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Evaluation of Drinking Water Quality at Bahri Water Purification Plant Using Traditional Methods

تقويم جودة مياه الشرب بمحطة تنقية مياه بحري بإستخدام الطرق التقليدية

A dissertation submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Environmental Engineering

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الآية

قال تعالي:

(أَوَلَمْ يَرَ ٱلَّذِينَ كَفَرُوٓاْ أَنَّ ٱلسَّمَٰوَٰتِ وَٱلْأَرْضَ كَانَتَا رَتْقًا فَفَتَقْنَٰهُمَا ۖ وَجَعَلْنَا مِنَ ٱلْمَآءِ كُلَّ شَىْءٍ حَىٍّ ۖ أَفَلَا يُؤْمِنُونَ)

صدق الله العظيم

سورة الانبياء الآية 30

Dedication

'' To my parents, sisters, friends, and all people who will be happy with my success''

Acknowledgment

Firstly, Thank God for helping me to complete this project. Secondly, I would like to express my gratitude to Dr. **Tyseer Yhya Moustafa** for her valuable assistance and supervision throughout the project time. Last but not least, To all employees at the Bahri station especially Engineer Fatima, Director of the Lab; Engineer Mona, Engineer from the Operations Department. The family of Razo International Academy is also one I can not disregard.

Abstract

The study objective dealt with evaluating the water quality of Bahri water purification plant. To achieve set goals, the results of the analysis of treated water were recorded for one year from the first of July 2021 until June 30, 2022. The importance of the study is that plant is considered the largest water production plant in the Republic of Sudan, as it produces 300,000 cubic meters per day. It invades many areas of the triangular capital, Khartoum. The study concluded that all the chemical elements conform to the specifications, but the turbidity of the water of the plant does not match the specifications, as well as the amount of residual chlorine, which caused the presence of coliform bacteria in some of the results of the analysis. The solution to the problem lies in the provision of purification materials such as poly aluminum chloride, PAC, as well as disinfection materials such as chlorine in sufficient quantities.

المستخلص

هدفت الدراسة إلى تقييم جودة المياه في محطة تنقية مياه بحري. لتحقيق الأهداف المحددة للدراسة، سجلت نتائج تحليل المياه المعالجة لمدة عام واحد من الأول من يوليو 2021 حتى 30 يونيو 2022. تكمن أهمية الدراسة في أن المحطة تعتبر أكبر محطة تنقية لإنتاج المياه في جمهورية السودان، حيث تنتج 300 ألف متر مكعب في اليوم. تغذي عدة مناطق من العاصمة المثلثة الخرطوم. وخلصت الدراسة إلى أن جميع العناصر الكيميائية مطابقة للمواصفات، إلا أن تعكر مياه المحطة لا يتطابق مع المواصفات السودانية، وكذلك كمية الكلور المتبقي التي تسببت في وجود بكتيريا القولون في بعض نتائج الدراسة. التحليل. يكمن حل المشكلة في توفير مواد التنقية – مثل بولي كلوريد الألومنيوم، وكذلك مواد التطهير مثل الكلور – بكميات كافية.

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Abbreviations

ABBREVIATIONS USED IN TEXT

EC	Electric Conductivity
HIIK	Heidelberg Institute for International Conflict Research.
NTU	Nephelometric Turbidity Unit
PAC	Poly aluminum chloride
ppm:	part per million
SSMO	Sudanese Standards and Metrology Organization
TCU	True Color Unit
TDS	Total Dissolved Solids
TSS	Total suspended solids
UN-Water	United Nations Water
UN-Water	United Nations Water.
WHO	World Health Organization

Key Word:

Water quality, drinking water, the parameter of water, WHO, SSMO, and Bahri purification.

CHAPTER ONE

General Introduction

1-1 Background:

Water is the backbone of life, and it is necessary for human life and all other living organisms on the earth. Humans cannot live without water because it makes up more than 78% of the human body. It enters the building of tissues and nerve cells. It helps in mental processes and blood circulation. It is considered food for the body because it contains useful minerals for the fitness of the body so it is necessary for human health.

Water makes up more than three-quarters of the globe and exists in many forms (solid, liquid, and gas). Water is also found on the surface of the earth or its interior in the form of groundwater. The water may be salty or fresh, as the amount of freshwater reaches approximately 2.5% of the amount of water on the surface of the earth and exists in the form of various forms such as lakes, rivers, groundwater, ice, moisture content, and others.

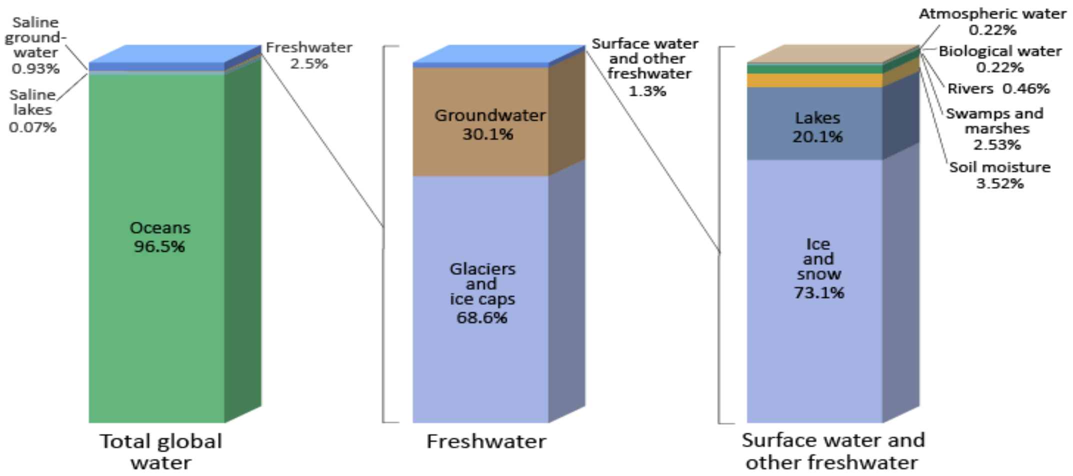


figure (1-1): Total global water (Gleick 1993)

Due to the presence of fresh water at a constant rate and its poor geographical distribution of it, in addition to the noticeably increasing population growth over time, and the pollution that occurs to it from natural sources or various human activities; Fresh water has become a very scarce and important resource and a great challenge for many countries of the world in providing it to its citizens in the required quantity and quality.

1-2 Statement of problem:

The research problem is to study the water quality of the Bahri water purification plant, which is the largest water production plant in Sudan, with a production capacity of about 300 thousand m^3 per day.

1-3 objectives:

1-3-1 General objective:

Checking and assessing the quality of water in the Bahri water purification plant.

1-3-2 Specific objectives:

- Simulating and conducting laboratory experiments to measure water quality characteristics of significance.
- Validating and comparing measured properties to the standard specifications for drinking water.
- Measuring and ascertaining the suitability of the purification steps at Bahri station.
- Detecting the materials used in the water purification process.
- Identifying obstacles to the operation of the Bahri station.

1-4 Study area:

This study is concerned with the Bahri station, which is located in the state of Khartoum - Khartoum Bahri locality on the banks of the Blue Nile in the city of Bahri. Founded in 1954 AD. It is the largest station in the Republic of Sudan. Its productivity is estimated at 300,000 cubic meters per day after its rehabilitation in 2013 AD, and it feeds large parts of Khartoum State. It consists of three stations (MENA WATER FZC. 2022).

1-4-1: Old Station (A)

Creation Date: 1954 AD

The old Bahri station consists of:

- Two suction pumps, each pump is **800** cubic meters per hour.
- Two sedimentation basins with a capacity of **1000** cubic meters each.
- Eight filtration ponds. The Volume of each is **(4*5*3)** cubic meters.
- Three low-pressure pumps with **250** cubic meters per hour.

- Four high-pressure pumps, with different productions (**300** and **400**) cubic meters per hour.
- Water filter collection store.
- The main warehouse, capacity is 133 cubic meters.

Note: Station (A) feeds Kober and Al-Amlak area.

1-4-2 The new station (B)

Creation Date: 1979 - 1986

- Six suction pumps, each pump is **1000** cubic meters per hour
- Two sedimentation basins, each basin capacity of 10000 cubic meters.
- Ten filtration ponds, The Volume of each is **(4*11*3)** cubic meters.
- Storage of filtered water with a capacity is **2000** cubic meters.
- Five low-pressure pumps with different outputs (1000 and 1500) cubic meters per hour.
- **Note: Station (B) feeds Al-Halfaya and the network of southern Bahri.**

1-4-3 The new station (C):

Creation date - 1999

- Five suction pumps, each pump is **1000** cubic meters per hour
- Four sedimentation basins, the capacity of each basin is 8000 cubic meters.
- Eighteen filter tanks, The Volume of each is **(4*11*3)** cubic meters.
- Five low-pressure pumps, with **1000** cubic meters per hour.

