Oct-21	470	490	480	10	420	430	425	5	452.5	30.94
Treated water total coliform (CFU/100 mL)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	00	00	00	00	00	00	00	00	00	00
Jan-21	00	00	00	00	00	00	00	00	00	00
Feb-21	00	00	00	00	00	00	00	00	00	00
Mar-21	00	00	00	00	00	00	00	00	00	00
Apr-21	00	00	00	00	00	00	00	00	00	00
May-21	00	00	00	00	00	00	00	00	00	00
June-21	00	00	00	00	00	00	00	00	00	00
July-21	00	00	00	00	00	00	00	00	00	00
Aug-21	00	00	00	00	00	00	00	00	00	00
Oct-21	00	00	00	00	00	00	00	00	00	00

Appendix 12: Total coliform at various units of MWTP during the study period.

Month	Total coliform (CFU/100 mL) After sedimentation				Total coliform (CFU/100 mL)) Clarifier outlet				Total coliform (CFU/100 mL) Filter outlet			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20					110	140	123.33	10.80	20	45	31.33	9.52
Jan-21	218	320	269.67	49.91	80	125	104.17	18.28	20	35	26.5	5.24
Feb-21	165	285	226.67	58.71	55	95	73.33	15.71	12	25	18.67	4.72
Mar-21	110	130	120.83	8.01	35	50	41.67	6.06	5	12	8.17	2.57
Apr-21	110	125	119.17	5.85	35	50	40.83	5.85	6	12	9.67	2.33
May-21	105	180	142.5	32.98	25	55	41.67	10.80	5	15	8	3.79
June-21	165	235	200	31.78	60	80	70	7.75	10	15	12.33	2.07
July-21	85	130	107.5	19.69	30	45	36.67	6.06	7	18	12.17	3.71
Aug-21	110	130	121.67	6.83	35	55	46.67	8.16	7	16	9.83	3.25
Oct-21	260	280	270	7.07	60	90	76.67	10.80	15	30	21.67	5.32

Appendix 13: Fecal coliform of raw water and treated water of MWTP during the study period.

Raw water fecal coliform (CFU/100 mL)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	80	90	85	5	40	50	45	5	65	22.36
Jan-21	65	75	70	5	30	40	35	5	52.5	19.69
Feb-21	45	55	50	5	35	50	43.33	7.64	46.67	6.83
Mar-21	20	35	28.33	7.64	20	35	26.67	7.64	27.5	6.89
Apr-21	25	40	33.33	7.64	30	45	36.67	7.64	35	7.07
May-21	20	35	26.67	7.64	35	45	40	5	33.33	9.31
June-21	25	40	31.67	7.64	40	55	46.67	7.64	39.17	10.68
July-21	20	30	25	5	30	40	35	5	30	7.07
Aug-21	55	70	61.67	7.64	35	50	43.33	7.64	52.5	12.14
Oct-21	65	75	70	5	60	75	66.67	7.64	68.33	6.06
Treated water fecal coliform (CFU/100 mL)										
Month	High tide				Low tide				Monthly Mean	SD
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD		
Dec-20	00	00	00	00	00	00	00	00	00	00
Jan-21	00	00	00	00	00	00	00	00	00	00
Feb-21	00	00	00	00	00	00	00	00	00	00
Mar-21	00	00	00	00	00	00	00	00	00	00
Apr-21	00	00	00	00	00	00	00	00	00	00
May-21	00	00	00	00	00	00	00	00	00	00
June-21	00	00	00	00	00	00	00	00	00	00
July-21	00	00	00	00	00	00	00	00	00	00
Aug-21	00	00	00	00	00	00	00	00	00	00
Oct-21	00	00	00	00	00	00	00	00	00	00

Appendix 14: Fecal coliform at various units of MWTP during the study period.

