QUALITATIVE ASSESSMENT OF JAR AND BOTTLED WATER AVAILABLE IN CHATTOGRAM CITY CORPORATION AREA FOR DRINKING PURPOSE

By

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A thesis submitted in partial fulfillment of the requirements for the degree of

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Declaration

I hereby declare that the work contained in this Thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the Thesis contains no material previously published or written by another person except where due reference is cited. Furthermore, the Thesis complies with PLAGIARISM and ACADEMIC INTEGRITY regulation of CUET.

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Abstract

Most of the common diseases observed in developing countries are due to drinking contaminated water. Clean and safe drinking water is essential for human life. It is generally considered that bottled and jar water is safe for human consumption. The present study was conducted to know whether the bottled and jar water sold in the Chattogram City Corporation area is safe for public health. To fulfil the objective, twenty (20) drinking jar water samples were collected from ten different populated spots, which are supplied by the local small water purification plants. Samples of ten (10) different brands of bottled water were also collected from the retail grocery store. Some physico-chemical properties, like pH, total dissolved solid (TDS), electrical conductivity (EC) and the concentration of seven heavy metals (Cd, Cr, Cu, Fe, Mn, Pb and Zn), were determined. Microbial content including total bacteria count (TBC) and total coliform count (TCC) were also evaluated. The pH value of jar and bottled water samples were within the WHO, EC, USEPA, BSTI and BIS acceptable limits. The TDS values were found to be very low in most samples, proving that the supplied drinking water did not conform to the taste standards. Only two jar water samples exceeded the electrical conductivity limit. This result confirms that the tested samples contain the required minerals for drinking water. The average TDS and EC values of jar water samples were higher than those of bottled water, which indicates lower mineral content in bottled water. To assess the heavy metal content in drinking water, seven heavy metals in tested bottle and jar water samples were investigated. Among all seven heavy metals, only copper (Cu) was detected in all jar and bottled water samples which was below the WHO, EC, USEPA, BSTI and BIS recommended value. The heavy metal, manganese (Mn) was detected in three jar water samples, while iron (Fe) was found only in one, which were much below the acceptable limit recommended by WHO, EC, USEPA, BSTI and BIS. In the context of microbial contamination, 40% of total jar water samples and 33.3% of bottled water samples were found contaminated by pathogenic micro-organisms in terms of total bacteria count, while no coliform bacteria were detected in any tested sample. This microbial data is giving us a worrying signal about drinking jars and bottled water marketed in Chattogram city.

বিমুর্ত

উন্নয়নশীল দেশগুলোতে অধিকাংশ প্রচলিত কারণ হলো দূষিত পানি পান। মানব জীবনের জন্য পরিস্কার এবং নরিাপদ পানি প্রয়োজন। এটি সাধারণত ধওে নেয়া হয় যে, বোতলজাত পানি মানুষের পানের জন্য নিরাপদ। চট্টগ্রাম সিটি কর্পোরেশন এলাকায় যেসকল বোতলজাত পানি বিক্রয় করা হয় সেগুলো জনস্বাস্থ্যের জন্য নিরাপদ কিনা জানতে বর্তমান গরেষণাকার্যটি পরচালনা করা হয়েছে। গরেষণাকার্যটির উদ্দেশ্য পূরণের জন্য নগরের দশটি জনবহুল এলাকা থেকে জারে রক্ষিত পানির ৩০টি নমুনা সংগ্রহ করা হয়েছিল, যেগুলি স্থানীয়ভাবে ক্ষুদ্র পানি বিশুদ্ধকরণ প্লান্ট থেকে সরবরাহ করা হয়ে থাকে। এছাড়াও খুচরা মুদি দোকান থেকে ১০টি ভিন্ন ব্র্যান্ডের বোতলজাত পানির নমুনা সংগ্রহ করা হয়েছিল। পানির নমুনাসমূহের কিছু ভৌত-রাসায়নিক ধর্ম, যেমন pH, মোট দ্রবীভূত কঠিন পদার্থ (TDS), তড়িৎ পরিবাহিতা (EC), সাতটি ভারী ধাতুর (Cd, Cr, Cu, Fe, Mn, Pb এবং Zn) পরিমান নির্নয় করা হয়েছিল। তাছাড়াও নমুনাতে মোট ব্যাকটেরিয়া সংখ্যা (TBC), মোট কলিফর্ম সংখ্যা (TCC) নির্নয় করা হয়েছিল। সকল নমুনার pH মান WHO, EC, USEPA, BSTI এবং BIS কর্তৃক নির্ধারিত সীমার মধ্যেই ছিলো। অধিকাংশ নমুনার TDS মান ছিলো খুব কম, যা পানির পর্যাপ্ত স্বাদ নিশ্চিত করেনা। শুধুমাত্র দু'টি জার পানির নমুনার তড়িৎ পরিবাহিতা গ্রহনযোগ্য সীমার চেয়ে বেশী ছিলো, যা এ নমুনা দু'টিতে পর্যাপ্ত পরিমান মিনারেল এর উপস্থিতি নিশ্চিত করে। জারে রক্ষিত পানির নমুনায় ঞউঝ এবং উঈ এর গড় মান বোতলজাত পানির ঞউঝ এবং উঈ এর গড় মান এর তুলনায় বেশী পাওয়া গেছে, যা বাতলজাত পানিতে কম পরিমান মনিারেল এর উপস্থিতি নির্দেশ করে। বোতলজাত পানিতে যে সাতটি ধাতুর উপস্থিতি পরিমাপ করা হয়েছিলো তার মধ্যে শুধু কপারের (Cu) উপস্থিতি সকল নমুনায় শনাক্ত হয়েছিলো। সকল নমুনায় Cu এর ঘনত্ব পানীয় জলের জন্য WHO, EC, USEPA, BSTI এবং BIS কর্তৃক নির্দেশিত সীমার মধ্যে ছিলো। জারে রক্ষিত পানির দু'টি নমুনায় লৌহ (Fe) এবং শুধুমাত্র একটি নমুনায় ম্যাঙ্গানিজ (Mn) শনাক্ত হয়েছিলো, যা WHO, EC, USEPA, BSTI এবং BIS কর্তৃক গ্রহণযোগ্য ঘনত্বের চেয়ে অনেক অনেক কম। পরীক্ষণে প্রাপ্ত নমুনাসমূহে মোট ব্যাকটেরিয়া সংখ্যা বিবেচনায় জারে রক্ষিত পানির মোট নমুনার ৪০% এবং বোতলজাত পানির মোট নমুনার ৩৩% রোগ সৃষ্টিকারী অনুজীব (pathogenic micro-organism) দ্বারা দূষিত, যদিও কোনো নমুনাতেই কলিফর্ম ব্যাকটেরিয়া শনাক্ত হয়নি। রোগ সৃষ্টিকারী অনুজীব সংক্রান্ত এ ফলাফল চট্টগ্রাম শহরে বাজারজাতকৃত বোতলজাত পানি নির্দ্বিধায় পানের বিষয়ে একটি শতর্কবার্তা প্রদান করছে।

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List of Abbreviations

AAS	Atomic Absorption Spectrometry
AERE	Atomic Energy Research Establishment
APHA	American Public Health Association
BDL	Below Detection Limit
BIS	Bureau of Indian Standards
BSTI	Bangladesh Standards and Testing Institution
CSD	Carbonated Soft Drink
DI	Deionized water
DO	Dissolved Oxygen
DoE	Department of Environment , Bangladesh
EC	Electrical Conductivity
EC	European Community
EPA	Environmental Protection Agency
EU	European Union Commission
FAAS	Flame Atomic Absorption Spectrophotometer
FC	Fecal Coliforms
GSB	Ghana Standard Board
GVs	Guideline Values
HPC	Heterotrophic Plate Count
HPI	Heavy Metal Pollution Index
IFRB	Institute of food and Radiation Biology
MCA	MacConkey Agar
NA	Nutrient Agar
NDWQS	National Drinking Water Quality Standard
NPI	Nemerow’s Pollution Index
PM	Pico Meter
PVC.HD	Polyvinyl Chloride High Density
PVC.LD	Polyvinyl Chloride Low Density
SASO	Saudi Arabian Standards Organizations
SD	Standard Deviation
SMCL	Secondary maximum Contaminant Level

SON	Standard Organization of Nigeria
SPC	Standard Plate Count
SSMO	Sudanese Standard Metrology Organization
TBC	Total Bacterial Count
TC	Total Coliforms
TCC	Total Coliform Count
TDS	Total Dissolved Solids
TVC	Total Viable Count
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

Chapter 1: INTRODUCTION

1.1 General

The present situation and problems associated with bottled and jar drinking water are discussed below.

1.2 Importance of Drinking Water

In addition to being an important nutrient, water is a fundamental component of the human body. We have the ability to go without food for up to several weeks, but we can only go a few days without water. Water is essential for the proper functioning of every system in the body, from the cells and tissues to the major organs. Water is responsible for transporting nutrients to all of the cells in our body as well as oxygen to the brain. When there is sufficient water in the body, a wide array of nutrients, including glucose, amino acids, vitamins, and minerals, can be absorbed and utilized by the body. Water helps the body eliminate waste and poisons, and it also assists in temperature regulation. The joints and muscles can both benefit from the lubrication provided by water.

1.3 Water Sources and Problems

Sources

The main sources of water in Bangladesh are surface water, ground water and rainwater.

Problems

Pollutants in surface waters come from a variety of sources, including agriculture, industry, households, and municipalities. The lack of proper management of home and industrial waste water is directly responsible for the deterioration of water quality, which in turn is directly tied to population density and industrial operations. Both urban and rural parts of Bangladesh rely heavily on groundwater as their primary supply of drinking water. The following factors have contributed to the creation of a problematic situation regarding the accessibility of ground water for human consumption:

i) Arsenic in ground water.

ii) Excessive dissolved iron.

iii) Salinity in the shallow aquifers in the coastal areas.

iv) Lowering ground water level.

v) Rock/stony layers in hilly areas.

The main problems with harvesting rainwater are that it is easy to get water from the surface or the ground, and people don't take the time or care to do it. Bangladesh also has a lot of problems with water storage and keeping the quality of the water from a bacteriological point of view. For surface water, underground, and rainwater to be used for drinking, it has to be cleaned and made safe through a long process.

1.4 Bottled and Jar Drinking Water

The term "bottled water" refers to water that is assumed to be treated, packaged, and then marketed in jars or simply bottles. Bottled water can also be referred to as packaged water. "Bottled water is a great beverage choice for hydration and refreshment because of its consistent safety, quality, good taste, and convenience," as stated by the International Bottled Water Association (IBWA). The origin of the water as well as the degree to which it has been purified can determine the type of bottled water that is purchased. For example, there is artesian well water, mineral water, distilled water, refined water, sparkling water, well water, and so on. There are nine different bottle capacities that can be purchased in Bangladesh. These capacities are 250 mL, 500 mL, 1 litre, 1.25 litres, 1.5 litres, 2.0 litres, 3.0 litres, 5.0 litres, and 6.0 litres. As a form of drinking water, filtered drinking jar water is distributed commercially to establishments such as restaurants, cafeterias, hospitals and clinics, educational institutions, diagnostic centres, residential areas, and almost all enterprises and workplaces. Suppliers offer a 25-litre drinking water jar pack. Considering the importance as drinking water to the people of Chattogram city bottled and jar water were chosen to check their quality in terms of physico-chemical, heavy metals content and microbial point of view’s.

1.5 Water Consumption Per Person Per Day in Bangladesh

It was determined that the daily per capita water consumption in Bangladesh for drinking purposes was 73.04 mL/kg/d, which is greater than the daily per capita water consumption in both the United States and Taiwan (Milton *et al*., 2006). According to the research that was carried out by Ahmed *et al*. (1987), the average daily usage of water for drinking, cooking (including cleaning dishes and utensils), bathing (including washing clothing), sanitation, and other uses was two litres, nine litres, twenty litres, and eight litres, respectively.

1.6 Small Bottled Water Plant in Bangladesh

The daily operations of a modest bottled water industry in Bangladesh are contributing to the country's expanding economy. In order for specialists in the water treatment industry to supply their clients with a new service that is seeing growing need. Typical flow chart of the small bottled water plant is shown in Figure 1.1.

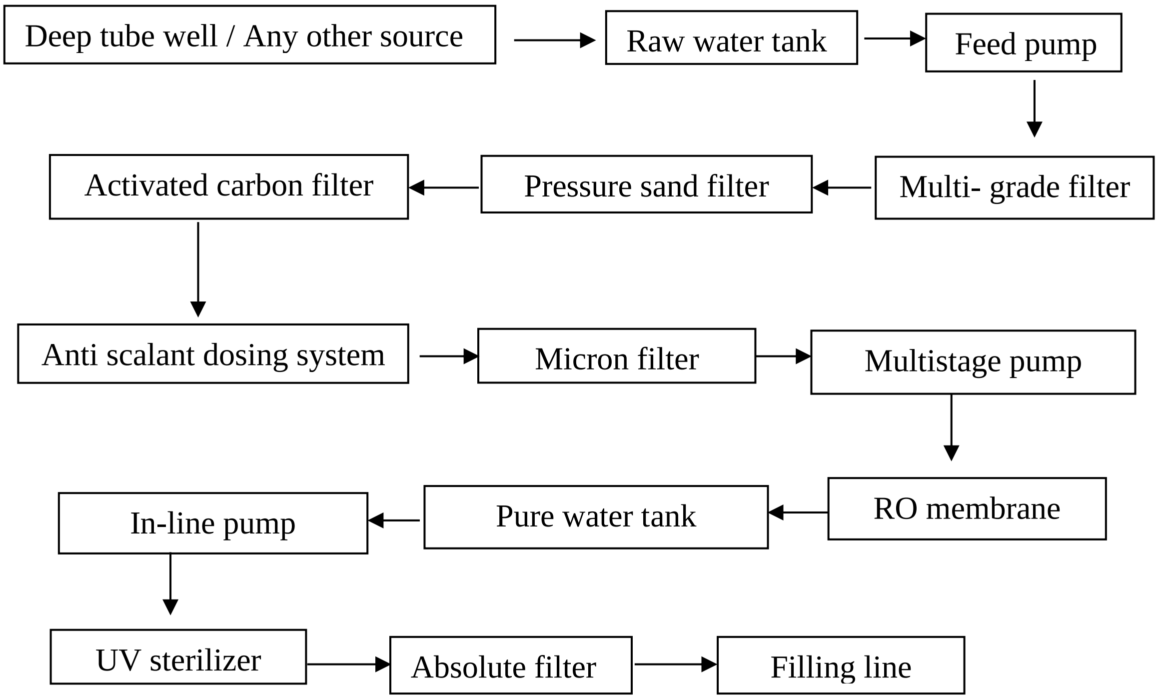

Fig. 1.1 Typical flow chart of a bottled water plant

1.7 Benefits of Bottled and Jar Drinking Water

i) Taste of bottled and jar drinking water: Bottled and jar drinking water taste is much better and far tastier.

ii) Safety: Purified bottled and jar drinking water, is safe from being contaminated.

iii) Suitability of bottled water: Bottled water is very convenient and safe, for carrying with someone.

iv) On emergencies: Bottled and jar drinking water meet the emergency need if there is a problem with the water supply for whatever reasons.

1.8 Disadvantages of Bottled and Jar Drinking Water

Due to the complexity of the filtering and disinfection methods used to produce bottled water, bacteria and viruses are still present. The majority of bottlers do not adhere to BSTI guidelines. Bottled or canned water rarely contains the right balance of minerals. Many companies were found led by the BSTI's mobile court for providing water containers without permission.

1.9 Demand for Bottled and Jar Drinking Water at Chattogram and Bangladesh

The city of Chattogram has around 2.7 million populations. It is the biggest industrial city in Bangladesh. After undergoing the necessary purification processes, the water that is withdrawn from the Halda and Karnaphuli Rivers in Bangladesh is distributed across the city of Chattogram by the Chattogram Water Supply and Sewerage Authority (CWASA), a government agency located in Bangladesh. However, the fundamental issue is that there is not enough awareness or regular monitoring of the water distribution system. This leads to contamination of the supply water. According to Zuthi *et al*. (2009), this city with a high population density has been dealing with a range of problems that are related to water, one of which is an inadequate supply of drinking water. The residents of Chattogram city are growing more and more reliant on the bottled and canned drinking water that is supplied by private businesses daily. Therefore, the experts have begun focusing their attention on the quality of the water that is suitable for consumption.

1.10 Aims and Objectives

1.10.1 Main Objectives

The objective of this study is to assess the pathogenic microbes and heavy metals content in bottled and jar drinking water marketed in the Chattogram City Corporation (CCC) area.

1.10.2 Specific Objectives

1. To analyze the physico-chemical parameters of the bottled and jar drinking water.
2. To determine the quantity of heavy metals in the bottled and jar drinking water and assess their quality in terms of heavy metal contamination.
3. To determine the presence of pathogenic microbes in bottled and jar drinking water samples in the Chattogram City Corporation (CCC) area.

1.11 Significance of this Study

Chattogram is the second largest city in Bangladesh with the population around 2.7 million. In Chattogram, the demand of drinking water is increasing like other cities of Bangladesh with the increasing of population and awareness about the drinking of pure water. Besides this, thousands of people from neighboring areas and other parts of Bangladesh visit this city everyday due to different purposes. To fulfill the huge demand of safe drinking water different companies are marketing mineral water in bottles or jars. Considering the health issue of the resident and visiting people of Chattogram city corporation area bottled and jar drinking water were chosen to assess their quality in this study. This study will provide an idea to the consumers whether the bottled and jar water are safe or injurious to their health. The findings of this study will also help the concerned authorities in preparing their strategies**.**

1.12 Flow Chart of the Present Research

The whole working procedure of the present research is precisely presented in the following flow chart (Figure 1.2).