Note: Station (C) feeds Burri station and The high-pressure station in Bahr

Figure (1-1): Bahri water purification plant (MENA WATER FZC. 2022)

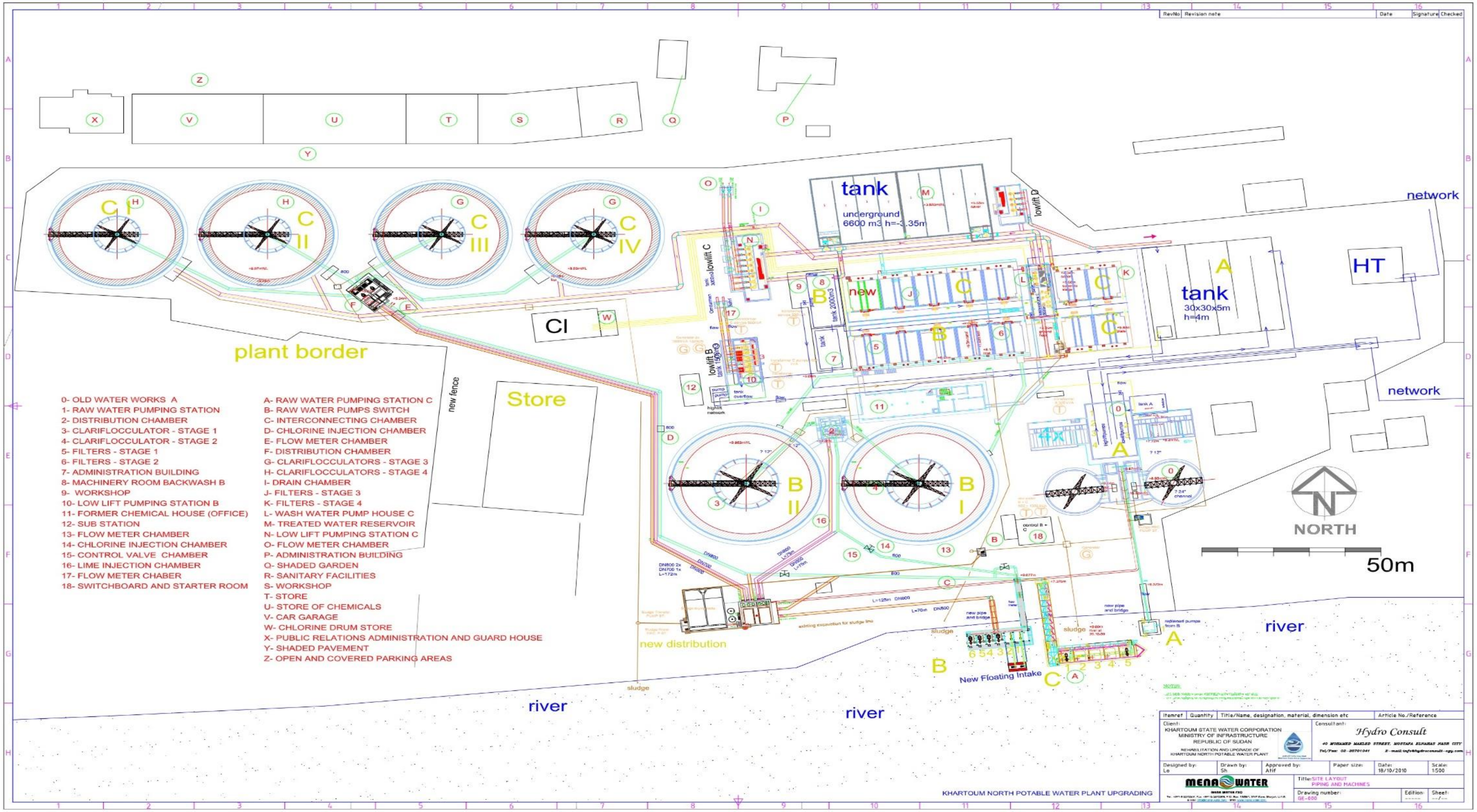


Fig. (1-2): Bahri Water Purification Plant (MENA WATER FZC. 2022).

CHAPTER TWO

Literature Review

2-1 Introduction:

Water is one of the most important elements for the continuation of life on Earth. Water is one of the most abundant natural resources, however, there is an issue with the way they are allocated. Due to this unequal distribution, there is a drinking water deficit in several countries.

Due to the increasing population density, the high standard of living of the global population, the rapidly expanding cities, and the vast industrial expansion occurring all over the world, many governments are seeking ways that will allow the use of wastewater after treatment.

Removing undesired chemicals, biological contaminants, suspended particles, and gases are all steps in the purification process. It is necessary to create water that is acceptable for a variety of functions.

2-2 Water resources:

Water resources are natural resources of water that are potentially useful for humans, for example as a source of drinking water supply or irrigation water. 97% of the water on the Earth is salt water and only three percent is fresh water; slightly over two-thirds of this is frozen in glaciers and polar ice caps. The remaining unfrozen freshwater is found mainly as groundwater, with only a small fraction present above ground or in the air. Natural sources of fresh water include surface water, under river flow, groundwater, and frozen water. Unconventional sources of fresh water can include treated wastewater (wastewater reuse) and desalinated seawater. Human uses of water resources include agricultural, industrial, household, recreational and environmental activities.

Water resources are under threat from water scarcity, water pollution, water conflict, and climate change. Fresh water is a renewable resource, yet the world's supply of groundwater is steadily decreasing, with depletion occurring most prominently in Asia, South America, and North America, although it is still unclear how much natural renewal balances this usage, and whether ecosystems are threatened **(Gleeson 2012)** The framework for allocating water resources to water users (where such a framework exists) is known as water rights.

2-3 Water security:

The term "water security" is often used with varying definitions. It emerged as a concept in the 21st century and is a broader concept than just the absence of water scarcity. When compared to the terms "food security" and "energy security" (which refer to reliable access to food or energy), an important difference with "water security" is that not only is the absence of water a problem but also its presence when there is too much **(Grey, 2007).**

The definition of water security by UN-Water was provided in 2013 is the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability (**Gorde and Jadhav 2013**).

An important threat to water security is water scarcity. There can be several causes of water scarcity including low rainfall, climate change, high population density, and overallocation of a water source. About 27% of the world's population lived in areas affected by water scarcity in the mid-2010s. This number will likely increase to 42% by 2050 **(Boretti 2019).**

There are two types of water scarcity: physical and economic water scarcity. Physical water scarcity is where there is not enough water to meet all demands, including that needed for ecosystems to function effectively. Arid areas (for example Central and West Asia, and North Africa) often suffer from physical water scarcity **(Kummu 2016).** On the other hand, economic water scarcity is caused by a lack of investment in infrastructure or technology to draw water from rivers, aquifers, or other water sources, or insufficient human capacity to satisfy the water demand. Much of Sub-Saharan Africa has economic water scarcity.

The main driving forces for the rising global demand for water are the increasing world population, improving living standards, changing consumption patterns, and expansion of irrigated agriculture. Climate change (including droughts or floods), increased water pollution and wasteful use of water can also cause insufficient water supply. Scarcity can and will likely intensify with most forms of economic development, but many of its causes can be avoided or mitigated.

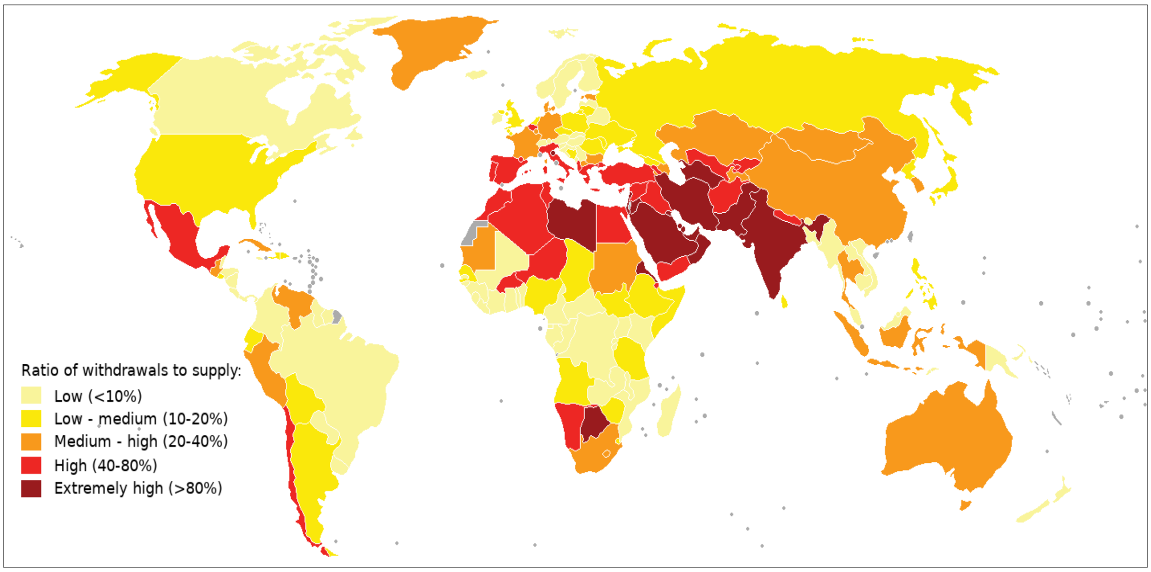


Figure (2-1): Water stress per country in 2019 (Kummu 2016)

2-4 water uses:

It is estimated that 8% of worldwide water use is for domestic purposes. **(Bradley et al. 2018)** These include drinking water, bathing, cooking, toilet flushing, cleaning, laundry, and gardening. Basic domestic water requirements have been estimated by Peter Gleick **(Gleick 1993)** at around 50 liters per person per day, excluding water for gardens.

Drinking water is water that is of sufficiently high quality so that it can be consumed or used without risk of immediate or long-term harm. Such water is commonly called potable water. In most developed countries, the water supplied to domestic, commerce and industry is all of drinking water standards even though only a very small proportion is consumed or used in food preparation.

844 million people still lacked even a basic drinking water service in 2017. Of those, 159 million people worldwide drink water directly from surface water sources, such as lakes and streams **(HIIK 2010)**

One in eight people in the world does not have access to safe water. Inappropriate use of water may contribute to this problem. The following tables provide some indicators of water use.

The per capita share of water is equal to 1000 cubic meters per year, and less than that is considered below the water poverty line.

2-5 Water pollution:

Water pollution is the contamination of water bodies, usually as a result of human activities, and it negatively affects its uses. Water bodies include lakes, rivers, oceans, aquifers, reservoirs, and groundwater. Water pollution results when contaminants are introduced into these water bodies. Water pollution can be attributed to one of four sources: sewage discharges, industrial activities, agricultural activities, and urban runoff including stormwater. It can be grouped into surface water pollution (either freshwater pollution or marine pollution) or groundwater pollution. For example, releasing inadequately treated wastewater into natural waters can lead to the degradation of these aquatic ecosystems **(Abdel-Magid and Abdel-Magid 2017)**. Water pollution can also lead to water-borne diseases for people using polluted water for drinking, bathing, washing, or irrigation. Water pollution reduces the ability of the body of water to provide the ecosystem services (such as drinking water) that it would otherwise provide.