Month	Fecal coliform (CFU/100 mL) After sedimentation				Fecal coliform (CFU/100 mL) Clarifier outlet				Fecal coliform (CFU/100 mL) Filter outlet			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20					10	25	15.83	6.15	4	8	6.17	1.60
Jan-21	22	50	33.33	12.01	7	18	12	4.15	3	7	5	1.41
Feb-21	20	30	25	3.69	6	16	11.17	4.49	3	8	5	1.79
Mar-21	8	18	12.17	3.49	4	15	8.83	4.40	1	5	3.17	1.47
Apr-21	10	25	15.67	5.32	2	8	5.5	2.35	0	5	2.17	1.72
May-21	9	25	14.83	5.98	2	12	6.83	3.37	0	3	1.5	1.22
June-21	15	25	19.67	3.50	4	9	6	1.90	1	4	2.17	1.17
July-21	12	28	19	6.20	2	10	6	2.76	0	3	1.33	1.03
Aug-21	25	45	33	7.32	6	14	9.5	3.08	2	5	3.17	1.17
Oct-21	30	45	35.5	5.61	10	18	13.83	2.99	2	6	3.67	1.63

Appendix 15: TDS of raw water and treated water of MWTP during the study period.

Month	Raw water TDS (mg/L)				Treated water TDS (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	46	203	124	84.72	51	106	78.33	28.87
Jan-21	61	313	186.67	136.57	36	158	96.83	65.55
Feb-21	51	235	143.17	99.15	34	126	80.17	48.77
Mar-21	46	412	229	199.37	32	266	148.33	127.44
Apr-21	36	135	85.17	52.78	30	84	56.67	27.43
May-21	84	2327	1205	1225.81	53	1485	767.67	783.25
June-21	41	158	99.83	62.28	33	87	59.67	28.14
July-21	38	45	41.83	2.99	32	35	33.33	1.21
Aug-21	35	45	39.83	4.35	34	47	40.83	5.78
Oct-21	39	48	43	3.46	40	54	47.5	5.61

Appendix 16: EC of raw water and treated water of MWTP during the study period.

Month	Raw water EC (μS/cm)				Treated water EC (μS/cm)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	93	402	247.67	168.33	102	214	157.5	59.72
Jan-21	123	620	370.83	270.03	74	315	194.67	131.09
Feb-21	103	473	288.167	200.66	71	253	162	98.59
Mar-21	94	825	459.33	398.75	61	455	257.67	213.26
Apr-21	76	271	173.67	105.53	55	148	101.67	49.31
May-21	172	4648	2409.33	2449.05	112	2537	1323.33	1325.49
June-21	83	321	202.33	128.54	65	176	120.5	60.43
July-21	75	92	83.83	8.30	63	67	65.5	1.512
Aug-21	8	92	69.67	31.20	70	93	81.17	11.57
Oct-21	80	97	88.5	7.97	80	106	92.83	13.01

Appendix 17: Temperature of raw water and treated water of MWTP during the study period.

Month	Raw water temperature (^0C)				Treated water temperature (^0C)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	20.3	21.9	21.12	0.76	22.5	23.6	23.03	0.52
Jan-21	21.6	22.4	22.02	0.33	24.5	24.6	24.57	0.05
Feb-21	22.8	23.6	23.2	0.40	25.1	25.5	25.283	0.17
Mar-21	25.5	25.9	25.68	0.15	26.8	26.9	26.85	0.05
Apr-21	25.7	26.3	26	0.27	26.8	27.6	27.18	0.39
May-21	26.3	26.6	26.45	0.10	27.3	27.5	27.4	0.09
June-21	24.2	24.7	24.47	0.23	25.1	25.3	25.22	0.08
July-21	24.1	24.7	24.4	0.30	25.1	25.8	25.48	0.32
Aug-21	25.7	26.6	26.15	0.42	25.3	25.8	25.53	0.23
Oct-21	25.1	25.7	25.4	0.26	25.2	25.5	25.37	0.12

Appendix 18: pH of raw water and treated water of MWTP during the study period.

Month	Raw water pH				Treated water pH			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	7.05	7.24	7.15	0.09	6.87	6.98	6.93	0.05
Jan-21	7.12	7.18	7.15	0.02	6.9	6.97	6.94	0.02
Feb-21	7.12	7.23	7.17	0.05	6.89	7.02	6.955	0.06
Mar-21	7.12	7.18	7.15	0.02	6.92	6.98	6.95	0.02
Apr-21	7.06	7.15	7.10	0.03	6.9	6.93	6.915	0.01
May-21	7.11	7.21	7.16	0.04	6.93	6.96	6.94	0.01
June-21	6.85	6.96	6.91	0.05	6.88	6.93	6.90	0.02
July-21	6.68	6.79	6.73	0.05	6.83	6.89	6.86	0.02
Aug-21	6.8	6.97	6.89	0.08	6.9	7.03	6.97	0.05
Oct-21	6.96	7.06	7.00	0.04	6.89	6.93	6.91	0.01

Appendix 19: Total hardness of raw water and treated water of MWTP during the study period.