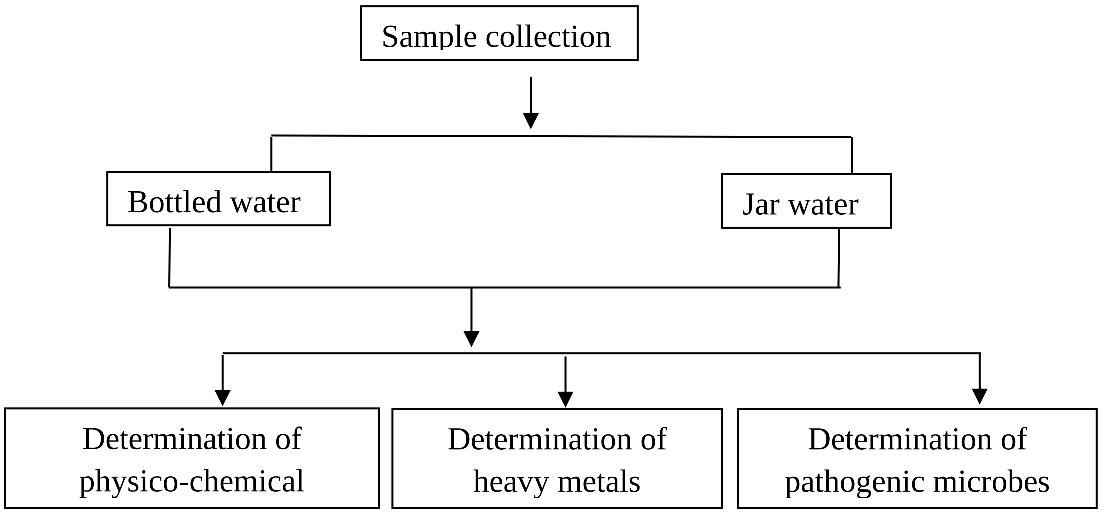

Fig. 1.2 Flow chart of the present research

1.13 Organization of the Thesis

This thesis consists of five chapters. Chapter 1 gives a general introduction to the background, aim and objectives, and the structure of the thesis. Chapter 2 includes a extensive literature review related to the objectives. Chapter 3 summarizes the general methodologies applied in the thesis, while Chapter 4 describes the research outcomes focusing research objectives. The major findings of this thesis and recommendations for future study are summed up in Chapter 5.

Chapter 2: LITERATURE REVIEW

2.1 Background

Evaluation of heavy metals and microbial contamination in drinking water is very important for ensuring that people in any part of the world live healthy lives. This applies to all regions of the world. Due to the reliability of its safety, quality, flavour, and taste, as well as its convenience, the consumption of bottled and jarred water is quickly growing not only in Bangladesh but also around the world. So, the quality parameters of these water have drawn the attention to the researchers. Bangladesh and other countries have contributed to this type of investigation in recent years. Numerous data are available in the literature regarding this matter. Among those, some most closely related results are given below.

2.2 Physico-chemical Parameters

Semarjian and his coworkers analyzed the physico-chemical and bacterial water content of 32 domestic bottled water brands collected from various markets in Lebanon in 2011 (Semerjian *et al*., 2011) and compared the results with the standard of identity restrictions established by the Lebanese Standards Institution in addition to numerous international water standards applicable to bottled waters. According to the findings, the vast majority of brands satisfied the various standards for bottled water's physico-chemical properties, with the exception of pH (four brands), hardness (two brands), and calcium (two brands).

Rahman *et al*. (2012) evaluated the physical and chemical properties of nine types of bottled water to see if they were safe for people to drink. The data were compared to the parameters set by the European Community (EC) and the guidelines set by the World Health Organization (WHO). They found that the hardness, TDS, and conductivity were lower than the standards set by WHO.

Koju *et al*. (2013) conducted a study of the potability of the water supply in the Kathmandu Valley. A total of 969 water samples were examined in order to identify different physical characteristics such as pH, temperature, conductivity, and turbidity. The pH, conductivity, and hardness of groundwater (both well and drilling) are all above WHO recommendations by 5%, 2%, 0.8%, and 36%, respectively. Additionally, turbidity was 36% above WHO recommendations.

The research that was conducted by Das *et al*. (2018) analyzed the physico-chemical characteristics of jar water that was obtained from the Chittagong Metropolitan city in Bangladesh. The Metropolitan area of Chittagong provided the location for the collection of samples from seven distinct highly inhabited locations. The physico-chemical properties of every sample of jar water that was examined were determined to fall within the allowable ranges.

Mina *et al*. (2018) carried out a study in which they took 38 water samples from drinking jars in Chittagong, Bangladesh, to find out if they were contaminated with microbes. All samples had normal levels of TDS and pH.

The physical quality of bottled water sold in high-traffic areas of Mangalore, which is located in the southern Indian state of India, was evaluated by Joseph and colleagues (2018). A total of 24 water bottles representing 12 different brands were chosen at random. The values of the analyzed physico-chemical parameters were below the allowable limits that are approved for drinking. Physico-chemical characteristics were within drinking limits.

The quality of the water delivered by DWASA to areas near Dhaka was studied by Islam *et al*. (2020). Standard procedures from the American Public Health Association (APHA) were used to analyze physico-chemical characteristics. Safe drinking water is indicated by sample readings of pH between 6.58 and 7.03 and dissolved oxygen (DO) between 6.10 and 7.50 mg/L.

Rahmanian *et al*. (2015) analyzed the physical and chemical characteristics of drinking water samples from all throughout the Malaysian state of Perak. Neighborhoods with both homes and businesses were included. pH, turbidity, conductivity, total suspended particles, and total dissolved solids were just some of the measures taken. All observed values were found to be well within the guidelines set forth by the NDWQS and the World Health Organization.

According to the findings of Farhadkhani *et al*. (2014), a total of 64 water samples were examined for temperature, pH, turbidity, and electrical conductivity. During the course of a period of five months in 2012–2013, samples were gathered from water taps and free-standing bottled water coolers in the city of Isfahan, which is located in Iran. According to the findings of the statistical study, the levels of pH, EC, and turbidity in the water did not significantly vary from one another.

A total of 84 samples of bottled water were collected from various locations around the world between January and June of 2012 and then analyzed for ten different physico-chemical parameters, including turbidity, electrical conductivity, total dissolved solids, pH, alkalinity, hardness, calcium, magnesium, nitrate, and sulphate, by Toma *et al*. (2013).

The use of contaminated drinking water exposes the community to a variety of water-borne illnesses, according to Patil *et al*.'s (2012) recommendation that the quality of drinking water be regularly assessed. The quality of the water was assessed during this study using a number of physico-chemical parameters, including colour, temperature, acidity, hardness, pH, sulphate, chloride, DO, BOD, COD, and alkalinity.

Yadav *et al*. (2015) conducted research in the Dhankuta Municipality of Nepal to investigate the physico-chemical characteristics of potable water. This water is used for both drinking and household purposes. The following physico-chemical parameters were measured to determine the quality of the drinking water: pH, alkalinity, TDS, DO, BOD, salinity, turbidity, and heavy metal and anion concentrations. The collected results were compared to the requirements set forth by the WHO and the EPA for both recreational and drinking water.

Research on the physico-chemical properties of the drinking water in the town of Ed-Dueim in Sudan was conducted by Homaida *et al*. (2013). The research was conducted in 2013. They analyzed the water to determine its levels of turbidity, electrical conductivity, pH, temperature, total dissolved solids, chloride, fluoride, calcium, iodine, magnesium, and sulphate. The findings that were obtained showed that all of the values were correct, with the exception of the turbidity, which was determined to be below the maximum limit that was established by the Sudanese Standard Metrology Organization (SSMO) and the WHO guideline standard. The findings that were obtained indicated that all of the values were correct. After conducting tests, it was determined that the water samples in question have adequate levels of both physical and chemical purity; hence, it was determined that the water may be safely consumed.

The physico-chemical characteristics of prominent mineral water brands in a Brazilian city were examined by Gomes *et al*. (2014). These characteristics included pH, conductivity, ionic concentration, and others. The findings were evaluated in light of the constraints imposed by the relevant Brazilian laws. When compared, the chemical compound concentrations that were printed on the labels and those that were detected by the study showed a significant amount of difference.

The physico-chemical properties of bottled and sachet water consumed by people in Ghana's Tarkwa Nsuaem Municipality were analyzed in a 2011 study (Asamoah *et al*.,

2011) that looked at the water's pH, temperature, taste, electrical conductivity, true colour, turbidity, total dissolved solids, total suspended solids, total alkalinity, and total hardness. Except for pH, Ba, and Cl levels, the sample concentrations were well within the ranges recommended by the WHO/Ghana Standard Board (GSB) for safe drinking water. Two samples had pH levels that were below the WHO/GSB threshold for safety. There were instances where the levels of Ba and Cl were too high.

Agboli *et al*. (2017) evaluated certain physical parameters of sachet water, including temperature, colour, odour, hydrogen, pH, and total dissolved solids (TDS), using 36 samples of sachet water sourced from nine different locations where sachet water is manufactured. The mean values for pH were 6.8, while the mean values for conductivity and TDS were 41.7 S/cm and 23.0 mg/L, respectively.

Ibrahim *et al*. (2015) collected and physically tested 23 different water brands, 15 of which were sachet waters and 8 were bottled waters. Their adherence to World Health Organization and Standard Organization of Nigeria (SON) drinking water specifications was determined by analyzing their physico-chemical properties using conventional analytical methods. None of the water brands tested had a visible indicator of their mineral content or batch number, and 20% lacked a clear manufacturing or expiration date, according to the physical examination results. The link between TDS and EC was expressed using an equation with a factor of 0.5 instead of the 0.67 required by the standard. 73.30 percent of the sachets and 25 percent of the bottled water tested in this investigation were found to be unsafe for human consumption.

Mohsin *et al*. (2019) studied the physico-chemical parameters of potable water supplied by government and private companies supplied to Bahawalpur city of India. They also studied the quality of bottled water available and consumed by the people of the city. The bottled water samples showed significant variations and alarmingly three brands were found chemically unfit for drinking purposes.

Atiku *et al*. (2018) used the water quality index (WQI) to evaluate the drinking water quality of a selection of drinking water sources in Abuja, Nigeria, including sachet water. They found that some of the sources had worse drinking water quality than others. When compared to the standards set by the World Health Organization (WHO), the physico-chemical properties of the water sources generally fell within acceptable levels.

A research conducted by Beatriz *et al*. (2021) reported almost zero mineral content in a bottled water sample. The values of electrical conductivity and total dissolved solids (TDS) were found very low in all bottled water samples.

2.3 Heavy Metals Concentrations

Cobbina *et al*. (2015) conducted an investigation into the prevalence of heavy metals in the sources of drinking water in the communities of Nangodi and Tinga, both of which are located in northern Ghana and are home to small-scale mining operations. They made the discovery that the water had mercury, arsenic, lead, zinc, and cadmium levels that were higher than the standards that had been established by the World Health Organization (WHO).

Rahman *et al*. (2012) conducted an investigation of the levels of major and trace elements that were present in nine different brands of bottled water in order to ascertain whether or not these levels were safe for human consumption. Both the parameter values (PVs) defined by the European Community (EC) and the guideline values (GVs) provided by the World Health Organization were used as benchmarks against which the obtained results were evaluated. The majority of the brands that were examined were found to have mineral concentrations that were significantly lower than the thresholds that are advised by the WHO. Heavy metals such as iron, zinc, and nickel were found in every sample that was analyzed. But Cu, Mn and Cr were found in three, two and five samples respectively. In other samples their concentration was found below the detection limit (0.001mg/L). The concentration, detected of these heavy metals were below the upper limit prescribed by WHO and EC. The concentration of Pb and Cd in all samples analyzed were found to be below the detection limit.

According to the findings of Flanagan *et al*. (2012), groundwater is not safe to drink because the risk of arsenic contamination is quite high across the entirety of Bangladesh. As a result of the fact that tube wells represent the primary source of drinking water for around 97% of the entire population residing in rural areas, between 35 and 77 million people have been chronically exposed to arsenic in the first decade of the new century.

Koju *et al*. (2013) conducted an investigation to determine whether or not the water that is used for drinking in the Kathmandu Valley is safe to use. Researchers analyzed a total of 969 water samples in order to determine the amounts of hardness, chloride, iron, arsenic, ammonia, nitrate, and microbial total coliform in the water. Iron, arsenic, chloride, and ammonia levels in ground water (well and bore) exceeded WHO guidelines at levels of 5%, 2%, 0.8%, 51%, 0.1%, 2%, and 11%, respectively.

Raw milk and water samples were collected in the city of Chittagong, Bangladesh, for the purpose of this study by Akther *et al*. (2016), who studied the presence of certain heavy metals such as chromium and zinc. A total of ten distinct farms, each situated in a different region of the country, each contributed a sample. The amounts of chromium and zinc in the water and milk were both significantly lower than the maximum allowable limit.

A study conducted by Das *et al*. (2018) analyzed the levels of heavy metals that were present in jar water that was obtained from the Chittagong Metropolitan city in Bangladesh. The Metropolitan area of Chittagong provided the location for the collection of samples from seven distinct, highly inhabited locations. Only a couple of the samples had a concentration of chromium that was higher than what is allowed, but the other heavy metals' concentrations were well below the acceptable range.

Islam *et al*. (2020) investigated the DWASA-provided water quality in and around Dhaka city. The essential and heavy metal content was evaluated in accordance with the established techniques recommended by the American Public Health Association (APHA). The levels of calcium and magnesium that were discovered were noteworthy. The human body cannot function properly without one of these components. There was no pollution of heavy metals in the water that was supplied by DWASA. According to the findings of this study, the overall level of quality of the potable water supply in Dhaka city ranged from satisfactory to exceptional.

Mina *et al*. (2018) conducted a study in which they collected 38 drinking jar water samples from Chittagong city, Bangladesh, in order to measure the levels of a number of heavy metals including Fe, As, Pb, and Cr. There was no trace of As, Pb, or Cr in any of the water samples that were analyzed; nevertheless, Fe was identified in low concentrations ranging from 0.02–0.05 mg/L.

Heavy metal concentrations in drinking water were investigated by Rahmanian *et al*. (2015), who gathered samples from a wide range of business and residential buildings across the Malaysian state of Perak. The concentrations of many heavy metals were measured and analyzed for both the winter and summer water samples collected. The results were then compared to the criteria set out by the World Health Organization and Malaysia's National Drinking Water Quality Standard (NDWQS). Both the WHO and the NDWQS found the results to be within their recommended safe ranges.

Patil *et al*. (2012) focused a lot of attention on the possibility of chronic poisoning brought on by the presence of heavy metals in water. These heavy metals include lead, cadmium, iron, and mercury, among others. Asamoah *et al*. (2011) found a greater quantity of barium than the WHO/GSB (Ghana Standard Board) threshold limit in bottled, or sachet water made by two firms in Ghana. The content of other heavy metals, such as manganese, cadmium, lead, and antimony, was found to be within the suggested range, however.

Some trace elements, such as lead, arsenic, barium, cadmium, chromium, copper, manganese, molybdenum, nickel, selenium, and zinc were investigated in 20 different brands of bottled water and household water collected from various parts of Riyadh by Nouri *et al*. (2014). The quantities of these trace elements in all of the samples were much below the safe upper limits set by the World Health Organization (WHO) and the Saudi Arabian Standards Organization.

The concentrations of trace metals and the physico-chemical properties of bottled water purchased from various supermarkets in Pretoria were determined by Olowoyo *et al*. (2022). They reported that the concentrations of Cr, Ni and Pb were above the recommended limit by WHO.

2.4 Microbial Quality

Ribeiro *et al*. (2006) investigated the quality of the water derived from a variety of sources throughout Portugal. Within a bottled water firm, the purposes of this study were to investigate the seasonal shifts in the levels of fungal contamination and to use methods from molecular biology to track out the origin of the fungal populations that were responsible for the contamination. He performed twice-monthly tests for the presence of fungal growth in the water from the water tank, the water filter, and the bottled water, and he discovered significant fungal contamination. The genera Penicillium, Cladosporium, and Trichoderma were the most common ones to be isolated, with Aspergillus and Paecilomyces coming in second and third, respectively, in terms of total numbers. He also noticed that there was a rise in the amount of fungus contamination during the warmer months, particularly in May and June.

Prasai *et al*. (2007) collected 132 samples of drinking water from various locations throughout the Kathmandu valley for the purpose of their research. Microbial characteristics were determined based on the samples. According to the total plate count and the coliform count, it was discovered that 82.6% and 92.4% of drinking water samples, respectively, exceeded the WHO guideline threshold for drinking water.

Pandey *et al*. (2012) investigated the standard of Nepal's drinking water throughout the Central Development Region. He examined a total of 243 samples, 130 of which were taken from springs and 113 from groundwater sources. The WHO requirements were exceeded by 20 of the samples of groundwater. In addition to this, he concluded that most of the springs and groundwater sources were significantly contaminated with feces-related coliform bacteria.

Akond *et al*. (2009) examined 225 carbonated soft drink (CSD) samples across nine brands to evaluate their bacteriological quality. The samples were taken at diverse locations in five major cities in Bangladesh. Most samples were found to be in violation of microbial standards set forth by bodies like the World Health Organization (WHO). Their research indicates that the readily available carbonated soft drinks in Bangladesh pose serious health risks to the population.

The microbial quality of commercially available bottled water was studied by Majumder *et al*. (2011) in the Bangladeshi city of Dhaka. They tested nine samples of locally bottled water marketed commercially in Bangladesh for total coliforms (TC) and faecal coliforms (FC). Most of the tested bottled waters were found to be unsafe, according to the data. Because of this, the presence of certain chronic diseases (renal failure, liver cirrhosis, and anemia) in the study area is to be expected, as 68.89% and 31.11% of the bottled water sampled in the current study showed heterotrophic plate counts (HPC) within a range of 1-500 CFU/mL and greater than 500 CFU/mL, respectively.

Semerjian *et al*. (2011) investigated the microbial water quality indicators of 32 local bottled water brands gathered from different markets in Lebanon in 2011. While fecal coliforms did not grow in any of the samples, total coliforms and heterotrophic plate counts were both positive for 18.8% and 59.4% of the samples, respectively.

Gangil *et al*. (2012) conducted research into the microbial safety of bottled water sold in the Indian city of Jaipur. Fifteen of the water samples (50%) failed the standard plate count. According to the Bureau of Indian Standards (BIS), 25 percent, 45 percent, 20 percent, and 5 percent of the samples were deemed unsafe for human consumption due to the presence of psychophilic organisms, coliforms, Escherichia coli, and staphylococci, respectively. In a comprehensive microbial analysis, 55 percent of samples were found to be unsafe for human consumption. There was a significant coliform level, an indicator of fecal contamination, in all brands of sachet water. Of the 15 brands of bottled water tested, six samples had a microbial value above the acceptable range, making them unsafe for human consumption. Of the sachets, two brands (40%) contained *E. coli*, and all of them were below the criteria for drinking water.