Sources of water pollution are either point sources or non-point sources. Point sources have one identifiable cause, such as a storm drain, a wastewater treatment plant, or an oil spill. Non-point sources are more diffuse, such as agricultural runoff. Pollution is the result of the cumulative effect over time. Pollution may take the form of toxic substances (e.g., oil, metals, plastics, pesticides, persistent organic pollutants, industrial waste products), stressful conditions (e.g., changes of pH, hypoxia or anoxia, increased temperatures, excessive turbidity, unpleasant taste or odor, and changes of salinity), or pathogenic organisms. Contaminants may include organic and inorganic substances. Heat can also be a pollutant, and this is called thermal pollution. A common cause of thermal pollution is the use of water as a coolant by power plants and industrial manufacturers.

Control of water pollution requires appropriate infrastructure and management plans as well as legislation.

2-6 Guidelines for drinking-water quality:

The primary purpose of the Guidelines for drinking-water quality is the protection of public health. The Guidelines provide the recommendations of the World Health Organization for managing the risk of hazards that may compromise the safety of drinking water **(WHO 2003, Cotruvo 2017)**.

The basic and essential requirements to ensure the safety of drinking water are a “framework” for safe drinking water, comprising health-based targets established by a competent health authority, adequate and properly managed systems (adequate infrastructure, proper monitoring, and effective planning and management) and a system of independent surveillance **(Cotruvo, 2017)**.

A holistic approach to the risk assessment and risk management of a drinking water supply increases confidence in the safety of the drinking water. This approach entails a systematic assessment of risks throughout a drinking water supply from the catchment and its source water through to the consumer and identification of how these risks can be managed, including methods to ensure that control measures are working effectively. It incorporates strategies to deal with the day-to-day management of water quality, including upsets and failures. In this respect, climate change in the form of increased and more severe periods of drought or more intense rainfall events leading to flooding can have an impact on both the quality and the quantity of water and will require planning and management to minimize adverse impacts on drinking water supplies. Climate change also needs to be considered in light of demographic change, such as the continuing growth of cities, which itself brings significant challenges to the drinking water supply. In support of the framework for safe drinking water, the Guidelines provide a range of supporting information, including microbial, chemical, and acceptability aspects. The Guidelines apply to large metropolitan and small community piped drinking-water systems and to non-piped drinking-water systems in communities and individual dwellings **(Cotruvo, 2017).**

2-6-1 Acceptability aspects:

1. Taste, odor, and appearance:

Aesthetic problems can frequently be prevented by improving conventional treatment techniques like coagulation, sedimentation, and chlorination. These treatment methods address taste, odor, and appearance issues. For the most part, ozonation, granular or powdered activated carbon, and aeration are effective ways to get rid of tastes and odors that are caused by organic chemicals and some inorganic substances, such as hydrogen sulfide **(Cotruvo, 2017).**

The best way to limit the tastes and odors that disinfectants generate is to carefully operate the disinfection process and pretreat to remove precursors. Chlorination followed by filtering can be used to remove manganese. Aeration-activated carbon in the form of granules, filtration, and oxidation are methods for eliminating hydrogen sulfide. By biological nitrification, ammonia can be eliminated. Hardness can be lowered through cation exchange or precipitation softening. Other tastes- and odor-causing inorganic chemicals (e.g. chloride and sulfate) are generally not amenable to treatment **(Cotruvo, 2017).**

2. Colour:

Drinking water should ideally have no visible color. Colour in drinking water is usually due to the presence of colored organic matter (primarily humic and fulvic acids) associated with the humus fraction of soil. Colour is also strongly influenced by the presence of iron and other metals, either as natural impurities or as corrosion products. It may also result from the contamination of the water source by industrial. Effluents may be the first indication of a hazardous situation. The source of color in a drinking water supply should be investigated, particularly if a substantial change has taken place. Most people can detect colors above 15 true color units (TCU) in a glass of water according to WHO guidelines (2004). Levels of color below 15 TCU are often acceptable to consumers. No health-based guideline value is proposed for color in drinking water **(Cotruvo, 2017).**

3. Temperature:

Palatability, viscosity, solubility, odors, and chemical reactions are influenced by temperature **(Beutler et al., 2014)**. Thereby, the sedimentation and chlorination processes and biological oxygen demand (BOD) are temperature dependent **(Davis, 2010)**. It also affects the biosorption process of the dissolved heavy metals in water **(Abbas et al., 2014, White et al., 1997).** Most people find water at temperatures of 10–15°C most palatable **(Davis, 2010, Abbas et al., 2014)**.

4. Turbidity:

Turbidity is the cloudiness of water **(Beutler et al., 2014)**. It is a measure of the ability of light to pass through water. It is caused by suspended materials such as clay, silt, organic material, plankton, and other particulate materials in water **(Alley, 2007)**.

Turbidity in drinking water is esthetically unacceptable, which makes the water look unappetizing. The impact of turbidity can be summarized in the following points:

It can increase the cost of water treatment for various uses **(Davis, 2010)**. The particulates can provide hiding places for harmful microorganisms and thereby shield them from the disinfection process **(Edzwald and Association, 2011)**.

Suspended materials can clog or damage fish gills, decreasing their resistance to diseases, reducing their growth rates, affecting egg and larval maturing, and affecting the efficiency of fish catching method **(Tarras-Wahlberg et al., 2003, Kiprono, 2017)**.

Suspended particles provide adsorption media for heavy metals such as mercury, chromium, lead, cadmium, and many hazardous organic pollutants such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and many pesticides **(White et al., 1997)**.

The amount of available food is reduced **(White et al., 1997)**because higher turbidity raises water temperatures. After all, suspended particles absorb more solar heat. Consequently, the concentration of dissolved oxygen (DO) can be decreased since warm water carries less dissolved oxygen than cold water.

Turbidity is measured by an instrument called a nephelometric turbidimeter, which expresses turbidity in terms of NTU or TU. A TU is equivalent to 1 mg/L of silica in suspension **(Beutler et al., 2014)**.

Turbidity of more than 5 NTU can be visible to the average person while turbidity in muddy water, exceeds 100 NTU **(Beutler et al., 2014)**. Groundwater normally has very low turbidity because of the natural filtration that occurs as the water penetrates through the soil **(Spellman, 2017, Viessman and Hammer, 1993)**.

2-6-2 Chemically derived contaminants

The following chemical substances were the ordinary checked parameters at Bahri water purification plant as observed by the reseacher.

1. Aluminum:

It’s the most abundant metallic element and constitutes about 8% of Earth’s crust. Aluminum salts are widely used in water treatment as coagulants to reduce organic matter, color, turbidity, and microorganism levels. Such use may lead to increased concentrations of aluminum in finished water. Where residual concentrations are high, undesirable color

and turbidity may ensue. Concentrations of aluminum at which such problems may occur are highly dependent on several water quality parameters and operational factors at the water treatment plant. Aluminum intake from foods, particularly those containing aluminum compounds used as food additives, represents the major route of aluminum exposure for the general public. The contribution of drinking water to the total oral exposure to aluminum is usually less than 5% of the total intake **(Cotruvo, 2017)**.
Naturally occurring Aluminum as well as aluminum salts used as coagulants in drinking-water treatment are the primary sources of aluminum in drinking water. The presence of aluminum at concentrations above 0.1–0.2 mg/l often leads to consumer complaints as a result of the deposition of aluminum hydroxide floc and the exacerbation of discoloration of water by iron. It is therefore important to optimize treatment processes to minimize any residual aluminum entering the distribution system. Under good operating conditions, aluminum concentrations of less than 0.1 mg/l are achievable in many circumstances. Available evidence does not support the derivation of a health-based guideline value for aluminum in drinking water **(Cotruvo, 2017)**.

2. Ammonia:

The term ammonia includes the non-ionized (NH_3) and ionized (NH_4^+) species. Ammonia in the environment originates from metabolic, agricultural, and industrial processes and disinfection with chloramine. Natural levels in groundwater and surface water are usually below 0.2 mg/l. Anaerobic groundwaters may contain up to 3 mg/l. Intensive rearing of farm animals can give rise to much higher levels in surface water. Ammonia contamination can also arise from cement mortar pipe linings. Ammonia in water is an indicator of possible bacterial, sewage, and animal waste pollution. Ammonia is a major component of the metabolism of mammals. Exposure to environmental sources is insignificant in comparison with an endogenous synthesis of ammonia. Toxicological effects are observed only at exposures above about 200 mg/kg body weight. Ammonia in drinking water is not of immediate health relevance, and therefore no health-based guideline value is proposed. However, ammonia can compromise disinfection efficiency, result in nitrite formation in distribution systems, cause the failure of filters for the removal of manganese and cause taste and odor problems **(Cotruvo, 2017).**

The threshold odor concentration of ammonia at alkaline pH is approximately 1.5 mg/l, and a taste threshold of 35 mg/l has been proposed for the ammonium cation. Ammonia is not of direct relevance to health at these levels, and no health-based guideline value has been proposed. However, ammonia does react with chlorine to reduce free chlorine and form chloramines **(Cotruvo, 2017)**.

3. Chloride:

Chloride occurs naturally in groundwater, streams, and lakes, but the presence of relatively high chloride concentration in freshwater (about 250 mg/L or more) may indicate wastewater pollution **(Chatterjee, 1996).** Chlorides may enter surface water from several sources including chloride-containing rock, agricultural runoff, and wastewater.

Chloride ions Cl^- in drinking water do not cause any harmful effects on public health, but high concentrations can cause an unpleasant salty taste for most people. Chlorides are not usually harmful to people; however, the sodium part of table salt has been connected to kidney and heart diseases **(WHO 2003)**. Small amounts of chlorides are essential for ordinary cell functions in animal and plant life.