Month	Raw water total hardness (mg/L)				Treated water total hardness (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	45	52	48	3.03	40	46	43.17	2.48
Jan-21	44	52	48.17	3.60	38	42	40.67	1.51
Feb-21	46	48	46.67	1.04	38	41	39.83	0.98
Mar-21	44	46	44.67	0.82	34	38	35.83	1.72
Apr-21	42	46	43.83	1.60	36	38	37.17	0.75
May-21	45	52	48.17	2.86	36	45	40.17	4.26
June-21	44	48	46.17	1.60	35	43	39	3.74
July-21	35	39	36.83	1.72	31	33	32	0.63
Aug-21	35	38	36.67	1.21	34	36	35.17	0.75
Oct-21	34	36	34.83	0.75	30	32	30.67	0.82

Appendix 20: Ca-hardness of raw water and treated water of MWTP during the study period.

Month	Raw water Ca-hardness (mg/L)				Treated water Ca-hardness (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	16	28	22.5	5.72	15	26	20.5	5.32
Jan-21	26	32	29.33	2.42	22	26	24	1.67
Feb-21	25	28	26.5	1.22	18	25	21	3.03
Mar-21	25	26	25.67	0.52	16	20	18	1.79
Apr-21	22	25	23.5	1.38	15	18	16.67	1.21
May-21	20	26	23.17	2.48	15	17	16.17	0.75
June-21	13	16	14.33	1.21	10	12	11	0.89
July-21	12	15	13.5	1.38	10	12	10.83	0.75
Aug-21	14	16	15	0.89	12	15	13.67	1.21
Oct-21	12	15	13.33	1.03	10	11	10.5	0.55

Appendix 21: Nitrate of raw water and treated water of MWTP during the study period.

Month	Raw water nitrate (mg/L)				Treated water nitrate (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	1.3	1.9	1.67	0.28	0.32	0.43	0.37	0.05
Jan-21	1.2	1.6	1.42	0.17	0.23	0.35	0.29	0.06
Feb-21	1.1	1.8	1.45	0.35	0.4	0.48	0.44	0.03
Mar-21	1.3	3.2	2.23	0.99	0.45	0.87	0.66	0.20
Apr-21	1.2	1.8	1.48	0.28	0.47	0.53	0.495	0.02
May-21	1.3	2.2	1.75	0.39	0.46	0.58	0.55	0.04
June-21	1	1.8	1.38	0.39	0.41	0.52	0.465	0.05
July-21	1.7	4.2	2.97	1.32	0.5	1.01	0.75	0.25
Aug-21	2.5	3.2	2.83	0.33	0.85	0.89	0.87	0.01
Oct-21	2.5	3.2	2.83	0.33	0.85	0.99	0.925	0.06

Appendix 22: Fluoride of raw water and treated water of MWTP during the study period.

Month	Raw water fluoride (mg/L)				Treated water fluoride (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	0.18	0.24	0.21	0.03	0.08	0.11	0.09	0.01
Jan-21	0.15	0.34	0.24	0.09	0.06	0.11	0.08	0.02
Feb-21	0.14	0.37	0.25	0.12	0.02	0.09	0.05	0.03
Mar-21	0.14	0.38	0.26	0.12	0.04	0.09	0.07	0.02
Apr-21	0.13	0.28	0.205	0.08	0.03	0.06	0.04	0.01
May-21	0.15	1.4	0.73	0.63	0.04	0.18	0.11	0.06
June-21	0.35	1.3	0.80	0.48	0.08	0.28	0.18	0.10
July-21	0.24	0.32	0.28	0.04	0.07	0.1	0.09	0.01
Aug-21	0.22	0.32	0.27	0.05	0.14	0.17	0.16	0.01
Oct-21	0.2	0.26	0.235	0.0	0.14	0.18	0.16	0.01

Appendix 23: Sulphate of raw water and treated water of MWTP during the study period.