Ahmed *et al*. (2013) tested a total of 46 bottled water samples originating from Dhaka, Bangladesh. These samples represented 16 distinct brands. They determined the levels of total coliforms, faecal indicator bacteria (such as thermotolerant *E. coli* and Enterococcus spp.), and potential bacterial pathogens (such as Aeromonas hydrophila, Pseudomonas aeruginosa, Salmonella spp., and Shigella spp.). There was a total of 16 different brands that were examined, and the results showed that 14 of those brands included total coliforms, 10 of those brands contained *E. coli*, and 7 of those brands contained Enterococcus spp. In addition, further examinations utilising polymerase chain reaction (PCR) indicated that nine, eight, six, and four more brands contained genes corresponding to A. hydrophila lip, P. aeruginosa ETA, Salmonella spp. invA, and Shigella spp. ipaH, respectively. According to the results of this research project, the level of microbial purity that may be found in bottled waters sold in Dhaka, Bangladesh, might differ significantly from one brand to another.

Koju *et al*. (2013) carried out a study to investigate the potability of the drinking water in the Kathmandu Valley. For determining the microbial count (total coliform), a total of 969 water samples were examined. The total coliform count in groundwater (well and bore) was found to be higher than the WHO limit of 86%.

Venkatesan *et al*. (2014) carried out a study with the purpose of evaluating the microbial quality of bottled and sachet drinking water that is offered in retail establishments in the city of Chennai. The results of the analysis showed that 33.3% of the 36 sachet water samples were unfit for human consumption because they did not satisfy the WHO drinking water standard of zero coliform per 100 ml. On the other hand, the standard was met by all the other samples, so the standard was adhered to appropriately.

In Nepal's Dharan Municipality, Pant *et al*. (2016) examined the bacteriological quality of bottled and tap water. They found heterotrophic bacteria in 100% of tap water samples and 87.5% of bottled water samples. Compared to 55.3% of tap water samples, 25% of bottled water samples tested positive for total coliforms. Faecal coliforms and streptococci were absent from all bottled water samples. 21.1% and 14.5% of tap water samples had fecal coliforms and streptococci, respectively. Only 54.2% of the bottled water samples had pH levels within the allowed range, but all tap water samples did.

When compared to tap water, bottled water was found to be of superior quality in terms of aesthetic considerations, microbial dangers, and lead contamination, according to another study that was conducted by Rahman and colleagues (2017).

According to the findings of Liu and Liu (2017), there is an extraordinarily high level of bacteria content as well as a rapid development of microbes in reusable drinking water bottles. Bottles used by children have an average of approximately 34,000 bacterium counts per mL, whereas bottles used by adults have an average of 75,000 bacterium counts per mL. The bacterial content can range anywhere from 0 to 2.4 105 CFU/mL when examined using the heterotrophic plate count (HPC).

In the study of Joseph *et al*. (2018) evaluated the bacteriological quality of bottled water sold in high-traffic areas of Mangalore, which is in the southern Indian state of India. There was a total of 24 water bottles from 12 different brands picked at random. Only 15 of the samples, or 62.5 percent, had a level of bacterial contamination that was within the approved safe limits for drinking.

According to the findings of Das *et al*. (2018), over 76% of the collected jar water samples were found to be contaminated with harmful organisms. This should be of grave concern to the people living in Chittagong Metropolitan city.

Mina *et al*. (2018) conducted a study in which they collected 38 drinking jar water samples from the city of Chattogram in Bangladesh with the purpose of determining the level of microbial contamination. In the molecular test, microbial contamination was identified in 60.53 percent of the samples, and in the biochemical test, it was found in 50 percent of the samples. The overall bacterial count was anywhere from 1.5 x 102 to 1.6 x 104 CFU/mL at its highest point. In samples of water measuring 100 milliliters, the total coliform count (TCCm) ranged from 14 to 40.

Sarker *et al*. (2019) evaluated the bacteriological profiles of water samples taken from a pond, a jar, and a tube well to determine whether the water was suitable for drinking and home use. From the area known as Nakla Paurosova in the Sherpur district of Bangladesh, a total of thirty samples were taken and submitted for analysis. Most of the surface water sample stations had been polluted because of the dumping of garbage and the washing of cattle, and as a result, they were unfit for consumption or any other home use. All the pond water samples tested positive for the presence of fecal coliform, and three of the jars and four of the tube wells contained contaminated water.

Researchers from Islam *et al*. (2020) looked into the DWASA-provided water quality in and around Dhaka city. The standard methods recommended by the American Public Health Association (APHA) were used to conduct the analysis of the microbial parameters. All the samples' total coliforms and fecal coliforms exhibited a value that was lower than 0.2 MPN/mL (a most probable number of less than 0.2 confirms the absence of the test organism in 1 mL). The total viable count (TVC) of each and every sample came in lower than the allowable limit of 100 CFU/mL. The result that was obtained was compared to the Bangladesh Standards and Testing Institution's (BSTI) permitted limit for drinking water as well as the Bangladesh guideline for the Environment Conservation Rules, 1997. According to the findings of this study, the quality of the bottled water available in the city of Dhaka ranged from satisfactory to exceptional on average.

Drinking and household water in the Dhankuta Municipality of Nepal were analyzed bacteriologically by Yadav *et al*. (2015). The data was compared to international norms set by the World Health Organization and the Environmental Protection Agency. The analysis of the water samples concluded that there was fecal and organic pollution in the drinking water resources based on the total coliform and fecal coliform levels.

Onyango *et al*. (2018) evaluated the microbial quality of the water sources and the level of pollution found in Isiolo County, which is in Kenya. A total of sixty samples of drinking water and water used in industrial food processing were examined for the presence of *E. coli*, Staphylococcus aureus, Clostridium pafringens, coliforms, and cysts. The samples were taken from both surface water and groundwater. They discovered that ground water had the highest mean counts of Clostridium pafringens, which were 1452 CFU/mL, whereas surface water had the highest mean counts of 3421 CFU/mL. There was a statistically significant difference (p 0.05) between the microbial counts in each of the water sources.

According to the findings of Homaida *et al*. (2013), the viable count of drinking water obtained from asbestos, polyvinyl chloride high density (PVC.HD), and polyvinyl chloride low density (PVC.LD) pipes ranged from 0.3 104 to 9.3 107 CFU/mL. They discovered that the levels of total coliform MPN ranged from 0.0 to 11 MPN/100 mL. While feces streptococci ranged from 0.0 to 3 MPN/100 mL, feces coliform levels ranged from 0.0 to 7 MPN/100 mL. Bacillus, Corynebacterium, Micrococcus, Staphylococcus, and Streptococcus were the genera of bacteria that were discovered to be the most prevalent in drinking water. Bacillus accounted for 44%, Corynebacterium for 31%, and Micrococcus for 13%.

Timilshina *et al*. (2012) conducted a microbial investigation on a random sample of thirty different commercial brands of bottled water that are currently on the market in the Kathmandu Valley in Nepal. In 90% of the samples, the count of heterotrophic bacteria was found to be higher than the acceptable level (50 CFU/mL), and in 63.3% of the samples, the count of total coliform bacteria was found to be higher than the WHO standards (CFU/mL). Because they had higher than acceptable levels of total coliform count and/or heterotrophic count, 90 percent of the bottled water brands tested were deemed unsafe for human consumption.

Gomes *et al*. (2014) conducted microbial tests on bottled mineral water distributed in the Brazilian state of Minas Gerais to determine the presence of coliforms, *E. coli*, Clostridium perfringens, Pseudomonas aeruginosa, Enterococcus spp., heterotrophic bacteria, fungi, and yeasts. The findings were evaluated in light of the constraints imposed by the relevant Brazilian laws. According to the microbial analysis, 52% of the samples that were examined exhibited levels of one or more types of micro-organisms that were excessive compared to the allowable levels.

According to Asamoah *et al*. (2011), the levels of total coliforms, *E. coli*, and total heterotrophic bacteria found in bottled and sachet water samples taken in Ghana's Tarkwa Nsuaem Municipality were found to be within the acceptable ranges established by the World Health Organization (WHO) and the Ghana Standard Board (GSB).

The bacterial status of sachet water that was consumed in the Hohoe Municipality in Ghana was evaluated by Agboli *et al*. (2017) in October of 2016. The evaluation took place at nine different manufacturing locations for sachet water located within the Municipality. Using a method called membrane filtration, the bacteria found in each of the 36 sachet water samples were analyzed for the number of total coliforms and *E. coli* that were present in CFU per 100 milliliters. Only two of the samples tested positive for *E. coli*, with corresponding counts of 4 and 5 CFU/100 mL. The presence of *E. coli* was found to be statistically dependent on the development of TC (P less than.05). The presence of *E. coli* in the sachet water is indicative of the presence of fecal components in the water as well.

Fifteen different brands of sachet water and eight different brands of bottled water were tested for their microbial characteristics by Ibrahim *et al*. (2015) in Nigeria. The results showed that only 26.67% of the sachet and 75.00% of the bottled water met the total coliform guidelines set by the World Health Organization and the Standard Organization of Nigeria for drinking water, while the remaining 73.30% and 25.00% were not suitable for human consumption.

Bacteriological tests of several selected drinking water sources in Abuja, Nigeria, were conducted by Atiku *et al*. (2018). The research found that the sachet water samples contained total coliform counts of 0.030 x 102 CFU/mL, as indicated by the study. The bacteriological results all came in higher than the WHO threshold of 0 CFU per 100 mL; hence, they did not satisfy the requirements of the international standard.

Hamad *et al*. (2022) investigated the bacteriological quality in some domestic bottled waters marketed in Al Anbar Province of Iraq. The bacteriological contents were found within permitted ranges of WHO and Iraqi standards.

The commonest microbial parameters were studied by Keleb *et al*. (2022) on 248 municipal tap water samples, 248 water samples from a household water storage container, and 38 bottled water samples. They that a good portion of all three types of samples were found positive for *E. coli* and total bacterial count (TC).

Chapter 3: METHODOLOGY

3.1 General

To accomplish the objectives of the research project, representatives of Chattogram City Corporation (CCC) were dispatched to various locations throughout the city to retrieve representative samples of bottled and jarred drinking water. The physico-chemical features, contents of heavy metals, and pathogen micro-organisms of the samples that were collected were evaluated with the help of conventional methodologies. A concise explanation of the procedures for analyzing the samples is provided below.

3.2 Study Area

The research work was carried out inside the territories of Chattogram's city corporation, which was founded on July 31, 1990, and covers an area of approximately 160.99 km2 in total. During this research, ten distinct areas in the CCC of Bangladesh were chosen for the collection of jar water samples; these locations are depicted in Figure 3.1. This study focuses on areas of Chattogram city where hawkers and smaller retail outlets sell a greater quantity of bottled water and jar water, respectively.

3.3 Sample Collection, Transportation and Processing

In this research, a total of 35 (thirty-five) different samples of bottled and jarred drinking water that are sold commercially were analyzed. The number of water samples contained in bottles and jars was ten and twenty, respectively. These were included in the group. A total of 10 distinct commercial brands of bottled water were purchased from various retail establishments across the country. There was a total of 20 jars of water samples taken from ten different locations (two samples were taken from each location). The information regarding the samples and the locations where they were collected may be found in Table 3.1. Each of the water samples from the jars were collected in two separate sets of sterile containers with caps; one set was used for physico-chemical studies, and the other set was used for microbial analysis. Following the procedure that was described by Marzan *et al*. (2018), the samples that were obtained were transported to the laboratory with care and in refrigerated containers. Before beginning the study, each sample was chilled to four degrees Celsius and kept there until it was time to perform the physico-chemical tests. The procedure for sampling the water in the drinking jar was carried out in a sterile and hygienic manner. In addition, the pH, TDS, and EC were measured with a multiparameter waterproof meter (model number HI 98194, country of origin: Romania). The concentrations of chromium, manganese, iron, copper, zinc, cadmium, and lead (Cr, Mn, Fe, Cu, Zn, Cd, and Pb) were determined with the use of a conventional atomic absorption spectrophotometer (a polarized Z-2000 Zeeman atomic absorption spectrophotometer from Hitachi, Japan).

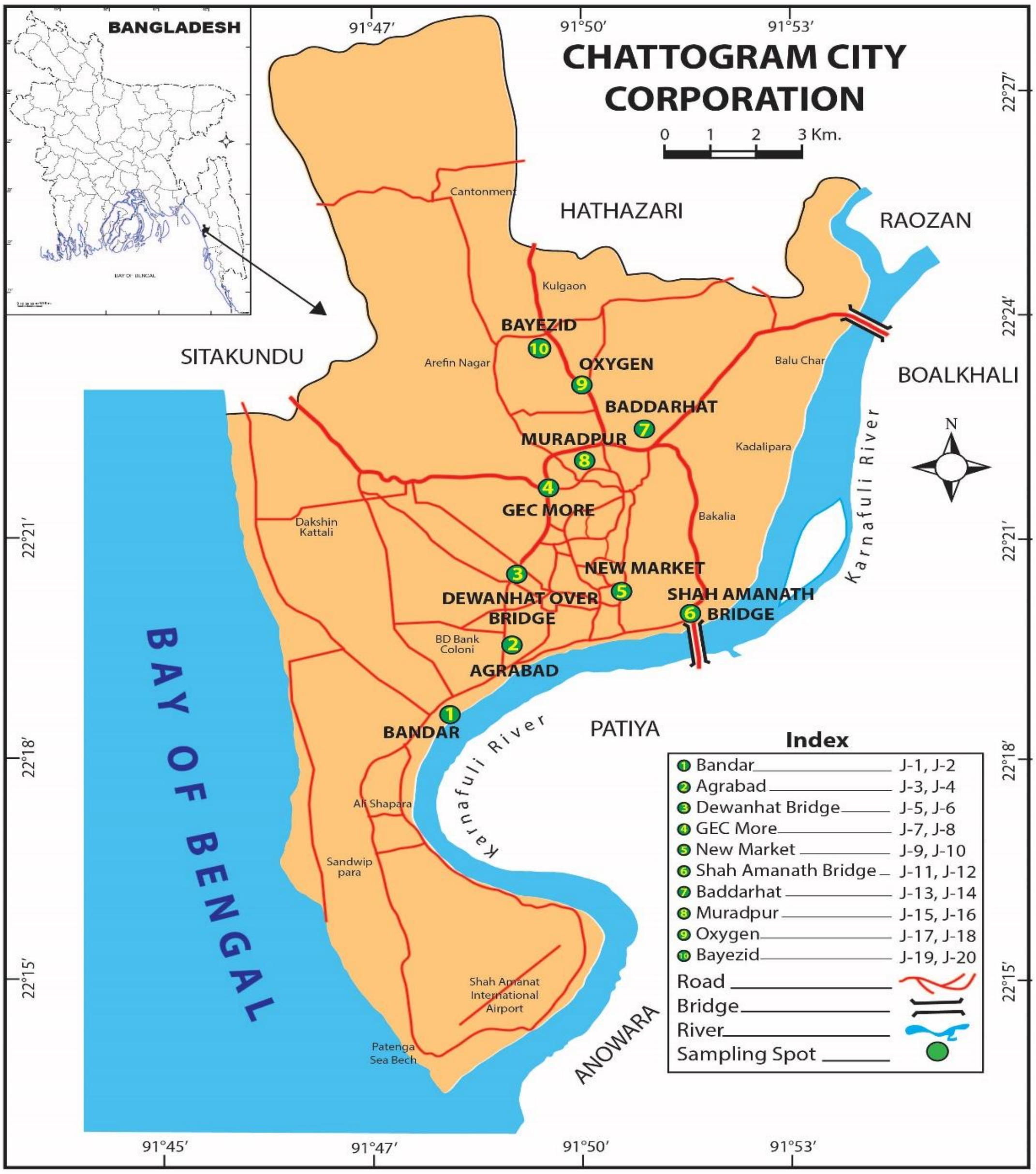

Fig. 3.1 Sampling location indicated in GIS map of Chattogram City Corporation area

Table 3.1. Location of jar water sample collection spots, bottled water brands and sample IDs

SL No.	Jar water		Bottled water	
	Sampling Location	**Sample ID**	**Brand Name**	**Sample ID**
01	Bandar	J-1, J-2	Mum	B-1
02	Agrabad	J-3, J-4	Mamia	B-2
03	Dewanhat Bridge	J-5, J-6	Fresh	B-3
04	GEC More	J-7, J-8	Muskan	B-4
05	New Market	J-9, J-10	Confidence	B-5
06	Shah Amanath Bridge	J-11, J-12	Rongdhanu	B-6
07	Bahaddarhat	J-13, J-14	ACME	B-7
08	Muradpur	J-15, J-16	Shyamoli	B-8
09	Oxygen	J-17, J-18	Dada	B-9
10	Bayezid	J-19, J-20	Rivera	B-10

3.4 Physico-chemical Characteristics of Bottled and Jar Drinking Water

The physical and chemical properties of water in a bottle or jar can be different based on where the water comes from and how it was treated. But there are some general physical and chemical parameters that are measured in drinking water.

3.4.1 pH: This indicates the degree to which the water is acidic or alkaline and is ranked on a scale that ranges from 0 to 14. The pH scale is scaled from 0 to 14, with 7 representing neutrality, 0 representing acidity, and 7+ representing alkalinity.

3.4.2 Total dissolved solids (TDS): This refers to the overall quantity of inorganic and organic compounds that have been dissolved in the liquid medium of the water. TDS, which is measured in parts per million (ppm), is a metric that can provide insight into the flavor and quality of water.

3.4.3 Electrical conductivity (EC): The conductivity of water is a measure of its ability to carry an electric current, and it varies with the number of dissolved ions per unit of water.

3.5 Determination of Physico-chemical Characteristics of Bottled and Jar Drinking water

3.5.1 Determination of pH:

A pH meter (pH Hanna Instrument Ltd. & 3310, pH meter Jenway, UK) was used to measure the pH of each sample.

3.5.2 Determination of Electrical Conductivity (EC):

All samples were tested with a multiparameter waterproof meter (HANNA, HI 98194) to assess their electrical conductivity (EC).

3.5.3 Determination of Total Dissolved Solids (TDS):

TDS was also determined by filtering the sample through the Whatman filter paper. In this case, an evaporating dish was used to hold 100 mL of filtrate onto a water bath. The weight of a dry evaporating dish was first recorded and designated as W_1. The filtration was transferred to an evaporating dish and placed in a water bath at a temperature of 105°C until all the liquid had evaporated, leaving a solid residue on top of the evaporating dish. The dish was then placed in an oven at 105°C for 2 hours, cooled in desiccators for 30 min, weighed and labeled as W_2. Weight of residue,

$$W = (W_2 - W_1)g$$

$$= (W_2 - W_1) \times 1000mg$$

$$TDS = \frac{W}{V} mg/mL = \frac{W}{V} \times 1000mg/L = \frac{W}{V} \times 1000ppm \quad (3.1)$$

3.6 Determination of Heavy Metals

3.6.1 Selection of Heavy Metals:

The following heavy metals were chosen because of the potential risk they pose to the public. This research looked at the effects of exposure to the heavy metals chromium (Cr), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), cadmium (Cd), and lead (Pb).