Sodium chloride may impart a salty taste at 250 mg/L; however, magnesium or calcium chloride is generally not detected by taste until reaching levels of 1000 mg/L **(Beutler et al., 2014)**. Standards for public drinking water require chloride levels that do not exceed 250 mg/L. There are many methods to measure the chloride concentration in water, but the normal one is the titration method by silver nitrate **(Beutler et al., 2014).**

4. Fluoride:

A moderate amount of fluoride ions (F^-) in drinking water contributes to good dental health**(Beutler et al., 2014, Omer, 2019**). About 1.0 mg/L is effective in preventing tooth decay, particularly in children **(Beutler et al., 2014).**

Excessive amounts of fluoride cause discolored teeth, a condition known as dental fluorosis **(Davis, 2010, Omer, 2019, Davis and Cornwell, 2008)**. The maximum allowable levels of fluoride in public water supplies depend on the local climate **(Davis and Cornwell, 2008).** In the warmer regions of the country, the maximum allowable concentration of fluoride for potable water is 1.4 mg/L; in colder climates, up to 2.4 mg/L is allowed.

5. Hardness:

Hardness is a term used to express the properties of highly mineralized waters **(Beutler et al., 2014)**. The dissolved minerals in water cause problems such as scale deposits in hot water pipes and difficulty in producing lather with soap **(Davis, 2010).**

Calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions cause the greatest portion of hardness in naturally occurring waters. They enter water mainly from contact with soil and rock, particularly limestone deposits **(Beutler et al., 2014, McGhee and Steel, 1991)**.

These ions are present as bicarbonates, sulfates, and sometimes as chlorides and nitrates **(Beutler et al., 2014, Davis and Cornwell, 2008, Davis, 2010)**. Generally, groundwater is harder than surface water. There are two types of hardness:

- Temporary hardness which is due to carbonates and bicarbonates can be removed by boiling.
- Permanent hardness which is remaining after boiling is caused mainly by sulfates and chlorides **(Beutler et al., 2014, DeZuane, 1997, Tchobanoglus et al., 2003)**.

Water with more than 300 mg/L of hardness is generally considered to be hard, and more than 150 mg/L of hardness is noticed by most people, and water with less than 75 mg/L is considered to be soft.

6. Iron and Manganese:

Although iron (Fe) and manganese (Mn) do not cause health problems, they impart a noticeable bitter taste to drinking water even at very low concentrations **(**Beutler et al., 2014, Davis, 2010).

These metals usually occur in groundwater in solution as ferrous (Fe^{2+}) and manganous (Mn^{2+}) ions. When these ions are exposed to air, they form the insoluble ferric (Fe^{3+}) and manganic ($Mn^{3+)}$ forms making the water turbid and unacceptable to most people **(Beutler et al., 2014)**.

These ions can also cause black or brown stains on laundry and plumbing fixtures **(Chatterjee, 1996)**. They are measured by many instrumental methods such as atomic absorption spectrometry, flame atomic absorption spectrometry, cold vapor atomic absorption spectrometry, and electrothermal atomic absorption spectrometry **(Beutler et al., 2014)**.

7. Nitrate and nitrite:

Nitrate and nitrite levels in our natural waters are important indicators of water quality. Nitrate and nitrite are both intimately involved in the overall nitrogen cycle of soil and higher plants and leaching of nitrate from fertilizers added to soils can result in elevated levels of nitrate in ground and surface waters. Nitrite can be formed during the biodegradation of nitrate, ammoniacal nitrogen, and other nitrogenous organic matter, and is an important indicator of fecal pollution of natural water systems. In addition, nitrite is readily oxidized to nitrate by dissolved oxygen, thus, decreasing oxygen levels in the water. When nitrate-contaminated water supplies are used as a source of drinking water adverse human health effects are also of great concern. Relative to nitrites, nitrates are compounds of lower toxicity, representing a danger only when ingested in excessive doses or when converted to nitrites **(Connolly and Paull, 20**01). Nitrites however can have several adverse effects on human health. For example, the in vivo reaction between nitrite and secondary or tertiary amines produces N-nitrosamines, which are potential carcinogens, mutagens, and/or teratogens. In addition, nitrite interacts with blood pigment to cause meta-hemoglobinemia, especially in infants (aka 'blue baby syndrome). This condition limits the blood's ability to carry oxygen from the lungs to the rest of the body. To guard against the above effects the US EPA has set the maximum contaminant level (MCL) for nitrate in drinking water at 10 mg/l **(Connolly and Paull, 2001)**.

8. Potassium:

Potassium is an essential element in humans and is seldom if ever, found in drinking water at levels that could be a concern for healthy humans. The recommended daily requirement is greater than 3000 mg. Potassium occurs widely in the environment, including all natural waters. It can also occur in drinking water as a consequence of the use of potassium permanganate as an oxidant in water treatment. In some countries, potassium chloride is used in ion exchange for household water softening in place of or mixed with, sodium chloride, so potassium ions would exchange with calcium and magnesium ions **(Cotruvo, 2017)**.

Currently, there is no evidence that potassium levels in municipally treated drinking-water, even water treated with potassium permanganate, are likely to pose any risk to the health of consumers. It is not considered necessary to establish a health-based guideline value for potassium in drinking water. Although potassium may cause some health effects in susceptible individuals, potassium intake from drinking-water is well below the level at which adverse health effects may occur. Health concerns would be related to the consumption of drinking water treated by potassium-based water treatment (principally potassium chloride for regeneration of ion exchange water softeners), affecting only individuals in high-risk groups (i.e. individuals with kidney dysfunction or other diseases, such as heart disease, coronary artery disease, hypertension, diabetes, adrenal insufficiency, pre-existing hyperkaliemia; people taking medications that interfere with normal potassium-dependent functions in the body; and older individuals or infants) **(Cotruvo, 2017).** It is recommended that susceptible individuals seek medical advice to determine whether they should avoid the consumption of water (for drinking or cooking) treated by water softeners using potassium chloride. When high-risk individuals have been advised by a physician to avoid elevated potassium intake from water, the recommended strategy is to limit the addition of potassium to water that will be ingested or to avoid ingesting such water. This can be done by having a proportion of the water bypass the softener altogether; this approach is recommended by several countries. Although technologies are available to remove potassium, they are generally more expensive and redundant when combined with the softening treatment **(Cotruvo, 2017)**.

9. Sodium:

Sodium salts (e.g. sodium chloride) are found in virtually all food (the main source of daily exposure) and drinking water. Although concentrations of sodium in potable water are typically less than 20 mg/l, they can greatly exceed this in some countries. The levels of sodium salts in the air are normally low concerning those in food or water. It should be noted that some water softeners can add significantly to the sodium content of drinking water. No firm conclusions can be drawn concerning the possible association between sodium in drinking water and the occurrence of hypertension. Therefore, no health-based guideline value is proposed. However, concentrations over 200 mg/l may give rise to unacceptable taste **(Cotruvo, 2017)**.

The taste threshold concentration of sodium in water depends on the associated anion and the temperature of the solution. At room temperature, the average taste threshold for sodium is about 200 mg/l. No health-based guideline value has been derived, as the contribution from drinking water to daily intake is small **(Cotruvo, 2017)**.

10.Sulfate:

Sulfate ions (SO_4^{2-}) occur in natural water and wastewater. The high concentration of sulfate in natural water is usually caused by the leaching of natural deposits of sodium sulfate (Glauber's salt) or magnesium sulfate (Epson salt) **(Davis, 2010, Davis and Cornwell, 2008)**. If high concentrations are consumed in drinking water, there may be objectionable tastes or unwanted laxative effects **(Davis and Cornwell, 2008)**, but there is no significant danger to public health.

11.Total dissolved solids:

Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and small amounts of organic matter that are dissolved in water. TDS in drinking water originates from natural sources, sewage, urban runoff, and industrial wastewater. Salts used for road de-icing in some countries may also contribute to the TDS content of drinking water. Concentrations of TDS in water vary considerably in different geological regions owing to differences in the solubilities of minerals **(Cotruvo, 2017)**.

Reliable data on possible health effects associated with the ingestion of TDS in drinking water are not available, and no health-based guideline value is proposed. However, the presence of high levels of TDS in drinking water may be objectionable to consumers **(Cotruvo, 2017)**.

The palatability of water with a total dissolved solids (TDS) level of less than about 600 mg/l is generally considered to be good; drinking water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/l. The presence of high levels of TDS may also be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers, and household appliances. No health-based guideline value for TDS has been proposed **(Cotruvo, 2017)**.

12.pH:

pH is the measure of the acidity of a solution of water. The pH scale commonly ranges from **0** to **14.** The scale is not linear rather it is logarithmic. For example, a solution with a pH of 6 is ten times more acidic than a solution with a pH of **7**. Pure water is said to be neutral, with a pH of 7. Water with a pH below 7.0 is considered acidic while water with a pH greater than 7.0 is considered basic or alkaline **(Gorde and Jadhav 2013)**

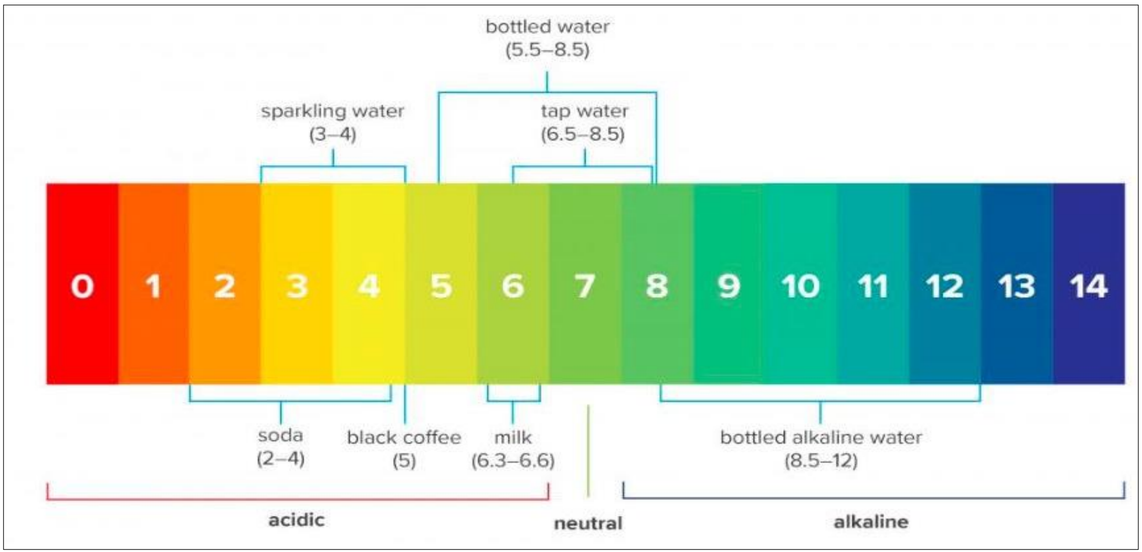


Fig (2-2): pH of common drinks (Gorde and Jadhav 2013)

pH and corrosion:

Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. For effective disinfection with chlorine, the pH should preferably be less than 8; however, lower- pH water is more likely to be corrosive. The pH of the water entering the distribution system must be controlled to minimize the corrosion of water mains and pipes in household water systems. Alkalinity and calcium management also contribute to the stability of water and control its aggressiveness to pipes and appliances. Failure to minimize corrosion can result in the contamination of drinking water and adverse effects on its taste and appearance. The optimum pH required will vary in different supplies according to the composition of the water and the nature of the construction materials used in the distribution system, but it is usually in the range of 6.5 to 8.5. No health-based guideline value has been proposed for pH **(Cotruvo, 2017)**.

13.Alkalinity:

Alkalinity is the total of components in the water that tend to elevate the pH to the alkaline side of neutrality. It is measured by titration with standardized acid to a pH value of 4.5 and is expressed commonly as milligrams per liter of calcium carbonate (mg/L as $CaCO_3$). Alkalinity is a measure of the buffering capacity (ability to resist changes in pH) of the water, and since pH has a direct effect on organisms as well as an indirect effect on the toxicity of certain other pollutants in the water, the buffering capacity is important to water quality. Commonly occurring materials in water that increase alkalinity are carbonates, bicarbonates, phosphates, and hydroxides. Limestone bedrock and thick deposits of glacial till are good sources of carbonate buffering. Lakes within such areas are usually well-buffered **(Gorde and Jadhav 2013).**

14.Conductivity:

Conductivity is a numerical expression of an aqueous solution's capacity to carry an electric current. This ability depends on the presence of ions, their total concentration, mobility, valence and relative concentrations, and the temperature of the liquid. Solutions of most inorganic acids, bases, and salts are relatively good conductors. In contrast, the conductivity of distilled water is less than 1 µmhos/cm. Because conductivity is the inverse of resistance, the unit of conductance is the mho (ohm spelled backward), or in low-conductivity natural waters, the micromho **(Gorde and Jadhav 2013).**

The relationship between EC and TDS:

Electrical Conductivity (EC) is a surrogate measure of Total Dissolved Solids (TDS).
Electrical conductivity methods are more advantageous as the measurement is faster than the gravimetric measurement of TDS and will be highly useful. It is also effective as compared to laboratory measurements.
The relationship between TDS and EC is a function of the type and nature of the dissolved cations and anions in the water. The relationship between EC and TDS is not directly linear, since the conductive mobility of ionic species is variable
In general, the TDS – EC relationship is given by the equation 2-1 **(Thirumalini and Joseph 2009).**

$$\mathbf{TDS = (0.55\ to\ 0.7)\ EC \quad ....(2\text{-}1)}$$

2-6-3 Microbial aspects:

A microorganism, or microbe, is an organism of microscopic size, which may exist in its single-celled form or as a colony of cells.

The scientific study of microorganisms began with their observation under the microscope in the 1670s by Anton van Leeuwenhoek. In the 1850s, Louis Pasteur found that microorganisms caused food spoilage. In the 1880s, Robert Koch discovered that microorganisms caused the diseases tuberculosis, cholera, diphtheria, and anthrax.

The human health effects caused by waterborne transmission vary in severity from mild gastroenteritis to severe and sometimes fatal diarrhea, dysentery, hepatitis, and typhoid fever. Contaminated water can be the source of large outbreaks of disease, including cholera, dysentery, and cryptosporidiosis; for the majority of waterborne pathogens, however, there are other important sources of infection, such as person-to-person contact and food.

Most waterborne pathogens are introduced into drinking-water supplies in human or animal feces, do not grow in water, and initiate infection in the gastrointestinal tract following ingestion **(Cotruvo 2017)**.

2-6-3-1 Waterborne diseases:

Water-borne illness remains a major source of worldwide human morbidity and mortality, and one-half of the world's population has suffered from diseases caused by polluted water and that pathogenic bacterium when present in potable waters cause typhoid fever, bacillary dysentery, and cholera **(Cotruvo, 2017)**. However, with improvements in epidemiological surveillance and clinical diagnosis of bacterial and non-bacterial gastroenteritis, there has been over the last decades an emergence of new forms of water-related illness. Several pathogenic strains of Escherichia coli in drinking water and food have been implicated in the intestinal complaints of humans **(Abdel-Magid and Abdel-Magid 2017)**.

New York State Department of Health (2005) stated that coliform bacteria are found in the digestive tract of all birds and mammals. Most coliform bacteria are not harmful themselves but point to an unsanitary condition and the possible presence of disease-causing organisms.

The coliform bacteria may not form a disease but can be used as an indicator of pathogenic disease. It is recommended that drinking water from private wells should be tested for the presence of bacteria at least once a year or when work has been done to the water supply system or when there is any time change in any of the water quality parameters (taste, color, turbidity … etc).

The drinking water quality standard for coliform bacteria is set at less than one coliform organism per 100 ml of water. Among the chemical toxin which can endanger human health, are those substances that can be present in water as decomposition products of organic compounds.

2-6-3-2 Bacteriological parameters:

Individual-pathogen monitoring in water is technically achievable but currently unfeasible due to the costs involved and the number of possible pathogens. Since numerous pathogens occur in feces, water is monitored for microbial contamination using indicator organisms such as **total coliforms** and **Escherichia coli**.

1. Total coliform:

The term “total coliform” refers to a large group of Gram-negative, rod-shaped bacteria that share several characteristics. The group includes thermotolerant coliforms and bacteria of fecal origin, as well as some bacteria that may be isolated from environmental sources. Thus, the presence of total coliforms may or may not indicate fecal contamination. Despite reservations about their usefulness as indicators of fecal contamination, the total coliform group remains a water quality indicator in many countries and continues to be used to some extent as a regulatory parameter. Indeed, even in situations in which fecal contamination is present, total coliforms are more numerous than E. coli, thereby representing a more sensitive indicator. Furthermore, some members of the total coliform group are considerably more resistant to disinfection than E. coli and are better indicators of poor disinfection. The presence of total coliforms in a water distribution system can also indicate a lack of system integrity. Thus, total coliform bacteria are commonly used to evaluate the general sanitary quality of water. **(Maheux et al, 2014)**

In the laboratory, total coliforms are grown in or on a medium containing lactose, at a temperature of 35 or 37°C. They are provisionally identified by the production of acid and gas from the fermentation of lactose **(Bartram and Ballance, 1996).**

2. *Escherichia coli* (*E. coli*):

E. coli is a species of bacteria that is naturally found in the intestines of humans and warm-blooded animals. It is present in feces in high numbers and can be easily measured in water, which makes it a useful indicator of fecal contamination for drinking water providers. *E. coli* is the most widely used indicator for detecting fecal contamination in drinking water supplies worldwide. In drinking water monitoring programs, *E. coli* testing is used to provide information on the quality of the source water, the adequacy of treatment, and the safety of the drinking water distributed to the consumer.

Significance of *E. coli* in drinking water systems and their sources, *E. coli* monitoring should be used, in conjunction with other indicators, as part of a multi-barrier approach to producing drinking water of acceptable quality. Drinking water sources are commonly impacted by fecal contamination from either human or animal sources and, as a result, may contain *E. coli*. Its presence in a water sample is considered a good indicator of recent fecal contamination. The ability to detect fecal contamination in drinking water is a necessity, as pathogenic microorganisms from human and animal feces in drinking water pose the greatest danger to public health. A maximum acceptable concentration **(MAC)** of none detectable per 100 mL is proposed for *Escherichia coli* in drinking water **(Cotruvo, 2017)**.

2-7 Water purification:

Water purification plants provide safe water from pollution. Where it gets rid of unwanted chemicals as well as microbial contamination, according to the stages of purification.

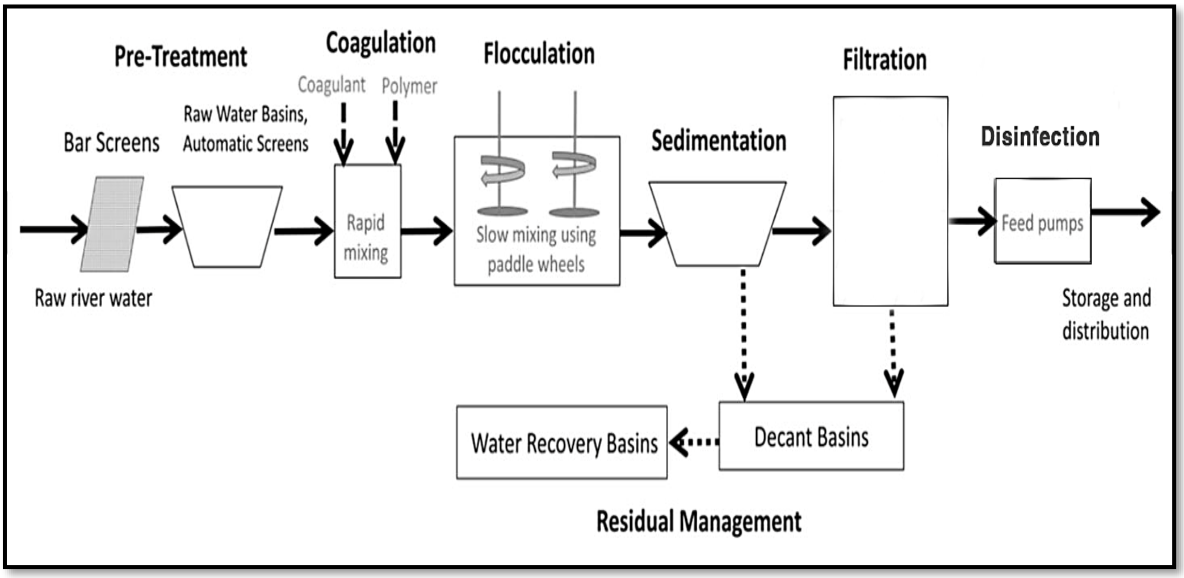


Figure (2-3) Components of water purification (Bukhary, 2020)

2-7-1 intake

An intake is a site chosen by the Engineer to take away the turbidity of water and take the necessary construction work to protect the bottom of the watercourse and its aspects in a way to ensure access to the current and future water intake level.