Month	Raw water sulphate (mg/L)				Treated water sulphate (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	12	18	14.67	2.50	18	22	19.33	1.63
Jan-21	11	14	12.67	1.21	16	20	17.33	1.51
Feb-21	10	18	14.17	3.54	18	23	20.17	2.14
Mar-21	14	26	20	5.55	17	29	23	5.55
Apr-21	16	23	19.5	2.88	20	28	23.5	2.81
May-21	18	30	23.83	6.08	22	36	29	6.63
June-21	22	32	27	4.47	26	36	30.83	4.67
July-21	18	24	20.67	2.34	22	27	24.5	1.87
Aug-21	14	16	15.17	0.75	19	24	21.17	1.72
Oct-21	13	17	14.83	1.60	17	23	20	2.37

Appendix 24: Phosphate of raw water and treated water of MWTP during the study period.

Month	Raw water phosphate (mg/L)				Treated water phosphate (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	0.12	0.18	0.15	0.03	0.02	0.05	0.04	0.01
Jan-21	0.14	0.19	0.165	0.02	0.03	0.04	0.04	0.01
Feb-21	0.11	0.17	0.14	0.02	0.03	0.05	0.04	0.01
Mar-21	0.12	0.16	0.14	0.02	0.02	0.06	0.04	0.02
Apr-21	0.1	0.15	0.13	0.02	0.02	0.04	0.03	0.01
May-21	0.15	0.29	0.22	0.07	0.03	0.08	0.05	0.02
June-21	0.11	0.25	0.18	0.07	0.03	0.06	0.05	0.01
July-21	0.17	0.44	0.31	0.14	0.05	0.11	0.08	0.02
Aug-21	0.26	0.48	0.37	0.10	0.07	0.11	0.09	0.02
Oct-21	0.18	0.23	0.205	0.02	0.07	0.09	0.08	0.01

Appendix 25: Fe of raw water and treated water of MWTP during the study period.

Month	Raw water Fe (mg/L)				Treated water Fe (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	0.21	0.25	0.27	0.02	0.04	0.06	0.05	0.01
Jan-21	0.1	0.13	0.12	0.01	0.04	0.06	0.05	0.01
Feb-21	0.12	0.14	0.13	0.01	0.05	0.06	0.06	0.01
Mar-21	0.1	0.13	0.12	0.01	0.05	0.06	0.06	0.01
Apr-21	0.12	0.15	0.14	0.01	0.04	0.07	0.06	0.01
May-21	0.12	0.19	0.15	0.03	0.04	0.07	0.06	0.01
June-21	0.14	1.1	0.61	0.51	0.06	0.18	0.12	0.06
July-21	0.41	1.08	0.73	0.34	0.05	0.18	0.12	0.07
Aug-21	0.56	1.1	0.83	0.28	0.09	0.14	0.12	0.02
Oct-21	0.13	0.17	0.15	0.01	0.05	0.07	0.06	0.01

Appendix 26: Zn of raw water and treated water of MWTP during the study period.

Month	Raw water Zn (mg/L)				Treated water Zn (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	0.15	0.18	0.16	0.01	0.03	0.08	0.05	0.02
Jan-21	0.13	0.18	0.16	0.02	0.02	0.04	0.03	0.01
Feb-21	0.12	0.22	0.17	0.05	0.02	0.06	0.04	0.02
Mar-21	0.11	0.13	0.12	0.01	0.04	0.06	0.05	0.01
Apr-21	0.13	0.15	0.14	0.01	0.04	0.06	0.05	0.01
May-21	0.12	0.18	0.15	0.02	0.04	0.06	0.05	0.01
June-21	0.21	0.27	0.24	0.03	0.07	0.09	0.08	0.01
July-21	0.14	0.19	0.17	0.02	0.03	0.05	0.04	0.01
Aug-21	0.13	0.17	0.15	0.01	0.02	0.04	0.03	0.01
Oct-21	0.1	0.15	0.12	0.02	0.03	0.05	0.04	0.01

Appendix 27: Cu of raw water and treated water of MWTP during the study period.