3.6.2 Preparation of Water Samples for Heavy Metal Determination:

To obtain a consistent suspension, the water sample was shaken up. After transferring the sample of 500 mL into an evaporating dish, acidifying it with 5 mL of nitric acid (HNO3), and evaporating 15 to 20 mL of it in a steam bath, the sample was ready for analysis. After that, the solution was moved along with any remaining solids in the dish into a 125-mL conical flask. After that, 5 mL of additional HNO_3, 10 mL of sulfuric acid (H_2SO_4), and a few glass beads (to prevent bumping) were added to the solution, and it was evaporated on a hot plate until dense fumes of SO_3 appeared in the flask. After the removal of all the HNO_3, the solution was reported to be clear (APHA, 1999). After the solution had been cooled to room temperature and carefully diluted to around 50 mL, it was filtered through a porcelain filter crucible, and the residue was rinsed away with two tiny portions of water. After that, the filtrate was transferred to a volumetric flask with a capacity of 100 mL, and the volume was brought up to the appropriate level using distilled water. In order to determine the levels of various metals in this solution, aliquots were obtained.

3.6.3 Analytical Technique

Using an air-acetylene flame, the samples were put through an atomic absorption spectrophotometer (AAS) from Hitachi, Japan (Model: polarized Z-2000 Zeeman atomic absorption spectrophotometer), which was used to conduct the analysis. At the appropriate metal wavelength, each and every one of the standard metal solutions as well as the sample metal solutions were evaluated.

3.6.4 Design of an Atomic Absorption Spectrophotometer

Basically, the atoms of all elements can be stimulated and are therefore capable of absorbing radiation, the AAS can basically be used to determine any element at all. The radiation source, the optical components of the light path, and the detector all affect the wavelength range that an AA spectrophotometer is capable of measuring. In actuality, the range runs from 852.2 nm, which is the resonance line of cesium that has the highest sensitivity, to 193.7 nm, which is the line of arsenic that is utilized for analysis most of the time in the early vacuum.

3.6.5 Methods of Heavy Metal Analysis

Each laboratory should consider the sample type and concentration levels, the number of elements that need to be determined, and the expenses that are implied by the option when deciding which analytical method is the most appropriate to use when determining metals. Because of this, flame and graphite furnace atomic absorption spectrometry (AAS), as well as inductively coupled plasma (ICP and ICP-MS) emission spectrometry, are the analytical procedures that are utilized the most frequently.

3.6.6 Principles of Atomic Absorption Spectrometry (AAS)

When determining how much of an analyte is present in a sample, this method relies on absorption spectrometry to do the measuring. In order to establish the relation between the observed absorbance and the analyte concentration, it relies on the Beer-Lambert Law, which necessitates the use of standards containing a known amount of the analyte. By taking in a specific amount of energy (radiation of a given wave length), the electrons of the atoms contained within the atomizer have the potential to be moved into higher orbitals, resulting in an excited state for a brief period of time (measured in nanoseconds).

This quantity of energy, also known as the wavelength, is unique to a given electron transfer that takes place in a particular element. The elemental selectivity of the method is due, in large part, to the fact that each wavelength only corresponds to a single element and that the width of an absorption line is only on the order of a few picometers (pm). A detector is used to monitor the radiation flux both with and without a sample in the atomizer. The ratio of these two values, known as the absorbance, is then used to convert the radiation flux to an analyte concentration using the Beer-Lambert law.

Equipment

The metal ions on prepared sample solutions were characterized with polarized Z-2000 Zeeman atomic absorption spectrophotometer (Z-2000 AAS Manual) to determine the amount of investigated metal ions which is shown in Figure 3.2. It has a strong magnetic field across the air-acetylene flame burner (having slot of 100×0.5 mm^2) and a hollow cathode corresponding lamp (Hitachi, radiation source). All instrumental settings were those recommended in the manufacturer’s manual book.

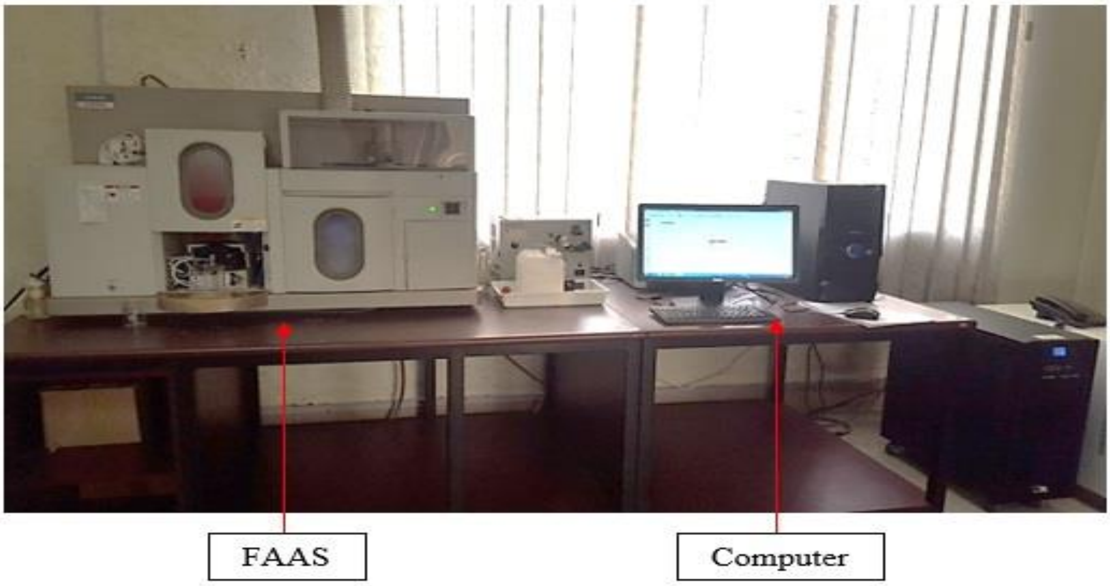

Fig. 3.2 Polarized Zeeman atomic absorption spectrophotometer setup at AECC

3.6.7 Blank Preparation

A blank sample was prepared by using an identical procedure without adding samples. It contains the same digestion reagents as the real samples with the same acid ratios. After digestion, the sample was treated as a blank sample and the same dilution factor was also used. It was analyzed by AAS after real samples and its value was subtracted from the real samples to check the accuracy of the instrument.

3.6.8 Analytical Technique and Accuracy Check

All the collected water samples were analyzed for Cr, Mn, Fe, Cu, Zn, Cd and Pb by atomic absorption spectrophotometer (Model: polarized Z-2000 Zeeman atomic absorption spectrophotometer. Hitachi, Japan) using flame atomic absorption spectrophotometer (FAAS). Before running the experimental samples, a mixed solution (DI water and 1% HNO_3) was run through the machine. By pressing the auto-zero switches the machine is prepared for metal analysis. For investigating a specific element, the respective hollow cathode lamp must be set in the specific lamp holder. Each sample runs three times and four seconds every time.

The machine counts the average value three times. It will then be converted to the ppm/ppb unit. In order to calculate the real value of the sample being analyzed, the value is multiplied by the dilution factor of the sample. Table 3.2 provides an overview of the lowest levels of detectability for each heavy metal. The procedure for the experiment required the use of ultrapure water. Before being used, every piece of glassware and container was cleansed with nitric acid at a concentration of 15%, then thoroughly rinsed with ultrapure water on many occasions, and lastly oven dried.

Table 3.2. The minimum instrumental detection limits of tested heavy metals

Cd	**Cu**	**Fe**	**Mn**	**Pb**	**Zn**	**Cr**
0.002	0.01	0.02	0.01	0.05	0.005	0.02

3.7 The Heavy Metal Pollution Index (HPI)

The HPI is a tool used to evaluate the degree of heavy metal pollution in a particular area (Opong *et al.*, 2021). It is based on the concentration of different heavy metals in soil, water, and other environmental media. The HPI is a composite index that combines the concentrations of several heavy metals, including chromium, Manganese, Iron, copper, zinc, cadmium and lead.

The HPI is calculated using the following formula:

$$HPI = \sum Ci / Pi \qquad (3.2)$$

Where: Ci = the concentration of each heavy metal in the water sample

Pi = the permissible limit for each heavy metal as defined by regulatory bodies

The HPI is usually expressed as a score between 0 and 1, with higher scores indicating greater levels of heavy metal pollution. The index can be used to compare different areas or to track changes in heavy metal pollution over time. The HPI is an important parameter for analyzing the possible dangers to one's health that may be posed by heavy metal contamination. Heavy metals at high concentrations are known to cause severe adverse effects on human health, including deterioration of the brain system, kidneys, and liver. Exposure to heavy metals over a prolonged period has also been linked to cancer and other chronic disorders.

3.8 The Nemerow's Pollution Index (NPI)

Nemerow's pollution index (NPI) is a method for evaluating the overall pollution level of an environment or a specific location (Dawood, 2017). It is a composite index that combines several environmental quality parameters such as air pollution, water pollution, and solid waste generation.

The NPI is calculated using the following formula:

$$\text{NPI} = \frac{C_n}{S_n} \quad (3.3)$$

where, Cn is the concentration of a pollutant in the environment and Sn is the standard limit for the pollutant established by regulatory agencies. The index measures the degree of deviation of the pollutant concentration from its standard limit. The NPI is usually expressed as a percentage, with higher values indicating higher levels of pollution. The NPI can be used to compare different locations or to track changes in pollution levels over time. The index can also be used to prioritize pollution control measures or to assess the effectiveness of pollution control programs. Nemerow's pollution index has some advantages over other methods of evaluating pollution levels, as it provides a single composite score that is easy to interpret and communicate to non-experts. It also allows for the incorporation of multiple pollutants and standards, and the weights assigned to each pollutant can be adjusted to reflect the relative importance of each pollutant in the specific context.

However, the NPI has some limitations, as it does not account for the potential synergistic effects of multiple pollutants, nor does it consider the variability of the environmental media in which the pollutants are present. Moreover, the NPI is only as accurate as the data used to calculate it, and any errors or inconsistencies in the data can lead to inaccurate results.

3.9 Total Bacterial Count (TBC) and Total Coliform Count (TCC)

3.9.1 Sampling

Before sampling the microbial samples, each plastic container (250 mL) was washed with sterile water three times. 200 mL sample was collected in each container for microbial analysis. A total of twenty samples were collected from identified ten areas for jar water analysis, two samples were taken from each area while ten bottles were collected for bottled water. All collected samples were transferred immediately by caring the cold container to the microbial laboratory of the Institute of Food and Radiation Biology (IFRB), Atomic Energy Research Establishment (AERE), Dhaka.

3.9.2 Media Preparation and Sterilization

Nutrient agar (NA) was used to determine the total bacterial count. This medium was prepared according to manufacturer instructions by taking 23.0 gm/L of ready-made powder (BD-Difco, New York, USA). The pH of the medium was checked and adjusted to the prescribed point and autoclave the medium at 121°C for 15 minutes under 15 psi pressure. MacConkey agar (MCA) was also used to determine the total coliform that was prepared by taking 40.0 gm/L of ready-made powder (BD-Difco, New York, USA). After adjusting the pH of the respected medium, the medium was autoclaved with the above conditions (Baird *et al*., 2015; Bordner *et al*., 1978; Eaton *et al*., 2005 and Geldreich *et al*., 1965). The composition of each media is shown in Table 3.3.

Table 3.3. The composition of nutrient agar and MacConkey agar media

Nutrient agar medium	
Peptone	5.0 gm
Beef extract	3.0 gm
Sodium chloride	5.0 gm
Agar	15.0 gm
Distilled water	1000 mL
pH	7.0 ± 0.2
MacConkey agar (MCA) medium	
Pancreatic digest of gelatin	17.0 gm
Peptone	3.0 gm
Lactose	10.0 gm
Bile salt	1.5 gm

Sodium chloride	5.0 gm
Agar	13.5 gm
Neutral red	0.03 gm
Crystal violet	1.0 mg
Distilled water	1000 mL
pH	7.4 ± 0.2

3.9.3 Enumeration of Total Bacterial Count (TBC)

To enumerate TBC, standard plate count (SPC) was applied in which samples were diluted up to 10^{-6} in test tubes containing 9 mL of sterile water by transferring 1 mL of sample from lower to higher dilution and thus, 10^{-1}, 10^{-2}, 10^{-3},10^{-4}, 10^{-5} and 10^{-6} were produced. 1 mL from each dilution was taken into sterile petri dish and poured 25 mL of appropriately cooled NA. Diluted samples and poured medium were mixed by rotating the plates clockwise and anticlockwise and allowed to solidify. Then the solidified plates were incubated at the inverted condition in the incubator set at 37°C for 24 hours. Upon completion of the incubation period, developed colonies were counted. Each sample was technically replicated and the results were expressed as CFU/mL. The number of bacteria in a dilution was calculated by multiplying the number of colonies developed with the dilution factor of the respective dilution. (Baird *et al*., 2015; Bordner *et al*., 1978; Eaton *et al*., 2005 and Geldreich *et al*., 1965).

3.9.4 Enumeration of Total Coliform Count (TCC)

To enumerate TCC, the membrane filtration technique was exploited in which 100 mL of sample was filtered through a 0.22 μm filter and then the filter was aseptically placed on previously prepared solidified MCA plates. After that, the plates were incubated at 37°C for 24 hours and checked for colonies developed. The pink colour colonies were considered coliform that was counted and recorded as CFU/100 mL. (Baird *et al*., 2015; Bordner *et al*., 1978; Eaton *et al*., 2005 and Geldreich *et al*., 1965). The equipment used in for microbial study is specified in Table 3.4.

Table 3.4. List of equipment for microbial analysis

SL No.	Machine / Equipment	Company	Model	Origin
1.	Autoclave	ALP Co. Ltd	MO-40LH	Japan
2.	Incubator	Binder	12-10677	Germany
3.	Dry heating sterilizer	Memert	F-Nr.: C512.0910	Germany
4.	Balance	Denver Instrument Co.	AA-160	USA
5.	pH meter	Jenway	3510	UK
6.	Colony counter	Gallenkamp	CNW330010X	UK

3.10 Pearson Correlation Coefficient for Physico-chemical Characteristics of Drinking Water

The Pearson correlation coefficient is a measure of the linear relationship between two variables. In the case of physico-chemical characteristics of drinking water, it can be used to measure the degree of association between pairs of characteristics.

To calculate the Pearson correlation coefficient, we need to calculate the covariance and standard deviation of both variables. The formula for the Pearson correlation coefficient is:

$$r = (n\Sigma XY - \Sigma X\Sigma Y) / \text{sqrt}\,[(n\Sigma X^2 - (\Sigma X)^2)\,(n\Sigma Y^2 - (\Sigma Y)^2)] \qquad (3.4)$$

Where,

n = the number of observations

ΣXY = the sum of the product of X and Y values

ΣX = the sum of X values, ΣY = the sum of Y values

ΣX^2 = the sum of squared X values, ΣY^2 = the sum of squared Y values

For example, let's say we have data on the pH and total dissolved solids (TDS) of a set of water samples. We can calculate the Pearson correlation coefficient between the two variables to determine if there is a relationship between them. The Pearson correlation coefficient can be useful in identifying patterns and relationships in water quality data. For example, it may be used to examine the impact that environmental factors have on water quality or the correlation that exists between the amounts of heavy metals and other characteristics that characterize the quality of the water. However, it is essential to keep in mind that correlation does not automatically imply causation, and additional investigation may be necessary to determine whether there is a causal relationship between the variables in question.

3.11 The Weight Arithmetic Water Quality Index (WAWQI)

The water quality index, often known as the WQI, is a method that evaluates the overall quality of a drinking water sample based on the number of different water quality factors. According to Ochuko *et al*. (2014), a mathematical method is utilized to analyze water quality and determine whether the water is safe for human consumption. In 1965, Horton established this index for the first time to evaluate water quality using the ten water characteristics that were used most at the time. In succeeding steps, the approach was altered by a variety of specialists. The Water Quality Index (WQI) is a single number that is used to reflect the overall quality of the water. It is commonly used to compare the quality of the water in various locations or during varying time periods. These indices make use of a wide variety of both quantitative and qualitative aspects of water quality. The relevance of a parameter, as well as its influence on the index, is reflected in the weight that is assigned to it, which is determined by the criteria that are specific to that parameter. According to Tyagi *et al*. (2013), a standard WQI methodology includes the following three stages: (1) parameter selection; (2) quality function determination for each parameter; and (3) aggregation using a mathematical equation.

To get the WQI, one must first determine the quality scores that should be assigned to each water quality measure individually. The score for the sample's quality is determined by comparing the amount of the parameter that was measured in the sample to the value of a standard or guideline. The quality score is typically expressed on a scale from 0 to 100, with a score of 100 indicating that the concentration is below the standard or guideline value, and lower scores indicating increasing deviation from the standard or guideline. Once the individual quality scores have been determined, they are combined into an overall index using a weighted arithmetic mean. The weights assigned to each parameter reflect its relative importance in the overall quality of the water. The formula for the WQI is as follows:

$$WQI = \Sigma WnQn \tag{3.5}$$

Where, Wn = the weight assigned to each water quality parameter Qn = the quality score for each water quality parameter. The WQI ranges from 0 to 100, with higher values indicating better water quality. A value of 0 indicates the poorest water quality, while a value of 100 indicates the best possible water quality. The WQI is a useful tool for evaluating the overall quality of a drinking water sample, as it takes into account multiple parameters that may affect water quality. However, the WQI has some limitations, as it assumes that all parameters are equally important and may not capture the full range of water quality issues that may be present in a sample. Therefore, it is important to supplement WQI analysis with other methods, such as risk assessments, to fully evaluate the potential health risks associated with exposure to pollutants in drinking water.

Chapter 4: RESULTS AND DISCUSSION

4.1 Physico-chemical Characteristics of Bottled and Jar Water Samples

When determining the overall quality of drinking water, physico-chemical qualities are essential elements to look at. The pH, electric conductivity, and total dissolved solids (TDS) levels of water samples taken from bottles and jars are examples of the physico-chemical parameters that are frequently analyzed. These physico-chemical properties provide an overall picture of the quality of drinking water samples from bottles and jars, and it is crucial to conduct regular testing to ensure that consumers have access to safe and healthy drinking water at all times.