2 - 7 - 2 Screening:

During which solid objects or pieces that can obstruct pumps or subsequent purification are removed.

2 - 7 - 3 Coagulation:

It aims to remove suspended colloidal substances (which cause turbidity) and they do not precipitate easily, so we resort to adding coagulant chemicals.

2 - 7 - 4 Flocculation:

It aims to collect the fine flocs formed in the previous stage to form larger flocculents that are easy to be deposited by clumping.

2 - 7 -5 Sedimentation:

This process aims to remove suspended materials and flocculants resulting from the addition of coagulants. The sedimentation is divided into two types: **natural sedimentation** and **chemical precipitation**.

(A) **Natural sedimentation**: The purpose of this process is to remove the largest possible percentage of suspended substances in water in private ponds without adding substances to help this sedimentation.
(B) **Chemical sedimentation**: The purpose of this process is to deposit the largest proportion of suspended materials By adding coagulant chemicals

● **Coagulants:**

There is a global agreement for materials to be used for drinking water purification stations **(Kumar 2017)** :

- PAC
- $Al_2(SO_4)_3 . 18H_2O$
- $Fe Cl_3 . 6H_2O$
- $Fe SO_4 . 7H_2O$
- $Fe_2 (SO4)_3 . 9H_2O$

.

2 - 7 - 6 Filtration:

Filtration is the process of passing water through the material to remove particulate and other impurities, including floc, from the water being treated. These impurities consist of suspended particles (fine silts and clays), biological matter (bacteria, plankton, spores, cysts, or other matter), and floc. The material used in filters for public water supply is normally a bed of sand, coal, or other granular substance. Filtration processes can generally be classified as being either slow or rapid.

2 - 7 - 7 Disinfection:

Disinfection is used in water treatment to reduce pathogens to an acceptable level. Disinfection is not the same as sterilization. Sterilization implies the destruction of all living organisms. Drinking water does not need to be sterile to be safe to drink. Three categories of human enteric pathogens are of concern in drinking water: bacteria, viruses, and amebic cysts. Disinfection must be capable of destroying all three **(Davis, 2010)**.
Physical means, including heating and ultraviolet rays, as well as chemical ones, like chlorine and ozone, can be utilized to carry out this operation.

2-7-7-1 Chlorine disinfection:

The most common disinfection method. Chlorine is a strong oxidant that rapidly kills many harmful microorganisms. The term chlorination is often used synonymously with disinfection. When chlorine is added to water, a mixture of hypochlorous acid (HOCl) and hydrochloric acid (HCl) is formed as presented in equations 2-2 and 2-3.

$$\mathbf{Cl_2 + H_2O \rightleftarrows HOCl + HCl} \ldots\ldots\ldots\ldots \textbf{(2-2)}$$

$$\mathbf{HCl \rightarrow H^+ + Cl^-} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(2-3)}$$

This reaction is pH dependent and essentially complete within a very few milliseconds.

The pH dependence may be summarized as follows:

• In dilute solution and at pH levels above 1.0, the equilibrium is displaced to the right and very little Cl_2 exists in the solution.

• Hypochlorous acid is a weak acid and dissociates poorly at levels of pH below about 6. Between pH 6.0 and 8.5 there occurs a very sharp change from undissociated HOCl to almost complete dissociation:

$$\mathbf{HOCl \rightleftarrows OCl^- + H^+} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(2-4)}$$

• Chlorine exists predominantly as HOCl at pH levels between 4.0 and 6.0.

• Below pH 1.0, depending on the chloride concentration, the HOCl reverts to Cl_2 as shown in Equation (**2-2**).

• At 20 C, above about pH 7.5, and at 0 C, above about pH 7.8, hypochlorite ions (OCl^-) predominate.

• Hypochlorite ions exist almost exclusively at levels of pH around 9 and above.

Chlorine existing in the form of HOCl and/or OCl is defined as free available chlorine or free chlorine **(Davis, 2010)**.

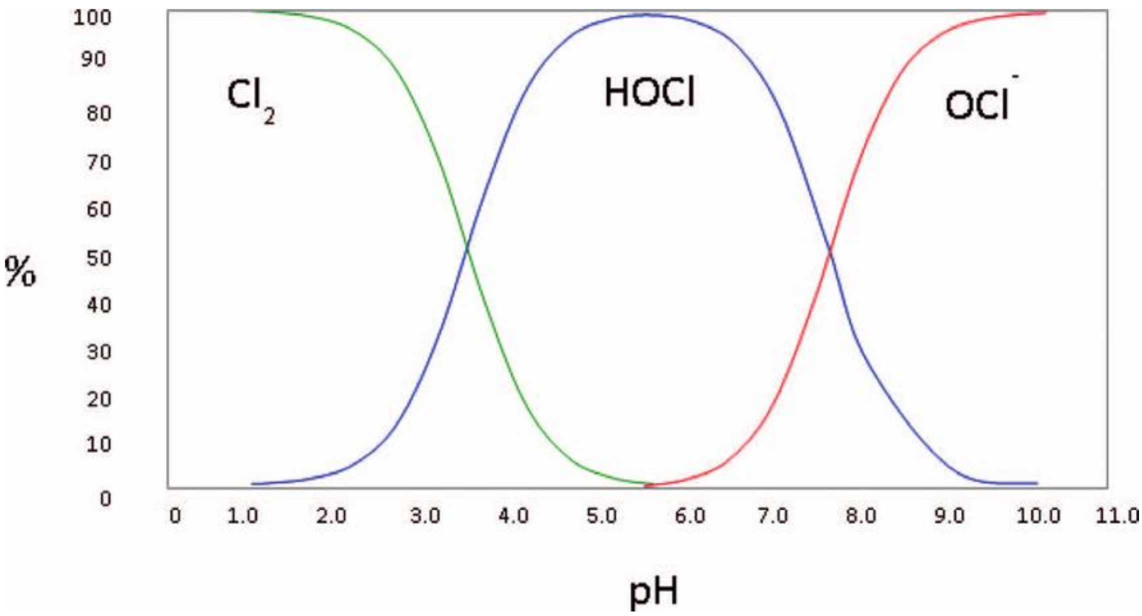


Figure (2-4). Effect of pH on a proportion of chlorine in the water. (Davis, 2010)

Chlorine levels up to 5 milligrams per liter (5 parts per million) are considered safe in drinking water. **For free chlorine**. For effective disinfection, there should be a residual concentration of free chlorine of ≥0.5 mg/l after at least 30 min contact time at pH <8.0. A chlorine residual should be maintained throughout the distribution system. At the point of delivery, the minimum residual concentration of free chlorine should be 0.2 mg/l. **(Cotruvo, 2017)**

The advantages of chlorination:

- Chlorination is a cheaper source than UV or ozone disinfection methods used to treat water.
- It is very effective against a wide range of pathogenic microorganisms.
- Dosing rates are controlled easily as they are flexible.
- The chlorine residuals left in the Water can make the disinfection process longer. They can be further used to evaluate their effectiveness.

Limitations:

Objections against chlorination are because of the esthetic, logistic, and health-related concerns.

Regarding the esthetic level, chlorination might be rejected as it imparts bad taste and odors to the water. The developed countries might teach their people about the good impacts of chlorination; however, less-developed countries lack this ability.

Limitations in using chlorine gas in a household context might include the distribution, procurement/manufacturing, dosing of chlorine, and accurate handling. The health hazards caused by chlorine are not only confined to its volatile nature. A great concern might be the byproducts and incompletely oxidized compounds present in chlorinated water that increase its toxicity. The most notorious byproducts of chlorination are chloro-organics and trihalomethane (THMs). Humic and fulvic acids are present in the water. When chlorine reacts with these acids, trihalomethane is formed. It has been identified in many studies that some of these chloro-organics are mutagens, toxins, or carcinogens. The well-known THM chloroform is an animal carcinogen. Some guidelines have been set by the United States Environmental Protection Agency, USEPA **(Epa 2001)** that THMs should not be greater than 0.10 mg/l. The high concentrations of THMs will lead to health complications **(Ishaq, 2018).**

CHAPTER THREE

Materials and Methods

3-1 Introduction:

The research was conducted by collecting information through field visits to the Bahri station and frequent visits to the Library of the College of Water and Environmental Engineering and websites. The bulk of the information came from the training period at the Bahri station because it was providing the results of laboratory analyzes of the station's water, In the period from 1st July 2021 to 1st June 2022. which were collected and analyzed by Microsoft Office Excel in Razo International Academy Office.

3-2 Libraries and websites:

Through libraries and websites the importance of water quality, water purification mechanisms, materials used for purification, and drinking water quality parameters were identified.