Month	Raw water Cu (mg/L)				Treated water Cu (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	0.1	0.15	0.13	0.02	0.02	0.04	0.03	0.01
Jan-21	0.11	0.17	0.14	0.03	0.02	0.04	0.03	0.01
Feb-21	0.16	0.24	0.2	0.03	0.02	0.06	0.04	0.01
Mar-21	0.2	0.23	0.21	0.01	0.03	0.05	0.04	0.01
Apr-21	0.14	0.25	0.20	0.05	0.03	0.05	0.04	0.01
May-21	0.13	0.32	0.22	0.10	0.02	0.06	0.04	0.02
June-21	0.13	0.18	0.15	0.02	0.04	0.06	0.05	0.01
July-21	0.12	0.16	0.14	0.02	0.02	0.04	0.03	0.01
Aug-21	0.15	0.19	0.17	0.02	0.03	0.06	0.04	0.01
Oct-21	0.12	0.18	0.15	0.02	0.04	0.06	0.05	0.01

Appendix 28: Mn of raw water and treated water of MWTP during the study period.

Month	Raw water Mn (mg/L)				Treated water Mn (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	0.1	0.12	0.11	0.01	0.02	0.03	0.02	0.01
Jan-21	0.1	0.12	0.11	0.01	0.01	0.03	0.02	0.01
Feb-21	0.08	0.09	0.09	0.01	0.01	0.03	0.02	0.01
Mar-21	0.06	0.11	0.09	0.02	0.01	0.03	0.02	0.01
Apr-21	0.07	0.09	0.08	0.01	0.01	0.02	0.01	0.01
May-21	0.07	0.14	0.11	0.03	0.01	0.03	0.02	0.01
June-21	0.1	0.15	0.12	0.02	0.02	0.04	0.03	0.01
July-21	0.12	0.14	0.13	0.01	0.02	0.04	0.03	0.01
Aug-21	0.1	0.13	0.12	0.01	0.01	0.02	0.02	0.01
Oct-21	0.1	0.13	0.11	0.01	0.03	0.04	0.035	0.01

Appendix 29: DO of raw water and treated water of MWTP during the study period.

Month	Raw water DO (mg/L)				Treated water DO (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	7.3	7.95	7.72	0.23	7.3	8.04	7.72	0.33
Jan-21	7.4	7.92	7.64	0.20	7.85	8.78	8.05	0.36
Feb-21	7.3	7.78	7.56	0.19	7.9	8.05	7.96	0.06
Mar-21	7.42	7.62	7.56	0.07	7.86	8.35	8.11	0.23
Apr-21	7.3	7.58	7.45	0.12	7.81	8.35	8.07	0.25
May-21	6.1	7.65	6.94	0.75	6.78	7.91	7.35	0.60
June-21	6.6	6.82	6.73	0.08	7.23	7.42	7.32	0.07
July-21	6.23	6.54	6.40	0.13	7.11	7.21	7.17	0.04
Aug-21	6.7	7.27	6.97	0.25	7.18	7.72	7.47	0.26
Oct-21	6.4	7.26	6.83	0.39	7.15	7.68	7.41	0.25

Appendix 30: BOD of raw water and treated water of MWTP during the study period.

Month	Raw water BOD (mg/L)				Treated water BOD (mg/L)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Dec-20	1.14	1.38	1.25	0.11	0.1	0.15	0.13	0.02
Jan-21	1.12	1.47	1.30	0.17	0.08	0.11	0.10	0.01
Feb-21	1.15	1.55	1.35	0.20	0.08	0.12	0.10	0.01
Mar-21	1.12	1.19	1.15	0.03	0.09	0.13	0.11	0.01
Apr-21	1.13	1.18	1.16	0.02	0.1	0.14	0.12	0.01
May-21	1.12	1.26	1.19	0.05	0.1	0.16	0.13	0.02
June-21	1.15	1.24	1.19	0.03	0.09	0.12	0.105	0.01
July-21	1.14	1.28	1.21	0.06	0.08	0.11	0.09	0.01
Aug-21	1.13	1.24	1.18	0.04	0.09	0.13	0.11	0.01
Oct-21	1.21	1.32	1.26	0.04	0.11	0.14	0.11	0.01