Table 4.1. The physico-chemical characteristics of bottled water samples

SL No.	Sample ID	pH (Measured)	pH (Mentioned on label)	TDS (mg/L) (Measured)	TDS (mg/L) (Mentioned	EC (μS/cm)	EC (μS/cm)
01	B-1	6.44	6.4-7.4	249.70	< 200	454	NM
02	B-2	7.51	6.4-7.4	42.90	< 250	78	NM
03	B-3	6.71	6.4-7.4	31.35	< 50	57	NM
04	B-4	7.37	6.4-7.4	59.95	< 250	109	NM
05	B-5	7.08	6.4-7.4	19.80	< 500	36	NM
06	B-6	6.59	6.4-7.4	65.45	< 50	119	NM
07	B-7	6.81	6.4-7.4	15.40	NM	28	NM
08	B-8	7.85	6.4-7.4	105.05	< 250	191	NM
09	B-9	6.74	6.4-7.4	134.20	< 250	244	NM
10	B-10	6.33	6.4-7.4	452.10	< 500	822	NM
Minimum		6.33		15.40		28	
Maximum		7.85		452.10		822	
Mean		6.94		117.590		213.8	
SD		0.496		136.969		249.035	

NM: Not Mentioned

Table 4.2. The physico-chemical parameters of jar water samples

Location	Sample ID	pH	TDS (mg/L)	EC (μS/cm)
Bandar	J-1	7.24	773.3	1406
	J-2	7.60	18.7	34
Agrabad	J-3	7.30	17.6	32
	J-4	7.25	14.3	26
Dewanhut Bridge	J-5	7.30	36.85	67
	J-6	6.98	86.9	158
GEC More	J-7	7.04	159.5	290
	J-8	6.99	145.2	264
New Market	J-9	6.67	11.55	21
	J-10	6.52	22.55	41
Shah Amanath Bridge	J-11	6.56	374	680
	J-12	6.67	121	220
Baddarhut	J-13	6.31	18.15	33
	J-14	6.26	117.15	213
Muradpur	J-15	6.34	155.1	282
	J-16	6.43	55	100
Oxygen	J-17	6.45	15.4	28
	J-18	6.45	14.3	26
Bayezid	J-19	6.50	3.85	7
	J-20	7.27	888.8	1616
Minimum		6.26	3.85	7
Maximum		7.6	888.8	1616
Mean		6.81	152.46	277.2
SD		0.415	248.806	452.363

4.1.1 pH

The pH of drinking bottled and jar water is an important factor to consider as it can affect the taste, corrosion of metal pipes, and the effectiveness of water treatment. The pH scale ranges from 0 to 14, with 7 being neutral. Values below 7 indicate acidity, while values above 7 indicate alkalinity. Drinking water with a pH level outside of the acceptable range of 6.5 to 8.5 can cause several issues. If the water is too acidic, it can corrode metal pipes and leach metals such as lead, copper, and zinc into the water. Ingesting high levels of these metals can cause health problems. If the water is too alkaline, it can cause a bitter taste and leave a residue on surfaces. In addition, the pH of water can also affect the effectiveness of water treatment methods. For example, the disinfection of water using chlorine is most effective at a pH of 6.5 to 8.5. If the water has a pH outside of this range, it may require additional treatment to ensure it is safe to drink. Therefore, monitoring the pH of drinking bottled and jar water is important to ensure that it is within the acceptable range for human consumption. Regular testing and treatment can help to maintain a safe and healthy drinking water supply. The physico-chemical results of the ten bottled water samples and twenty jar water samples collected from ten different spots of Chattogram City Corporation (CCC) were showed in Table 4.1 and 4.2 respectively. Table 4.3 shows the recommended guideline values of WHO/EC/BDS and for drinking mineral water. The maximum WHO required limit of pH is 7.0-8.5 and EC recognized pH limit is from 6.5-9.5. The obtained pH values in bottled water samples are shown in Figure 4.1. Out of total ten bottled water samples analyzed, two samples (B-1 and B-10) had pH values below 6.5 and six (J-13, to J-18) out of twenty jar water samples had pH values below 6.5. Other commercially available bottled drinking water samples pH were analyzed and obtained the results within the limits recommended by WHO/EC. pH values of sample B-1 was higher than the mentioned values on label. The pH values observed in this study was found very similar to another study on bottled water in Bangladesh (Rahman *et al.* 2012).

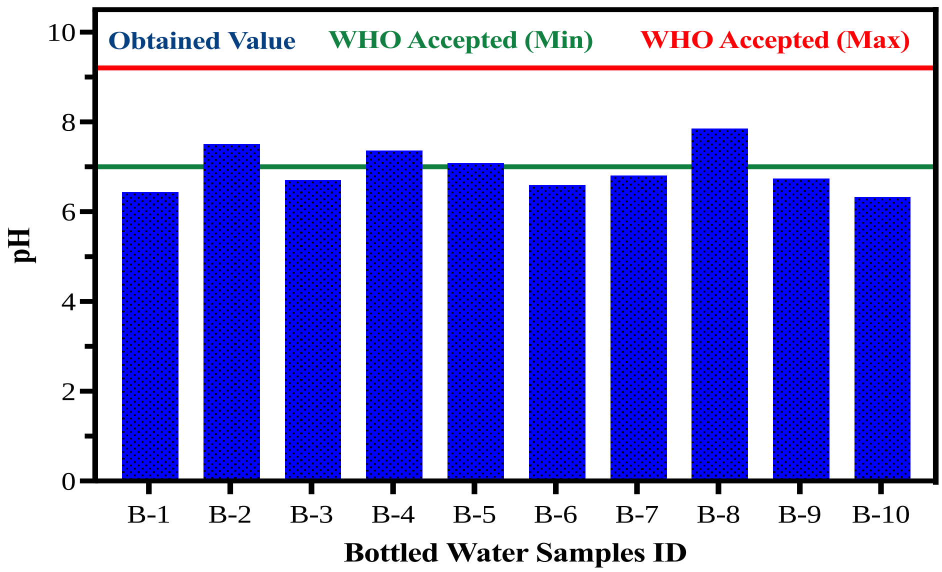

Fig. 4.1 pH of bottled water samples including the WHO recommended limit

The obtained pH values in jar water samples are shown in Figure 4.2a and 4.2b respectively.

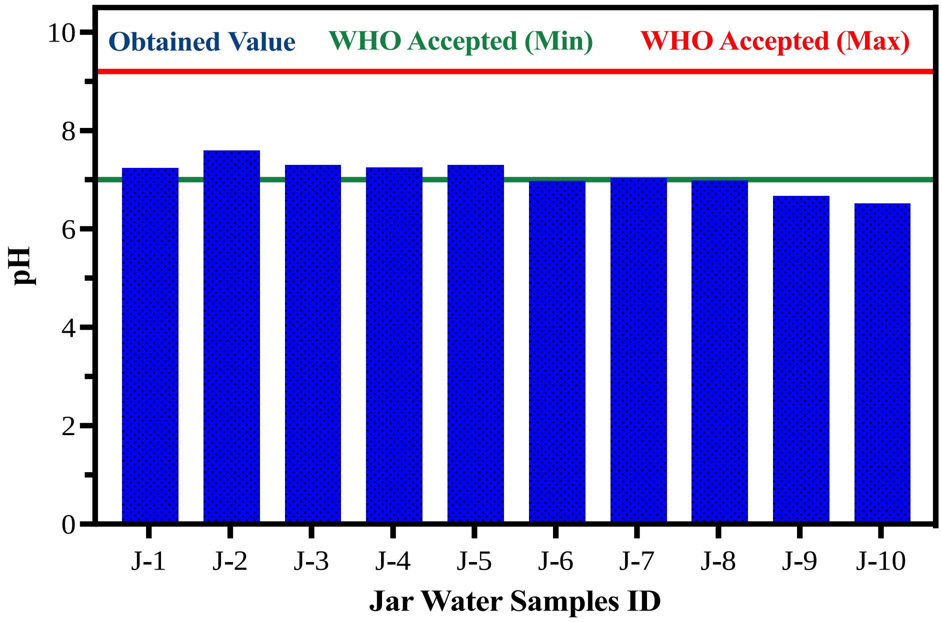

Fig. 4.2a pH of jar water samples including the WHO recommended limit

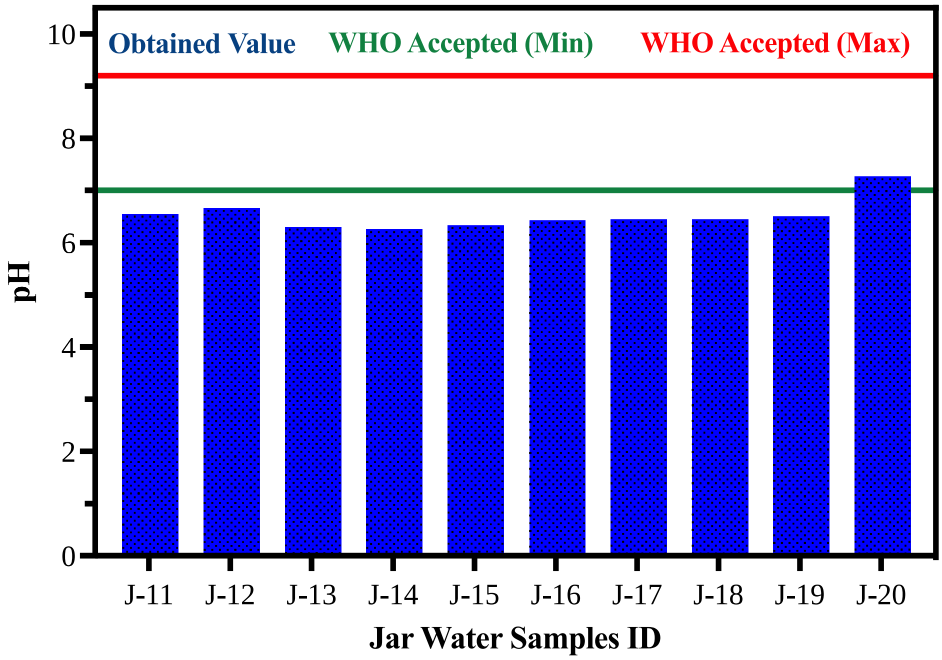

Fig. 4.2b pH of jar water samples including the WHO recommended limit

The following Table (4.3) shows the (WHO 2011), (EC 1983) and (BDS) suggested guideline values of some physico-chemical parameters for drinking water.

Table 4.3. Drinking water standards for physico-chemical parameters recommended by (WHO 1996, 2006, 2011) and (EC 1983, 1998)

The following Table (4.3) shows the (WHO 2011), (EC 1983), (USEPA 2018), (BSTI 1997), BIS 2012) suggested guideline values of some physico-chemical parameters for drinking water.

Table 4.3. Drinking water standards for physico-chemical parameters recommended by (WHO 1996, 2006, 2011), (EC 1983, 1998), (USEPA 2018), (BSTI 1997), (BIS 2012)

Standards/Parameters	**pH**	**EC (µS/cm)**	**TDS (mg/L)**
WHO limit	7.0-9.2	400-1500	500-1500
EC limit	6.5-9.5	2500	0-500
USEPA limit	6.5 – 8.5	--	500
BSTI limit	6.4 – 7.4	800	500* /1000
BIS limit	6.5 – 8.5	--	500

* for mineral water

4.1.2 Electrical conductivity (EC)

Electrical conductivity (EC) is a measure of the ability of water to conduct an electrical current, which is related to the concentration of dissolved minerals and salts in the water. The higher the concentration of minerals and salts, the higher the EC of the water. In drinking bottled and jar water samples, EC is an important parameter to measure because it provides an indication of the water's overall mineral content, which can impact its taste and potential health effects. The EC can also be used to determine the presence of certain contaminants, such as heavy metals and other dissolved solids. Drinking water with a low EC typically has a low concentration of dissolved minerals and salts and may be referred to as "soft water." In contrast, water with a high EC may have a high concentration of dissolved minerals and salts and may be referred to as "hard water." While hard water is generally safe to drink, it may have an unpleasant taste or smell and can cause mineral buildup in plumbing systems, which can lead to clogging and other issues. Additionally, high concentrations of dissolved solids in water can have potential health effects if consumed in excessive amounts. Therefore, measuring the EC of drinking bottled and jar water samples is an important part of ensuring that the water is safe and healthy for human consumption. The EC of drinking bottled and jar water samples are presented in Tables 4.1 and 4.2. Samples B-10, J-1 and J-20 showed the higher EC values than the Bangladesh standard (BDS), but those were below the other standards. The World Health Organization (WHO) recommends an acceptable range for EC of 400 to 1500 micro siemens per centimeter (µS/cm) for drinking water (WHO 2011). Comparison of obtained and acceptable values of EC of bottled water samples are shown in Figure 4.3.

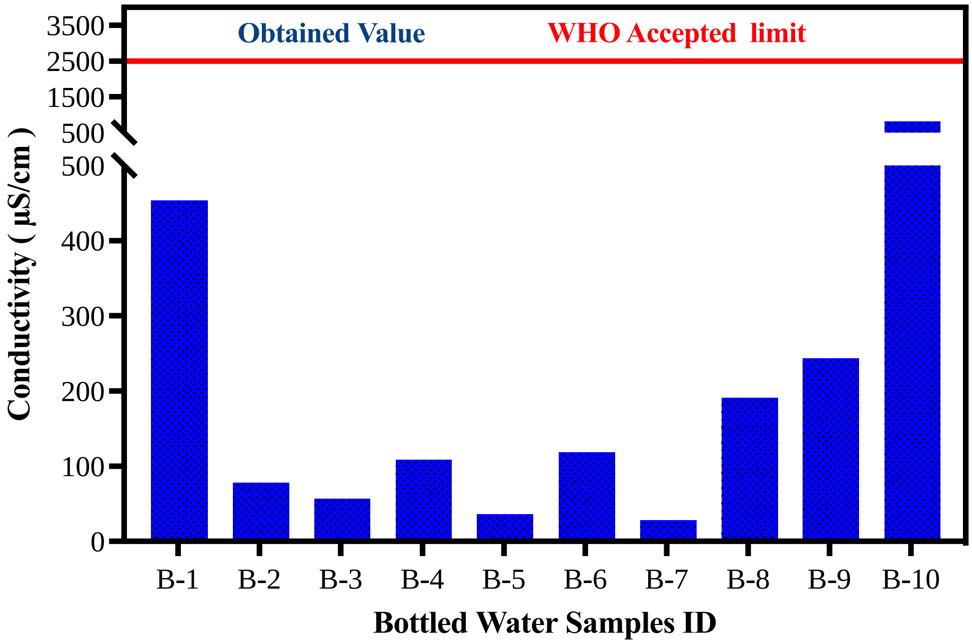

Fig. 4.3 Electrical conductivity of bottled water samples including the WHO recommended limit

Comparison of obtained and acceptable electrical conductivity values in jar water samples are shown in Figure 4.4a and 4.4b. All of the drinking bottled and jar water samples tested were well within the EC's recommended limit of 2500 μS/cm.

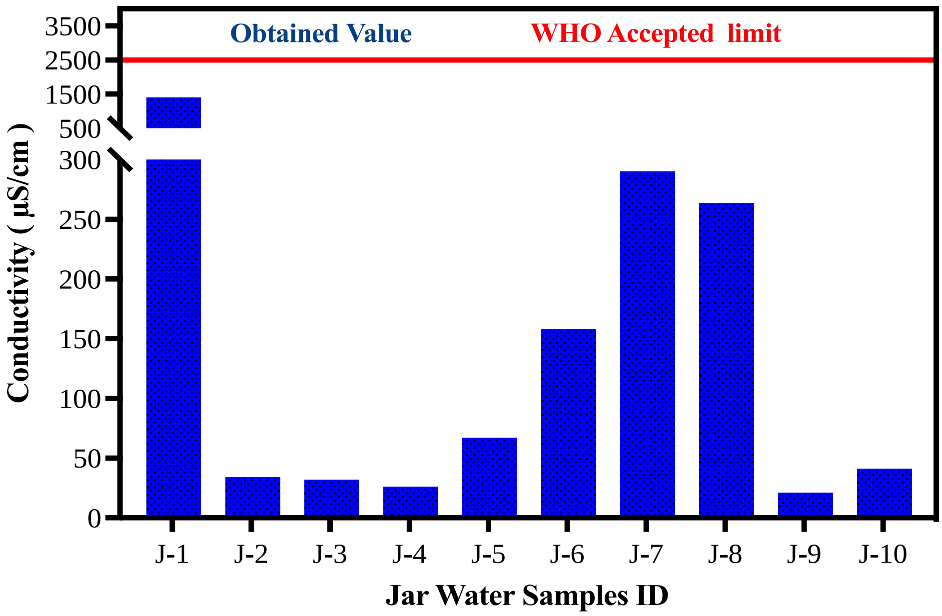

Fig. 4.4a Electrical conductivity of jar water samples including the WHO recommended limit

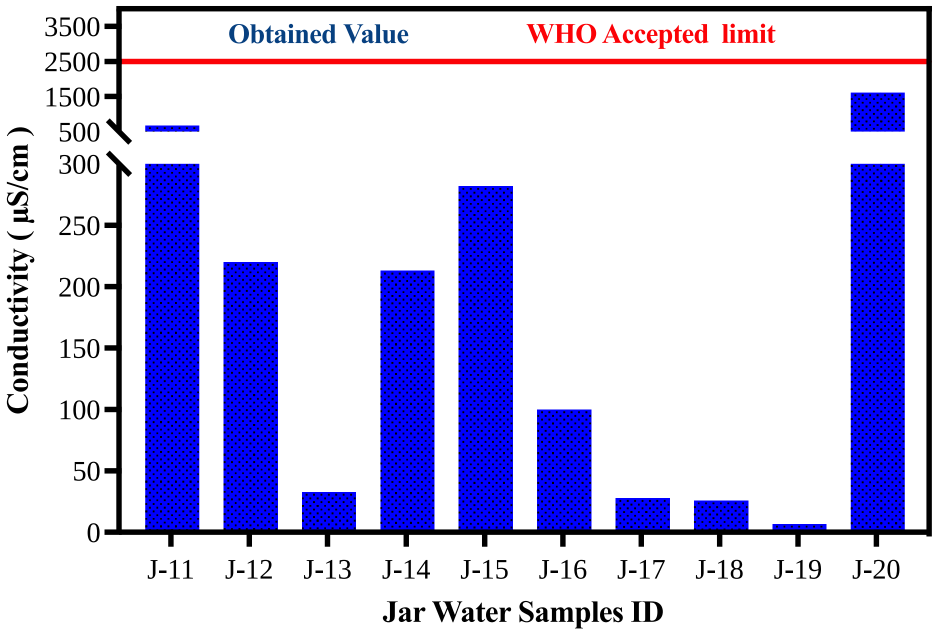

Fig. 4.4b. Electrical conductivity of jar water samples including the WHO recommended limit

4.1.3 Total Dissolved Solids (TDS)

The concentration of inorganic and organic components that are dissolved in water is referred to as the total dissolved solids, or TDS for short. The total dissolved solids (TDS) level is an essential indicator of the quality of drinking water in jars and bottles. The term "total dissolved solids" (TDS) refers to a mixture of many different types of chemicals, including minerals, salts, metals, and even other organic compounds. A taste that is salty or bitter may be the result of elevated TDS levels, which may also be an indicator of the presence of contaminants such as heavy metals, pesticides, or other types of pollution. The TDS content in drinking water can be measured in either parts per million (ppm) or milligrams per liter (mg/L), depending on the sample type. The United States Environmental Protection Agency has established a secondary maximum contaminant limit (SMCL) for TDS in drinking water at 500 mg/L (USEPA 2023). The World Health Organization recommends a maximum TDS level of 500 ppm for drinking water. While there are certain dissolved minerals that are good for human health, overly high TDS levels in drinking water may be a cause for concern for certain individuals, particularly those with immune systems that are already impaired. High levels of TDS may also be an indication that the water has been contaminated by industrial or agricultural activity, which, if eaten in large quantities, may have the potential to have negative impacts on one's health. As a result, it is essential to determine the TDS level of drinking water samples included in bottles and jars to guarantee that the water is fit for human consumption and does not pose any health risks. Regular testing can assist in the identification of possible problems and ensuring that proper treatment methods are in place to preserve the quality and safety of drinking water. According to the Indian standard specification for drinking water, drinking water can be categorized as TDS 300 mg/L excellent, 300–600 mg/L good, 600–900 mg/L fair, 900–1200 mg/L poor, and >1200 mg/L unacceptable (ISI 1983). Excellent drinking water has a total dissolved solids concentration of less than 300 mg/L. Like other findings reported in literature (Rahman *et al.*, 2012; Islam *et al.*, 2016), the TDS values of most of the samples were found below the limits recommended different by various standards, like WHO, EC, USEPA, BDS and BIS. Except for sample B-10, every single one of the bottled drinking water samples is rated "excellent." The value B-10 belongs to the 'good' category. Apart from samples J-1 and J-20, all of the jar water samples are considered to be in the 'good' category. Both the J-1 and the J-20 are in "good' condition. In addition to having an unpleasant flavor, water with extraordinarily low TDS concentrations sometimes lacks minerals and has a taste that is "flat" and "insipid." Conductance and TDS were shown to be associated when it was proven that when TDS grew, so did EC. The acquired results and the values specified on the label are reported in Table 4.1, and the achieved results are illustrated in Figure 4.5.