3-3 Training period:

Personal interviews were conducted with the operational engineers of the Bahri station to learn about the station, its components, water treatment steps, and materials used to purify the Blue Nile water. It was also made to know, through the station's laboratory, the materials and devices used, the methods of their use, and the daily and monthly experiments**.**

3-4 Daily experiences:

Water sampling points were identified to be at the last stage of the water purification stage. Grab samples were taken on daily bases for the duration of the project. All experiments were conducted following standard methods for the examination of water and wastewater **(AWWA. 2017)**. Daily experiences and tasks shouldered the following:

3-4-1 Appearance (estimation)

3-4-2 Odor(estimation)

3-4-3 Colour(estimation)

3-4-4 pH:

Direct reading color comparison method**.** The pH of the water was measured by direct reading with the Colour Comparator Device, after adding two drops of Phenol Red Index to 10 ml of the sample and observing the color change.

Figure (3-1): Colour Comparator Device, Phenol Red Index

3-4-5 Residual Chlorine:

Residual Chlorine of the treated water was measured by direct reading also with a Colour Comparator Device, adding an N,N-diethyl-p-phenylenediamine (DPD) pill to 10 ml of the sample and observing the color change. The result is reported in (mg/l).

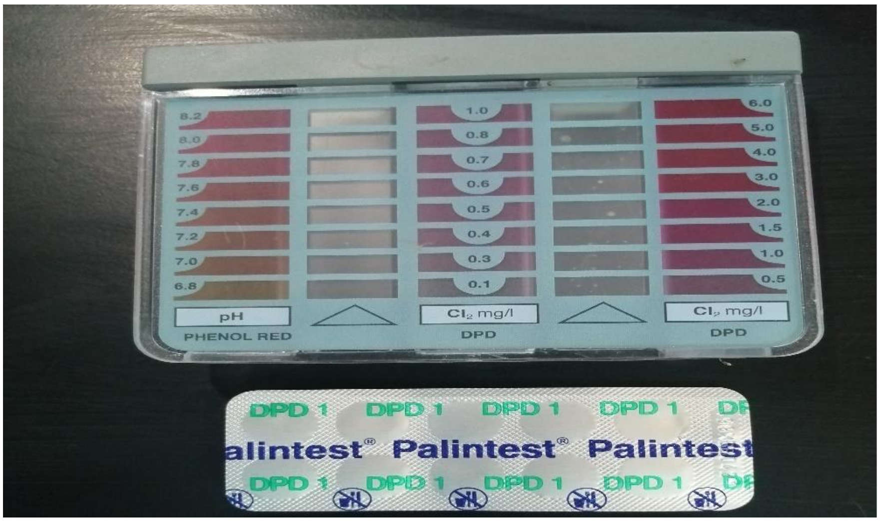


Figure (3-2): Colour Comparator Device and DPD pill

3-4-6 Turbidity (Nephelometric method):

Direct reading by using (HACH) 2100 Turbidity meter. the result was reported in the Nephelometric Turbidity Unit (NTU).

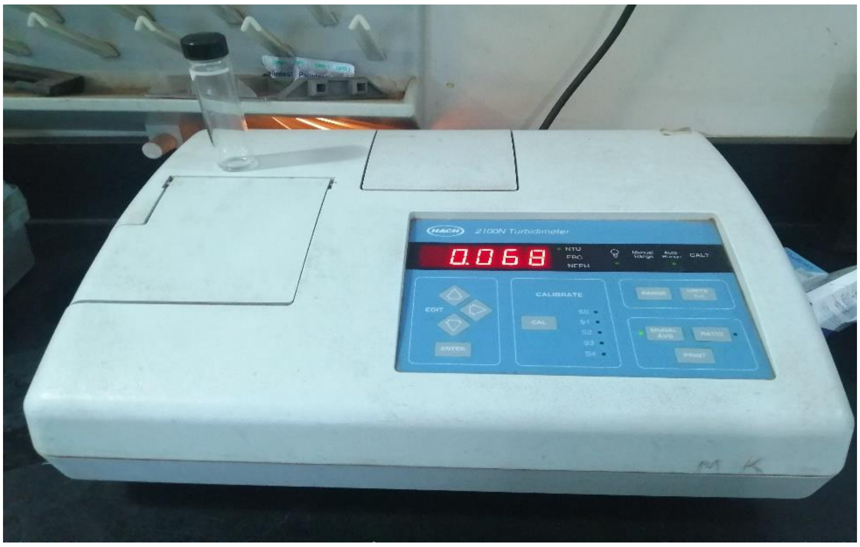


Figure (3-3): Turbidity meter

3-4-7 Total Alkalinity:

This experiment was done by titration, where 50 ml of the sample was placed, then three drops of orange methyl evidence were added, and the color turned yellow, the titration was done with 20% sulfuric acid in the pipette until the color changed to orange, After that, we calculate the volume of the pipette missing and multiply it by 20 to get the total alkalinity. The result is reported in (mg/l).

Figure (3-4): Instruments used for calibration

3-5 Monthly experiences and tasks:

3-5-1. Total Hardness:

This experiment was carried out by titration, where 50 ml of the sample was placed, then 1 ml of Ammonia Buffer and a little bit of Black-T powder were added, and the color turned violet. The titration was done with E.D.T.A with a concentration of 20% in the pipette until the color changed to blue. After that, we calculate the volume of the pipette missing and multiply it by 20 to get the total hardness. The result is reported in (mg/l).

Figure (3-5): Instruments used for calibration

3-5-2 Calcium:

This experiment was carried out by titration, where 50 ml of the sample was added, then 1 ml of NaOH and a little bit of Murexide were added, and the color turned pink. The titration was done with E.D.T.A with a concentration of 20% in the pipette until the color changed to violet. After that, we calculated the missing volume from the pipette and multiplied it by 20 to get calcium. The result is reported in (mg/l).

Figure (3-6): Instruments used for calibration

3-5-3 Magnesium:

Magnesium was determined by using mathematical methods by subtracting the calcium hardness from the total hardness the amount that remained contributed to the magnesium. The result is reported in (mg/l) as shown in equation 3-1.

$$mg = \frac{T.H - Ca}{0.4} * 0.24 \quad \ldots\ldots\ldots\ldots \quad (3 - 1)$$

Where:

mg≡ Magnesium.

T.H≡ Total Hardness.

ca≡ Calcium.

3-5-4 Chloride:

This experiment was done by titration, where 50 ml of the sample was placed, then 3 drops of Potassium Chromate were added, and the color turned yellow. The titration was done with Silver Nitrate with a concentration of 20% in the pipette, until the color changed to brown, after that, we calculated the missing volume from the pipette and multiplied it by 20 to get Chloride. The result is reported in (mg/l).

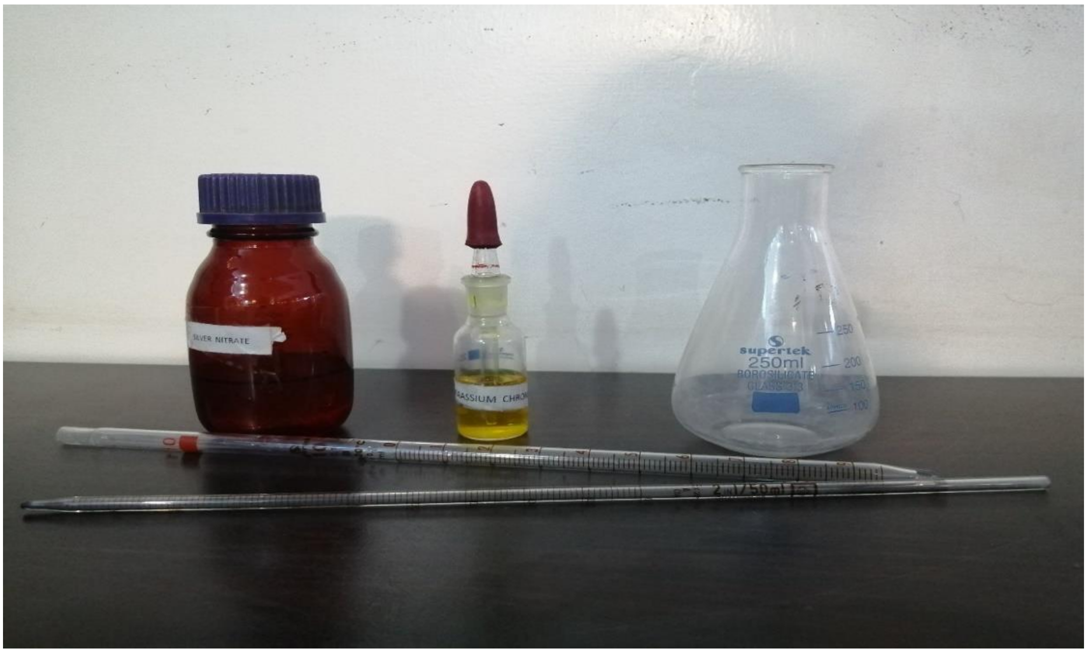


Figure (3-7): Instruments used for calibration

3-5-5 Electric conductivity:

Direct reading by using a conductivity meter. Results reported in µs/cm.

Figure (3-8): Conductivity Meter

3-5-6 Total dissolved solids (TDS):

Direct reading for the **Total dissolved solids** is measured by using a conductivity (TDS) meter, the result was reported in mg/l.

3-5-7 Sodium:

The amount of sodium in the sample was measured with a flame device. The device was filtered with distilled water, and then a capillary tube was inserted into the sample. The color of the flame changed from blue to orange, and a sodium reading is obtained, and the result was reported in mg/l.

Figure (3-9): Flame Device

3-5-8 Potassium:

The amount of potassium in the sample was measured with the Flame device. The device was filtered with distilled water, and then the capillary tube was inserted into the sample. The color of the flame changes from blue to yellow, and the potassium reading is recorded, the result is reported in mg/l.

3-5-9 Device Spectro Dr6000:

This device is used to measure each of (**Mn - Al_3 - F - Fe - NH_3 - PO - SO_4 - NO^-_3 – NO_2^- ...etc.**) in the sample.