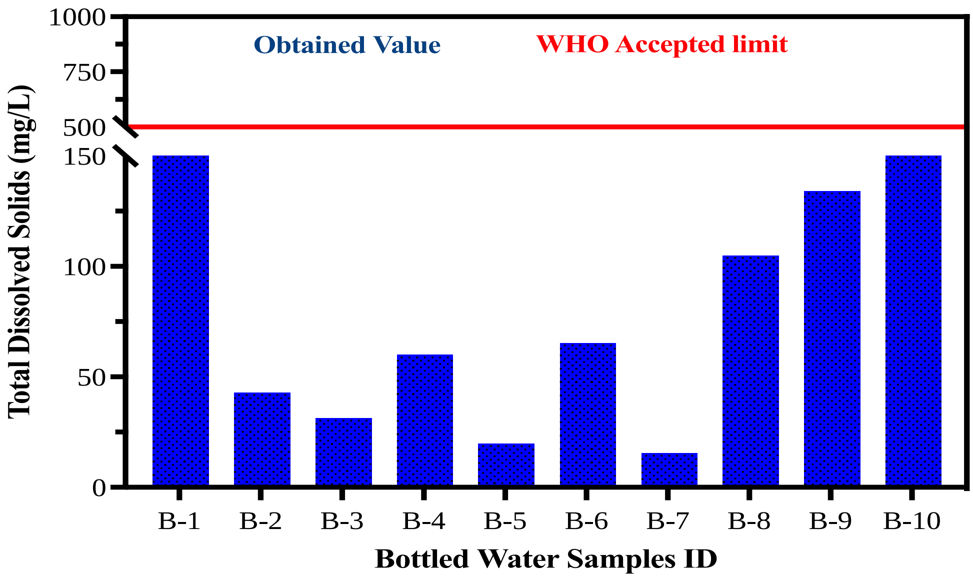

Fig. 4.5 TDS of bottled water samples including the WHO recommended limit

A comparison of the obtained results and acceptable values by WHO are presented in Figures 4.6a and 4.6b.

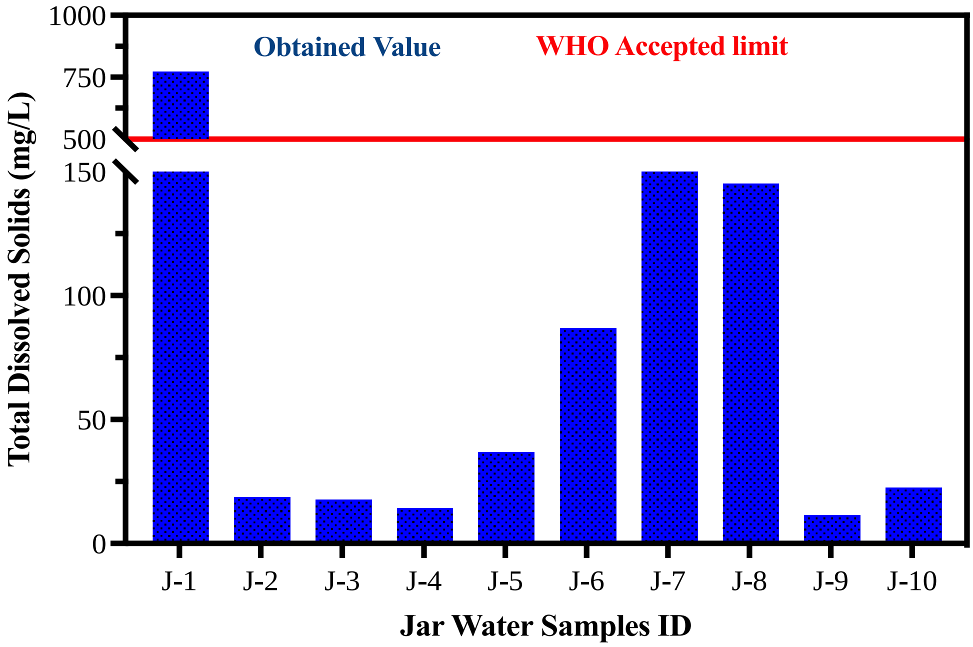

Fig. 4.6a TDS of jar water samples including the WHO recommended limit

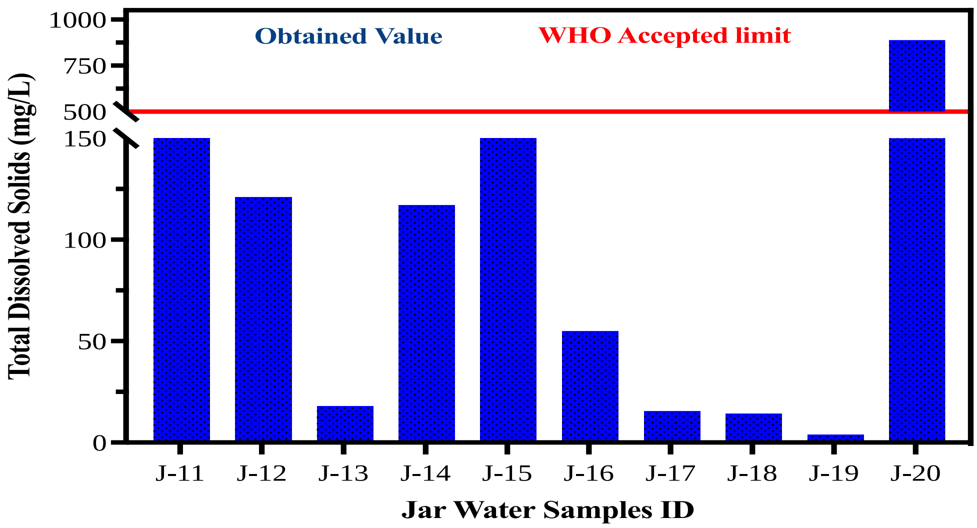

Fig. 4.6b TDS of jar water samples including the WHO recommended limit

4.2 Heavy Metal Analysis

Heavy metals are a class of toxic elements that can be found in drinking water, including in bottled and jar water samples. These metals can occur naturally or be introduced through human activities such as industrial and agricultural processes, mining, and landfill leachate. Exposure to heavy metals can have serious health consequences, particularly with prolonged or repeated exposure. Common heavy metals that can be present in drinking water include lead, arsenic, mercury, and cadmium. Even at low concentrations, these metals can have negative impacts on human health, causing various health issues ranging from acute toxicity to chronic exposure, including developmental and reproductive problems, neurological damage, and increased risk of cancer. The World Health Organization (WHO) has developed recommendations for the maximum safe quantities of heavy metals that can be found in drinking water. In many countries, the government or other regulatory agencies mandate routine testing of drinking water samples for heavy metal levels. This testing is done to guarantee that the water is safe for human consumption and can be found on the labels of bottled and jarred drinking water. Heavy metals in drinking water need to be tested and monitored on a consistent basis in order to identify any potential health problems and guarantee that proper treatment procedures are carried out in order to keep drinking water safe and healthy. To determine the levels of seven different heavy metals (Cr, Mn, Fe, Cu, Zn, Cd, and Pb) in bottled and jar water samples, an atomic absorption spectrophotometer was utilized to do the analysis. Based on the results of the test, it was determined that the levels of Cr, Mn, Fe, Cu, Zn, Cd, and Pb observed in the bottled water samples were not beyond the detection threshold of the equipment (Table 3.2). Heavy metals such as chromium, manganese, iron, copper, zinc, cadmium, and lead are examples of the types of elements that may be present in drinking water. Heavy metals pose a significant risk to human health, particularly when they are inhaled for extended periods of time or when people are exposed to the metals on a frequent basis. Iron and manganese are naturally occurring metals that have the potential to be found in drinking water in regions that have high concentrations of both elements in the soil. High concentrations of iron and manganese in drinking water can give the water a metallic flavor and produce coloring and staining; however, modest concentrations of these elements in water do not pose a health risk. Table 4.4 displays the recommended drinking water guideline values as established by the WHO (WHO 2011) and the EC (EC 1983). Table 4.4 displays the maximum amount of iron that can be present in drinking water according to a regulation established by the European Commission (EC) in 1983.

Table 4.4. The WHO (WHO 1996, 2006, 2011), EC (EC 1983, 1998), USEPA (USEPA 2018), BSTI (BSTI 1997) and Indian standard (BIS 2012) recommend heavy metal concentrations in drinking water

Standards/ Characteristics	**Mn mg/L**	**Fe mg/L**	**Pb mg/L**	**Cu mg/L**	**Zn mg/L**	**Cd mg/L**	**Cr mg/L**
WHO limit	0.4	-	0.01	2.0	3.0	0.003	0.05
EC limit	0.5	2.0	0.01	2.0	0.0-5.0	0.005	0.05
USEPA limit	0.05	--	--	1.3	7.4	--	--
BSTI limit	0.1	0.3-1.0	0.05	1.0	5.0	0.005	0.05
BIS limit	0.1	0.3	0.05	0.05	5.0	0.003	0.05

All the bottled and jar water samples that were put through the testing process had iron level that was below the detection limit of the instrument. The European Commission (EC) has established a recommendation (EC 1983) that states that drinking water may have no more than 2.0 mg/L of iron. Although just one of the jar water samples (J-12) was found to include iron at a concentration of 0.231 mg/L (Table 4.6), this level is well within the acceptable range established by the recommendation, which is focused more on factors related to appearance, such as taste, odor, and color, than on concerns related to human health. Iron is a nutrient that the human body cannot live without since it is necessary for the creation of hemoglobin, which is responsible for transporting oxygen throughout the body. However, excessive iron in drinking water can cause a number of concerns, including discoloration, staining of clothing and plumbing fixtures, and an unpleasant metallic taste. These issues can be avoided by drinking water that contains only the appropriate amount of iron. The presence of high concentrations of iron in drinking water can also encourage the growth of bacteria associated with iron, which can lead to the clogging of pipes and the production of a putrid odor. As a result, it is essential to make certain that the iron level of drinking water is within the standard parameters to ensure that the water is of high quality and to avoid any cosmetic problems. If the iron content of the drinking water is found to be higher than the recommended levels, treatment may be necessary to bring the concentration of iron down to an acceptable level. The removal of iron from drinking water is often accomplished by the processes of sedimentation, filtration, oxidation, and ion exchange. Copper is yet another nutrient that cannot be produced by the human body and is necessary for the body to perform its normal physiological processes. However, an excessive amount of copper in drinking water can create health problems such as stomach cramps, nausea, and vomiting. This is especially true for people who have Wilson's disease, a genetic illness that inhibits the body's ability to handle copper. Copper in drinking water at high enough concentrations can cause liver and kidney damage if consumed over a prolonged period. Copper was discovered in all the bottled and jarred water samples; however, the ranges for the bottled water samples were between 0.012 and 0.027 mg/L (Figure 4.7), and the ranges for the jarred water samples were between 0.016 and 0.033 mg/L (Figures 4.8a and 4.8b).

When the amount of copper in drinking water falls within the parameters set forth by the WHO, the water is regarded as being fit for human consumption. The recommended value for copper in drinking water established by the WHO (WHO 2011) and the EC (EC 1983) is 2 mg/L. This number was determined based on health concerns, such as limiting the danger of immediate gastrointestinal effects, as well as long-term health impacts, such as damage to the liver and kidneys. As a direct consequence of this, the amount of copper found in each and every sample of bottled and jarred water that was examined fell within the parameters set forth by the WHO and the EC. To maintain a high level of water quality and steer clear of potential dangers to one's health, it is essential to check that the amount of copper present in one's drinking water falls within the parameters set forth by the WHO.

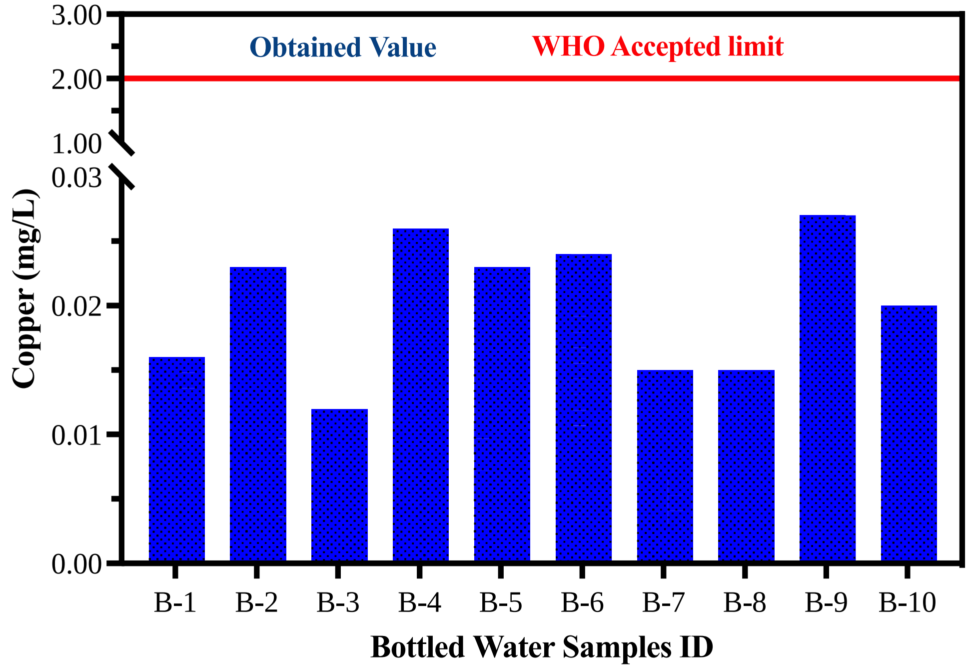

Fig. 4.7 Copper content in bottled water samples including the WHO recommended limit

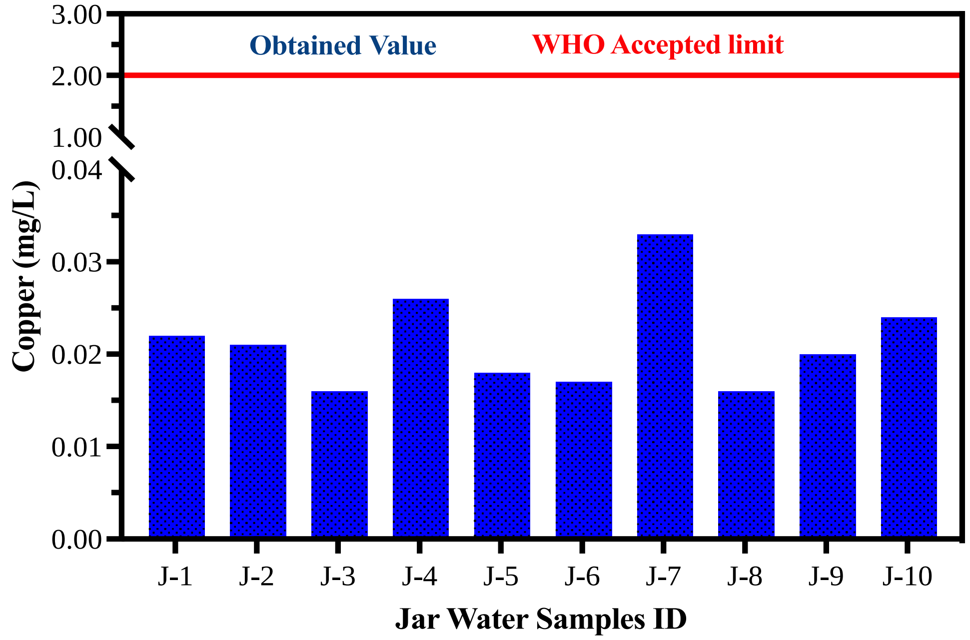

Fig. 4.8a Copper content in jar water samples including the WHO recommended limit

If the copper content in drinking water is above the WHO guidelines (WHO 2011), treatment may be required to reduce the concentration of copper to an acceptable level.

Common treatment methods for reducing copper in drinking water include reverse osmosis, distillation, and ion exchange.

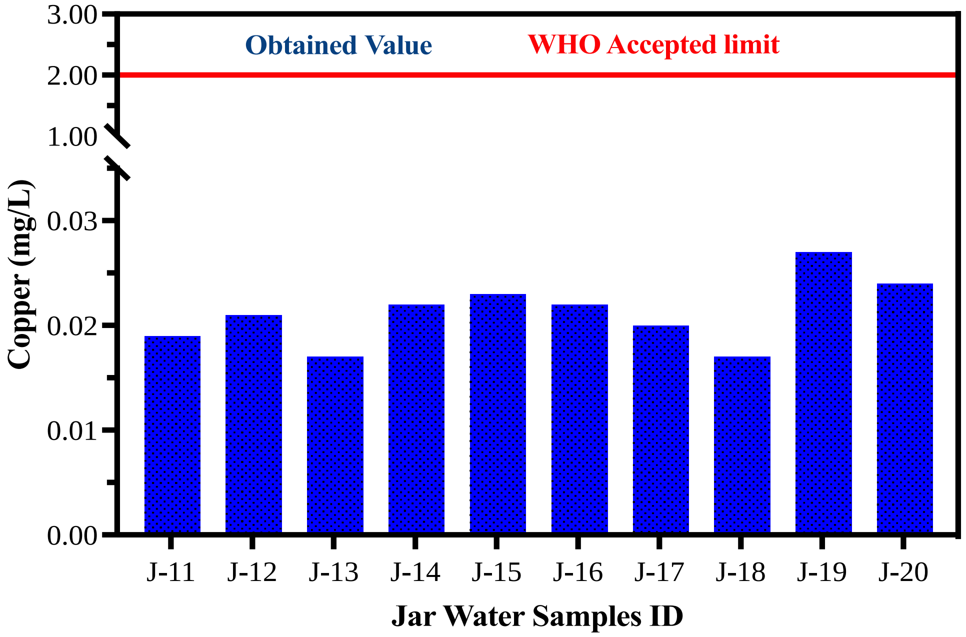

Fig. 4.8b Copper content in jar water samples including the WHO recommended limit

Manganese is yet another essential nutrient for the human body, and it is necessary for a number of different physiological processes. However, manganese levels in drinking water that are too high can be harmful to one's health and induce a variety of neurological symptoms, such as tremors, memory loss, and cognitive deficiencies, especially in newborns and young children. Adults who have had long-term exposure to high levels of manganese in their drinking water may develop symptoms similar to those of Parkinson's disease. The levels of manganese found in samples J-12, J-14, and J-15 that were examined were, respectively, 0.014 mg/L, 0.067 mg/L, and 0.059 mg/L (Table 4.6). These measurements fell short of the thresholds set by the WHO (WHO 2011) and the EC (EC 1983), which were respectively 0.4 mg/L and 0.5 mg/L. It is regarded as safe for human consumption if the amount of manganese in drinking water falls within the parameters set forth by the WHO. It is possible that manganese reduction treatment will be necessary to bring the concentration of manganese in the drinking water down to an acceptable level if the WHO and EC criteria are exceeded. Ion exchange, sedimentation, and filtration are the most commonly used water treatment procedures for lowering manganese levels in drinking water. In jar water samples, the concentrations of the remaining four heavy metals, which include Cr, Zn, Cd, and Pb, are all below the limit for detection. Table 4.5 displays the heavy metal concentration measured in milligrams per liter of bottled water samples analyzed and obtained from the CCC zone.

Table 4.5. The concentration of heavy metals (mg/L) in bottled water samples

ID	Cr	Mn	Fe	Cu	Zn	Cd	Pb
B-1	BDL	BDL	BDL	0.016	BDL	BDL	BDL
B-2	BDL	BDL	BDL	0.023	BDL	BDL	BDL
B-3	BDL	BDL	BDL	0.012	BDL	BDL	BDL
B-4	BDL	BDL	BDL	0.026	BDL	BDL	BDL
B-5	BDL	BDL	BDL	0.023	BDL	BDL	BDL
B-6	BDL	BDL	BDL	0.024	BDL	BDL	BDL
B-7	BDL	BDL	BDL	0.015	BDL	BDL	BDL
B-8	BDL	BDL	BDL	0.015	BDL	BDL	BDL
B-9	BDL	BDL	BDL	0.027	BDL	BDL	BDL
B-10	BDL	BDL	BDL	0.020	BDL	BDL	BDL
Minimum	BDL	BDL	BDL	0.012	BDL	BDL	BDL
Maximum	BDL	BDL	BDL	0.027	BDL	BDL	BDL
Mean	BDL	BDL	BDL	0.020	BDL	BDL	BDL
SD	0.000	0.000	0.000	0.005	0.000	0.000	0.000

BDL: Below Detection Limit

Among the seven heavy metals studied only copper was detected in all bottled water samples what is discussed before. Rest of them (Cr, Mn, Fe, Zn, Cd and Pb) were below the detection limit in bottled samples (Tables 4.5). Chromium is a heavy metal that can be found in drinking water from natural sources or from industrial activities such as electroplating and leather tanning. Exposure to hexavalent chromium, a highly toxic form of chromium, can cause lung cancer and other respiratory problems.

Table 4.6. The concentration of heavy metals (mg/L) in the studied jar water samples

ID	Cr	Mn	Fe	Cu	Zn	Cd	Pb
J-1	BDL	BDL	BDL	0.022	BDL	BDL	BDL
J-2	BDL	BDL	BDL	0.021	BDL	BDL	BDL
J-3	BDL	BDL	BDL	0.016	BDL	BDL	BDL
J-4	BDL	BDL	BDL	0.026	BDL	BDL	BDL
J-5	BDL	BDL	BDL	0.018	BDL	BDL	BDL
J-6	BDL	BDL	BDL	0.017	BDL	BDL	BDL
J-7	BDL	BDL	BDL	0.033	BDL	BDL	BDL
J-8	BDL	BDL	BDL	0.016	BDL	BDL	BDL
J-9	BDL	BDL	BDL	0.020	BDL	BDL	BDL
J-10	BDL	BDL	BDL	0.024	BDL	BDL	BDL
J-11	BDL	BDL	BDL	0.019	BDL	BDL	BDL
J-12	BDL	0.014	0.231	0.021	BDL	BDL	BDL
J-13	BDL	BDL	BDL	0.017	BDL	BDL	BDL
J-14	BDL	0.067	BDL	0.022	BDL	BDL	BDL
J-15	BDL	0.059	BDL	0.023	BDL	BDL	BDL
J-16	BDL	BDL	BDL	0.022	BDL	BDL	BDL
J-17	BDL	BDL	BDL	0.020	BDL	BDL	BDL
J-18	BDL	BDL	BDL	0.017	BDL	BDL	BDL
J-19	BDL	BDL	BDL	0.027	BDL	BDL	BDL
J-20	BDL	BDL	BDL	0.024	BDL	BDL	BDL
Minimum	BDL	0.014	BDL	0.016	BDL	BDL	BDL
Maximum	BDL	0.067	0.231	0.033	BDL	BDL	BDL
Mean	BDL	0.047	0.231	0.0213	BDL	BDL	BDL
SD	0.000	0.019	0.052	0.004	0.000	0.000	0.000

BDL: Below Detection Limit

Zinc is an essential mineral that can also be found in the water that people drink. Although small amounts of zinc are required for human health, excessive amounts of zinc in one's drinking water can lead to symptoms such as nausea, vomiting, and diarrhea. Cadmium is a dangerous heavy metal that can be found in drinking water. It can come from natural sources like rocks and soil, or it can come from industrial processes like mining and smelting. Cadmium can harm the kidneys, create respiratory issues, and increase the risk of cancer if exposed to it over a long period of time. Lead is a very poisonous heavy metal that can be introduced into drinking water using lead plumbing and fittings, as well as using lead in industrial processes like mining and smelting. In infants, lead poisoning can cause developmental and cognitive issues, while in adults, excessive amounts of lead poisoning can induce seizures, comas, and even death.

There are several treatment methods that can be used to reduce heavy metals from drinking water. The most common methods include: coagulation and filtration; ion exchange; reverse osmosis; activated carbon adsorption and electro-dialysis. It's important to note that different heavy metals require different treatment methods. Some methods may work better for certain types of heavy metals, so it's important to determine which heavy metals are present in the water before selecting a treatment method. Additionally, some treatment methods may not be effective at removing all types of heavy metals, so it's important to consult with a water treatment professional to determine the best method for a specific situation.

4.2.1 The Heavy Metal Pollution Index (HPI)

The Heavy Metal Contamination Index (HPI) is a measure that evaluates the level of contamination in water samples caused by heavy metals. The heavy metal pollution index (HPI) calculates a pollution index value for a given water sample by taking into consideration the quantities of a number of different heavy metals present in the sample. The higher the value of the HPI, the greater the amount of heavy metal pollution that is present in the water. The World Health Organization (WHO) and the European Commission (EC) both give guidelines for heavy metal pollution in water, including the use of the Heavy Metal Pollution Index (HPI) as a measure for assessing the degree of heavy metal pollution in water samples. These guidelines may be found on each of their respective websites. The World Health Organization (WHO) has established recommendations for the maximum quantities of different heavy metals that are allowed to be present in drinking water. These metals include chromium, manganese, iron, copper, zinc, cadmium, and lead, amongst others. These recommendations are meant to safeguard the general population's health and guarantee that the water supply is fit for human consumption. The European Commission also establishes standards for the maximum amounts of heavy metals that are allowed in water. These metals include lead, cadmium, chromium, and a variety of others. The EC recommendations are applicable to all varieties of water, including drinking water, surface water, and groundwater alike. The World Health Organization (WHO) and the European Commission (EC) have both acknowledged the significance of utilizing the Heavy Metals Contamination Index (HPI) to evaluate the degree of heavy metal contamination in water samples. The heavy metal pollution index (HPI) is a helpful tool for evaluating the overall degree of heavy metal pollution in a water sample. It can also assist in the identification of potential health hazards connected with exposure to heavy metals. The HPI can take values anywhere from 0 to infinity. Values of the Heavy Metal Potential Index (HPI) that are higher than one suggests that there is heavy metal pollution present in the water; values that are lower than one indicate that the water is safe for human consumption. The magnitude of the HPI value can be used to infer the seriousness of the pollution that has been measured. A higher HPI rating indicates a higher overall amount of pollution. Because the HPI ranges for heavy metal contamination in drinking bottle water (Table 4.7) were below 1 (the HPI Index), this indicates that the concentration of heavy metals in the water is not at a level that is hazardous to human health.

Table 4.7. Heavy metals pollution index (HPI) of bottled water samples

Parameter	**Standard permissible limit $(\mu g/L)$, S_i**	**Ideal value $(\mu g/L)$, I_i**	**Mean con. $(\mu g/L)$, M_i**	**Unit weight value, W_i**	**Sub-index, Q_i**	**$W_i Q_i$**	**Mean HPI**
Cd	5	3	0	0.2000	150.0000	30.0000	91.6310
Cr	50	0	0	0.0200	0.0000	0.0000	0.0000
Cu	1500	50	20.1	0.0007	2.0621	0.0014	0.0042
Fe	300	0	0	0.0033	0.0000	0.0000	0.0000
Mn	300	100	0	0.0033	50.0000	0.1667	0.5091
Pb	10	0	0	0.1000	0.0000	0.0000	0.0000
Zn	15000	5000	0	6.66×10^{-05}	50.0000	0.0033	0.0102

The HPI ranges for heavy metal contamination jar water (Table 4.8) samples were below 1 (HPI Index), it means that the concentration of heavy metals in the water is not at a level that poses a risk to human health.

Table 4.8. Heavy metals pollution index (HPI) of jar water samples

Parameter	Standard permissible limit $(\mu g/L), S_i$	Ideal value $(\mu g/L), I_i$	Mean con. $(\mu g/L), M_i$	Unit weight value, W_i	Sub-index, Q_i	W_iQ_i	Mean HPI
Cd	5	3	0	0.2000	150.0000	30.0000	91.6310
Cr	50	0	0	0.0200	0.0000	0.0000	0.0000
Cu	1500	50	21.3	0.0007	1.9793	0.0013	0.0040
Fe	300	0	12	0.0033	4.0000	0.0133	0.0407
Mn	300	100	7	0.0033	46.5000	0.1550	0.4734
Pb	10	0	0	0.1000	0.0000	0.0000	0.0000
Zn	15000	5000	0	6.66×10^{-05}	50.0000	0.0033	0.0102

However, it's important to note that the HPI may not necessarily reflect the overall quality of the water. Other factors such as microbial contamination, organic pollutants, and physical properties of the water may also affect its safety and quality. Therefore, while it's a good sign if the HPI is within the WHO and EC guidelines, it's still important to regularly monitor the quality of the water to ensure that it continues to meet these standards and is safe for consumption.

4.2.2 The Nemerow's Pollution Index (NPI)

The Nemerow's pollution index (NPI) is a method for evaluating the overall level of pollution in water samples, including drinking water samples. This index is used to measure the overall degree of pollution in water. The NPI considers the quantities of several pollutants present in the water sample. These pollutants can include heavy metals, organic compounds, and other types of contaminants. The NPI can take on values anywhere from 0 all the way up to infinity, with higher values indicating larger amounts of pollution in the water sample. If the value is zero, then the water sample does not include any pollutants; if the value is one or higher, then the water sample is polluted. Since the NPI ranges for heavy metal contamination in drinking bottle water (Table 4.9 and jar water (Table 4.10) samples were below 1 (NPI Index), this indicates that the total amount of pollution in the water is not at a level that is dangerous to human health. However, similar to the HPI, it is essential to keep in mind that the NPI may not necessarily be an accurate representation of the water's quality as a whole. In addition to microbial contamination and organic contaminants, the water's physical characteristics may also be a factor in determining both its quality and its level of risk. Therefore, even though it's a good indicator if the NPI is within the parameters established by the WHO and the EC, it's still vital to frequently test the quality of the water to make certain that it continues to fulfill these standards and that it is safe for consumption. In addition, it is essential to keep in mind that various types of pollutants may have various effects on a person's health. As a result, it is essential to recognize and keep track of the many pollutants that may be present in the water to guarantee that their concentrations are also well within the range of what is considered safe.

Table 4.9 Nemerow's Pollution Index (NPI) of bottled water samples

NPI values										
Sam. ID	**pH**	**EC**	**TDS**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Pb**	**Zn**
		(µS/cm)	**(mg/L)**							
B-1	0.757	1.513	0.499	0	0	0.016	0	0	0	0
B-2	0.884	0.260	0.086	0	0	0.023	0	0	0	0
B-3	0.789	0.190	0.063	0	0	0.012	0	0	0	0
B-4	0.867	0.363	0.119	0	0	0.026	0	0	0	0
B-5	0.833	0.120	0.039	0	0	0.023	0	0	0	0
B-6	0.775	0.396	0.131	0	0	0.024	0	0	0	0
B-7	0.801	0.093	0.031	0	0	0.015	0	0	0	0
B-8	0.924	0.636	0.210	0	0	0.015	0	0	0	0
B-9	0.793	0.813	0.268	0	0	0.027	0	0	0	0
B-10	0.745	2.740	0.904	0	0	0.020	0	0	0	0
Mean	0.817	0.713	0.235	0	0	0.0201	0	0	0	0
Minimum	0.745	0.093	0.031	0	0	0.012	0	0	0	0
Maximum	0.924	2.740	0.904	0	0	0.027	0	0	0	0

Table 4.10. Nemerow's Pollution Index (NPI) of jar water samples

NPI values										
Sam. ID	**pH**	**EC**	**TDS**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Pb**	**Zn**
		(µS/cm)	(mg/L)							
J-1	0.852	4.686	1.546	0	0	0.022	0	0	0	0
J-2	0.894	0.113	0.037	0	0	0.021	0	0	0	0
J-3	0.858	0.106	0.035	0	0	0.016	0	0	0	0
J-4	0.853	0.086	0.028	0	0	0.026	0	0	0	0
J-5	0.858	0.223	0.074	0	0	0.018	0	0	0	0
J-6	0.821	0.526	0.175	0	0	0.017	0	0	0	0
J-7	0.828	0.966	0.319	0	0	0.033	0	0	0	0
J-8	0.822	0.88	0.290	0	0	0.016	0	0	0	0
J-9	0.785	0.070	0.023	0	0	0.020	0	0	0	0
J-10	0.767	0.136	0.045	0	0	0.024	0	0	0	0
J-11	0.772	2.266	0.748	0	0	0.019	0	0	0	0
J-12	0.785	0.733	0.242	0	0	0.021	0.770	0.140	0	0
J-13	0.742	0.110	0.036	0	0	0.017	0	0	0	0
J-14	0.736	0.710	0.234	0	0	0.022	0	0.670	0	0
J-15	0.746	0.940	0.310	0	0	0.023	0	0.590	0	0
J-16	0.756	0.333	0.110	0	0	0.022	0	0	0	0
J-17	0.758	0.093	0.031	0	0	0.020	0	0	0	0
J-18	0.758	0.086	0.028	0	0	0.017	0	0	0	0
J-19	0.765	0.023	0.007	0	0	0.027	0	0	0	0
J-20	0.855	5.386	1.777	0	0	0.024	0	0	0	0
Mean	0.801	0.924	0.305	0	0	0.021	0.038	0.070	0	0
Minimum	0.736	0.023	0.007	0	0	0.016	0	0.000	0	0
Maximum	0.894	5.386	1.777	0	0	0.033	0.77	0.670	0	0

4.3 Microbial Analysis

Microbial analysis is an important measure of water quality in drinking bottled and jar water samples. Microbes such as bacteria, viruses, and protozoa can be present in water, and their presence can have serious health consequences. In particular, the presence of pathogenic micro-organisms such *as E. coli, Salmonella,* and *Cryptosporidium* can cause illnesses such as diarrhea, nausea, and vomiting. These pathogens can be introduced into the water through a variety of sources, including sewage or animal waste contamination, and can survive in water for extended periods. Microbial analysis of drinking bottled and jar water samples typically involves testing for the presence of specific microbial contaminants using methods such as culture-based techniques or molecular biology assays. These tests can detect the presence of harmful bacteria and other pathogens, as well as assess the overall microbial quality of the water. In many countries, drinking bottled and jar water samples are regulated by the government or other regulatory bodies, which mandate regular testing for microbial contamination to ensure that the water is safe for human consumption. Regular testing and monitoring of microbial contaminants in drinking water are crucial to identify any potential health risks and ensure that appropriate treatment measures are taken to maintain safe and healthy drinking water. The result of microbial parameters in bottled water collected from CCC regions is shown in Table 4.11 and Figure 4.9.

Table 4.11. Microbial parameters of bottled water samples

Samples	**Microbial Parameters**	
	Total bacterial count (CFU/mL)	**Coliform count/100mL**
B-1	1.836×10^3	ND
B-2	0.015×10^3	ND
B-3	0.302×10^3	ND
B-4	1.050×10^3	ND
B-5	0.2×10^3	ND
B-6	0.002×10^3	ND
B-7	0.68×10^3	ND
B-8	0.36×10^3	ND
B-9	4.2×10^3	ND
B-10	0.048×10^3	ND

The total bacterial count was found in all ten brands of bottled water gathered from ten different Chattogram City Corporation locations. The total bacterial count for three of ten bottled water samples (B-1, B-4, and B-9) exceeds the acceptable limit while eight jar samples (J-1, J-2, J-3, J-5, J-9, J-12, J-13 and J-16) out of twenty are above the tolerable limit.

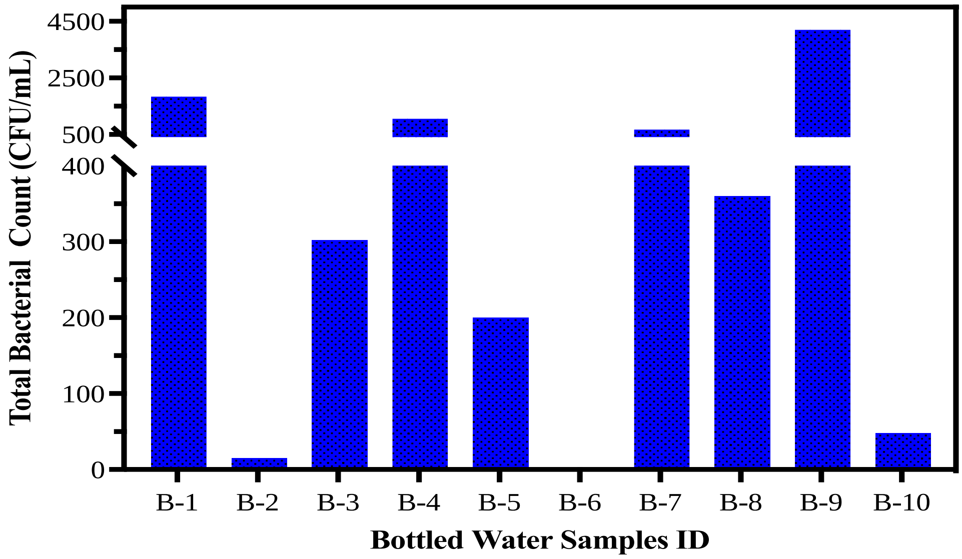

Fig. 4.9 The total bacterial counts in bottled water samples

The microbial parameters of drinking jar water samples are shown in Table 4.12, and Figure 4.10a and 4.10b.

In the context of microbial contamination, 40% of portable bottled water samples and 33.33% of jar water samples were found to be infected by pathogenic micro-organisms. All bacterial pathogens and opportunistic pathogens are heterotrophic bacteria, and some of them can grow on the medium that is used for definitive standard plate counts or heterotrophic plate counts in drinking water differential media to separate pathogens and adaptable pathogens from non-pathogens. In spite of the fact that the findings of the study indicate that the majority of samples from both categories fall below the tolerance threshold, the study also found that a sizeable percentage of samples from both types of categories were found to be beyond the tolerance limit. All of the bottled and jarred water samples are clean enough to pass the World Health Organization's drinking water requirement of zero coliforms per 100 mL.

Table 4.12. Microbial parameters of jar water samples

Samples	Microbial parameters	
	Total Bacterial Count (CFU/mL)	Coliform Count/100mL
J-1	1.0×10^3	ND
J-2	1.596×10^3	ND
J-3	1.665×10^3	ND
J-4	0.60×10^3	ND
J-5	4.0×10^3	ND
J-6	0.10×10^3	ND
J-7	0.896×10^3	ND
J-8	0.784×10^3	ND
J-9	4.0×10^3	ND
J-10	0.2×10^3	ND
J-11	0.132×10^3	ND
J-12	1.71×10^3	ND
J-13	2.178×10^3	ND
J-14	0.38×10^3	ND
J-15	0.545×10^3	ND
J-16	2.255×10^3	ND
J-17	0.014×10^3	ND
J-18	0.132×10^3	ND
J-19	0.54×10^3	ND
J-20	0.56×10^3	ND

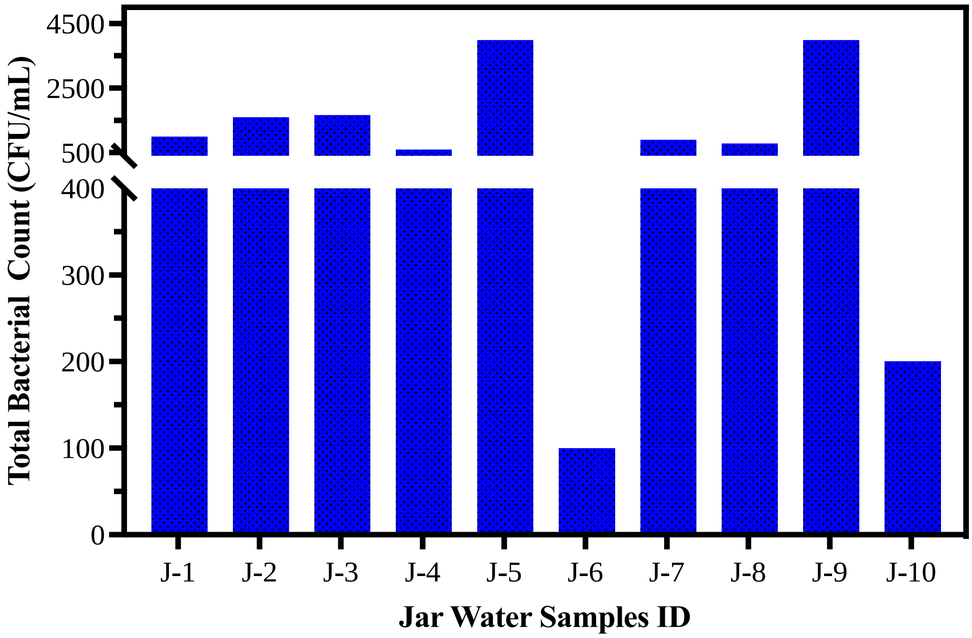

Fig. 4.10a Total bacterial counts in jar water samples

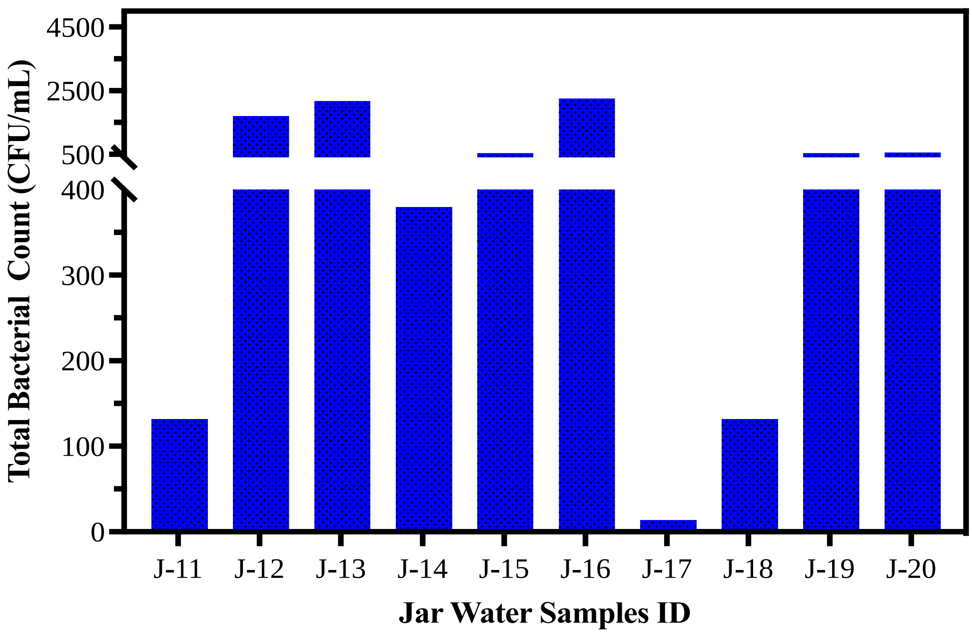

Fig. 4.10b Total bacterial counts in jar water samples

4.3.1 Pearson Correlation Coefficient Matrix of Drinking Water Samples

The Pearson correlation coefficient shown in Table 4.13 and Table 4.14 are statistical measure of the strength of the linear relationship between two variables. In the context of drinking water samples, the Pearson correlation coefficient can be used to assess the degree of correlation between different water quality parameters. For example, the correlation between pH and EC, or between iron and manganese concentrations.

Table 4.13. Pearson correlation coefficient matrix of bottled water samples

Parameter	pH	TDS	Cr	Mn	Fe	Cu	Zn	Cd	Pb	TBC	Coliform
pH	1										
TDS	-0.515	1									
Cr	0.000	0.000	1								
Mn	0.000	0.000	0	1							
Fe	0.000	0.000	0.000	0.000	1						
Cu	0.079	-0.034	0.000	0.000	0.000	1					
Zn	0.000	0.000	0.000	0.000	0.000	0.000	1				
Cd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1			
Pb	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1		
TBC	-0.199	0.092	0.000	0.000	0.000	0.333	0.000	0.000	0.000	1	
Coliform	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1

TBC=Total bacterial count (CFU/mL)

Coliform count per 100 mL

The Pearson correlation coefficient is ranges from -1 to +1. A value of -1 indicates a perfectly negative correlation, a value of +1 indicates a perfectly positive correlation, and a value of 0 indicates no correlation. The magnitude of the coefficient represents the strength of the correlation, with larger absolute values indicating stronger correlations. There was no strong correlation found among different parameters measured in this study.

Table 4.14. Pearson correlation coefficient matrix of jar water samples

Parameter	**pH**	**TDS**	**Cr**	**Mn**	**Fe**	**Cu**	**Zn**	**Cd**	**Pb**	**TBC**	**Coliform**
pH	1										
TDS	0.296	1									
Cr	0.000	0.000	1								
Mn	-0.431	-0.029	0.000	1							
Fe	-0.077	-0.030	0.000	0.085	1						
Cu	0.034	0.153	0.000	0.096	-0.014	1					
Zn	0.000	0.000	0.000	0.000	0.000	0.000	1				
Cd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1			
Pb	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1		
TBC	0.204	-0.213	0.000	-0.185	0.108	-0.209	0.000	0.000	0.000	1	
Coliform	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1

TBC=Total bacterial count (CFU/mL)

Coliform count per 100 mL

If the result of the Pearson correlation coefficient is +1, it indicates a perfect positive correlation between the two variables. This means that as one variable increases, the other variable also increases in a linear fashion. For example, if we were looking at the relationship between age and height in a group of people, a Pearson correlation coefficient of +1 would indicate that as age increases, height also increases in a linear fashion. Simultaneously, if the result of the Pearson correlation coefficient is -1, it shows that there is a perfect negative correlation between the two variables. This indicates that the value of the other variable will experience a linearly decreasing trend whenever the value of the first variable grows. If we were looking at the relationship between temperature and ice cream sales, for instance, a Pearson correlation coefficient of -1 would imply that ice cream sales decline in a linear fashion as temperature increases. This would be the case if we looked at the relationship between temperature and ice cream sales. A robust and predictable association exists between the two variables, whether the Pearson correlation coefficient is positive or negative. This is the case regardless of whether the value is +1 or -1. However, it is essential to keep in mind that correlation does not imply causation, and additional investigation is necessary to ascertain the underlying cause-and-effect relationship that exists between the two variables in question.

4.3.2 Water Quality Index of Drinking Water Samples

The Water Quality Index (WQI) ranges from 0 to 100, with higher values indicating poorer water quality. This index was developed by the United States Environmental Protection Agency. If the value is 0, it indicates that the water quality satisfies all of the requirements for the parameters that were checked, and if the value is 100, it shows that the water quality does not satisfy the prerequisites for any of the parameters that were examined. The general guideline for interpreting the WQI score ranges is shown in Table 4.15.

Table 4.15. Water quality index (WQI) range, status and possible usage of the water sample (Bouslah *et al*., 2017)

WQI range	Water quality status	Possible usage
0-25	Excellent	drinking, irrigation and industrial
26-50	Slightly polluted(good)	drinking, irrigation and industrial
51-75	Moderately polluted (poor)	irrigation and industrial
76-100	Polluted (very poor)	irrigation
Above 100	Excessively polluted (unsuitable)	proper treatment required before use

The water quality indices (WQI) of all measured parameters for bottled and jar waters are presented in Tables 4.16 to 4.18.

Table 4.16. Water quality index of bottled water samples

SL No.	Parameter	Observed value	Standard value	Wn	Quality rating Qn	Weighted value Wn.Qn
1	pH	7.00	8.5	0.0003	0.00	0.0000
2	EC	213.80	300	8.59×10^{-06}	71.27	0.0006
3	TDS	117.59	500	5.15×10^{-06}	23.52	0.0001
4	Cd	0.00	0.003	0.8600	0.00	0.0000
5	Cr	0.00	0.05	0.0515	0.00	0.0000
6	Cu	0.02	1	0.0026	2.01	0.0052
7	Fe	0.00	0.3	0.0086	0.00	0.0000
8	Mn	0.00	0.1	0.0258	0.00	0.0000
9	Pb	0.00	0.05	0.0515	0.00	0.0000
10	Zn	0.00	5	0.0005	0.00	0.0000
				ΣWn = 1	ΣQn = 96.795	ΣWnQn = 0.0059
WQI = ΣQnWn / ΣWn = 0.0059/1 = 0.0059						

Table 4.17. Water quality index of jar water samples

SL No.	Parameter	Observed value	Standard value	Wn	Quality rating Qn	Weighted value Wn.Qn
1	pH	6.81	8.5	0.0003	0.00	0.0000
2	EC	277.2	300	8.59×10^{-06}	92.40	0.0008
3	TDS	152.45	500	5.15×10^{-06}	30.49	0.0002
4	Cd	0.00	0.003	0.8600	0.00	0.0000
5	Cr	0.00	0.05	0.0515	0.00	0.0000
6	Cu	0.02	1	0.0026	2.13	0.0055
7	Fe	0.012	0.3	0.0086	3.85	0.0331
8	Mn	0.01	0.1	0.0258	7.00	0.1804
9	Pb	0.00	0.05	0.0515	0.00	0.0000
10	Zn	0.00	5	0.0005	0.00	0.0000
				ΣWn = 1	ΣQn = 135.86	ΣWnQn = 0.2199
WQI = ΣQnWn / ΣWn = 0.2199/1 = 0.2199						

All the bottle and jar water samples were rated as having high drinking quality (WQI value 50). (Table 4.15). Nine out of the ten water parameters tested of the total samples showed good-quality drinking water (WQI value <25), and only the parameter EC showed poor-quality drinking water (WQI value >70), which indicates moderately polluted.

If the water quality index (WQI) values of a water sample high compared to the WHO and EC guidelines, it suggests that the water quality is poor and may pose a risk to human health and the environment. This indicates that the water samples have higher levels of contaminants and pollutants than what is considered safe for human consumption or environmental protection in terms of electrical conductivity. The obtained values of WQI in terms of TDS for jar water samples indicates slightly (26-50) levels of contaminant and pollutants. It is also important to note that while WHO and EC guidelines provide a useful reference for water quality, they are not necessarily applicable to all regions or situations. Some regions may have different water quality standards or regulations based on local conditions and water use patterns. Therefore, it is important to consider site-specific information and local regulations when assessing water quality and making decisions about water management and treatment.

Table 4.18. Water quality index for the physico-chemical parameters of bottled and jar water samples

Sample	**Parameter**	**Water quality index**	**Water quality status**
Bottled water	pH	0.000	Excellent
	EC	71.267	Moderately polluted (poor)
	TDS	23.518	Excellent
	Cr	0.000	Excellent
	Mn	0.000	Excellent
	Fe	0.000	Excellent
	Cu	2.010	Excellent
	Zn	0.000	Excellent
	Cd	0.000	Excellent
	Pb	0.000	Excellent
Jar water	pH	0.000	Excellent
	EC	92.400	Polluted (very poor)
	TDS	30.490	Slightly polluted (good)
	Cr	0.000	Excellent
	Mn	0.070	Excellent
	Fe	3.850	Excellent
	Cu	2.125	Excellent
	Zn	0.000	Excellent
	Cd	0.000	Excellent
	Pb	0.000	Excellent

Chapter 5: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Portable drinking water systems are common everywhere in the world for our daily consumption, but it is very important to maintain the quality of bottled and jar water. In this research, it was found that-

i. The physico-chemical properties of bottled and jar water samples were within the guidelines of national and international standard.

ii. Copper was detected in all the tested bottled and jar water samples and it ranged from 0.012 to 0.027 mg/L and 0.016 to 0.033 mg/L respectively. These values copper content are within the guidelines of national and international standard.

iii. Only few jar water samples contained Fe and Mn. Those values were below the values indicated in the guidelines recommended WHO and EC.

iv. The analysis also revealed that the concentration of Cd, Cr, Fe, Mn, Pb and Zn in bottled water, and Cd, Cr, Pb and Zn in jar water samples were below the detection limit of the instrument.

v. The tested drinking water samples contain pathogenic micro-organisms. The pathogenic bacteria were present in one-third of the tested bottled and jar water samples.

vi. The bottled water quality was found comparatively better than the quality of jar water.

vii. The concern aouthority should consider the quality of bottled and jar drinking water with great importance due to their direct relation to the public health.

5.2. Recommendations

i. Considering the level of pathogenic micro-organisms content in the drinking bottled and jar water, it may be needed to check their existing disinfection process and performance to reduce the presence of micro-organism levels and minimize the related expected health risk.

ii. The authorized team or office should regulate the drinking bottled and jar water production, distribution, and quality of water, including regulations on the source of water, operation of drinking water systems, contaminant levels and reporting systems.

iii. The quality of bottled and jar water should be monitored and inspected frequently by the concern authority because the presence of trace metals observed, however they were within the recommended limit.

iv. Emphasize proper labeling on bottles and create awareness not to drink expired and unlabeled water.

v. Bottled water and jar drinking water plants should not be given less priority for inspection due to skilled man power.

vi. The quality of drinking water from other sources in Chattogram city can be assessed by the researchers.

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