Figure (3-10): Spectro Dr6000

<u>3-6 MEMBRANE FILTER TEST:</u>

For coliform bacteria, use about 100 ml of water is passed through a membrane filter (pore size 0.45 µm). This membrane is then placed on a thin, absorbent pad saturated with a differential or selective medium (Figure 3.10). For example, total coliform organisms are sought, and a **modified Endo medium (mEndo broth)** is used as per testing procedure. For coliform bacteria, the filter is incubated at 35 ° C for 18 to 24 hours. enumerating colonies that have a green sheen indicates the number of coliform bacteria in a water sample.

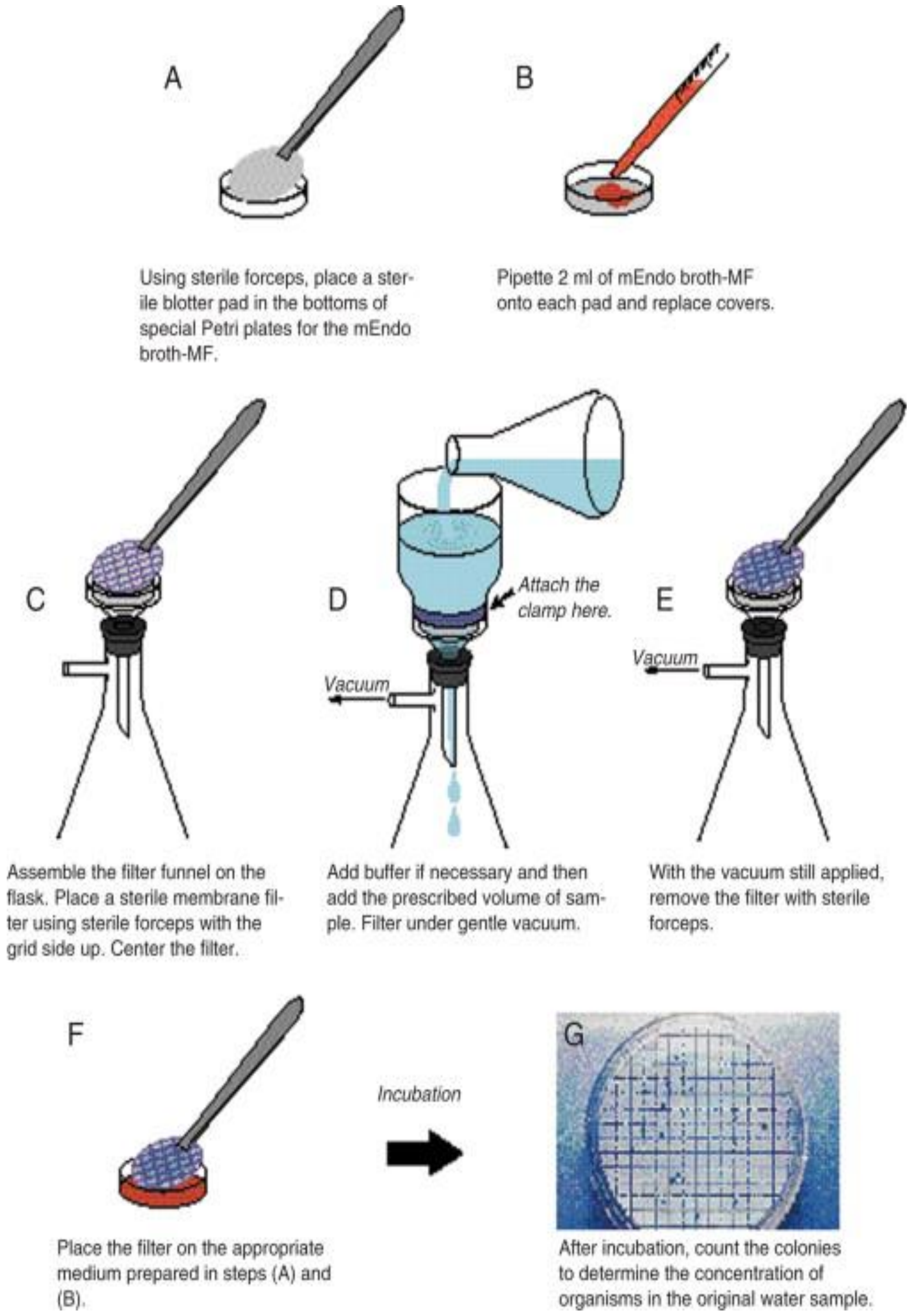


Figure (3-11): Membrane filter test (WHO 2004)

CHAPTER FOUR

Results and Discussion

Overview:

To test and detect the quality of the treated water from the Bahri water purification plant, laboratory analysis was performed for each station independently. The findings are displayed and analyzed in the form of tables and charts, as discussed herein.

4-1 Station (A):

Table (4-1) and Figures (4-1) to (4-4) illustrate the maximum and minimum values as detected at station (A). Concerned parameters included turbidity, pH, chlorine, and total alkalinity. The testing period covered different seasons for July to June.

Table (4-1) The maximum and minimum value of station (A)

Months	Station (A)							
	Turbidity		pH		Chlorine		Total Alkalinity	
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
	NTU		-		mg/L		mg/L	
July	46	5.9	8.2	7.7	3	0	98	86
August	92	8.8	8	7.7	1.3	0	98	68
September	36	6	8	7.6	2	0	84	66
October	106	19.3	8.1	7.6	1	0	112	70
November	47	10.1	8.1	7.6	3	0	74	68
December	23	5.9	8.1	7.5	3	0	78	70
January	7.6	2.8	8	7.6	1	0	84	76
February	4.5	2.4	8.1	7.7	0	0	90	78
March	3.5	1.8	8.2	7.7	0.8	0	94	80
April	7.1	3.1	8.1	7.4	3	0	84	78
May	23	4.4	8	7.6	3	0	88	80
June	20	20	8	8	3	0	90	84

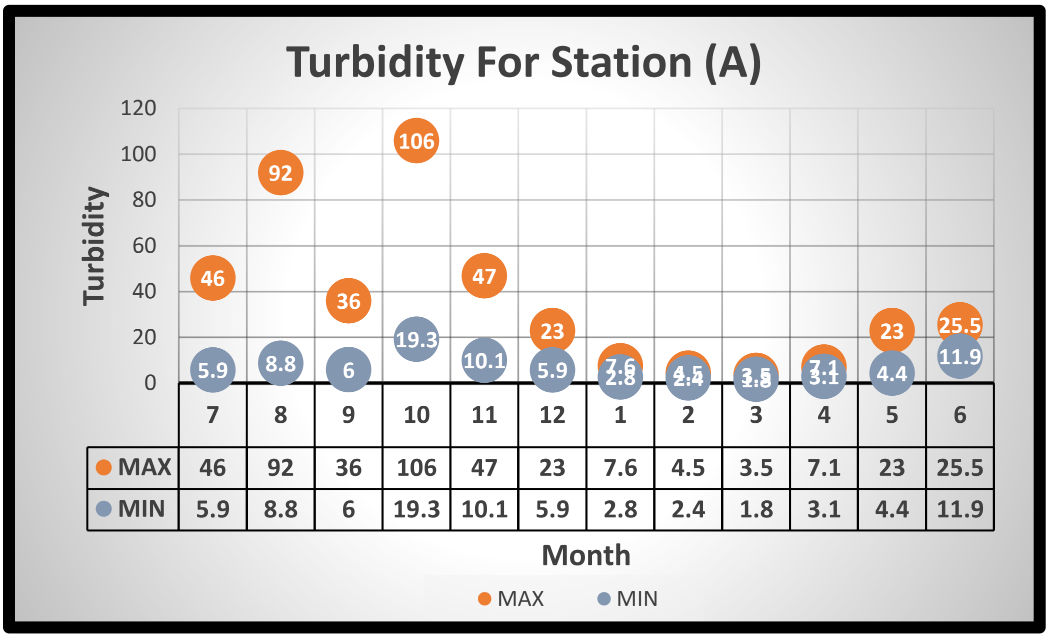


Figure (4-1): The maximum and minimum turbidity for Station (A)

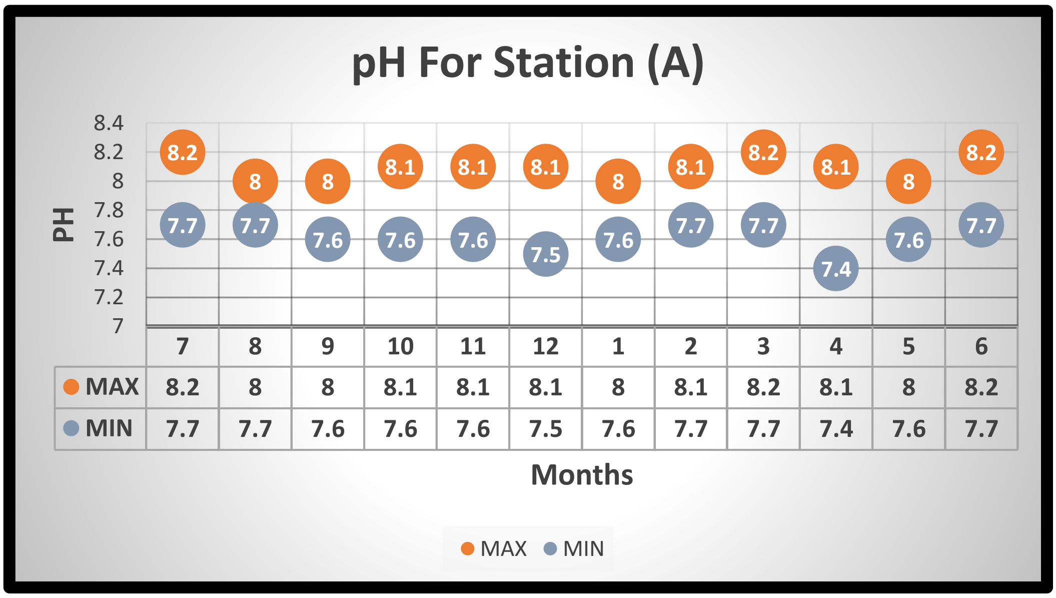
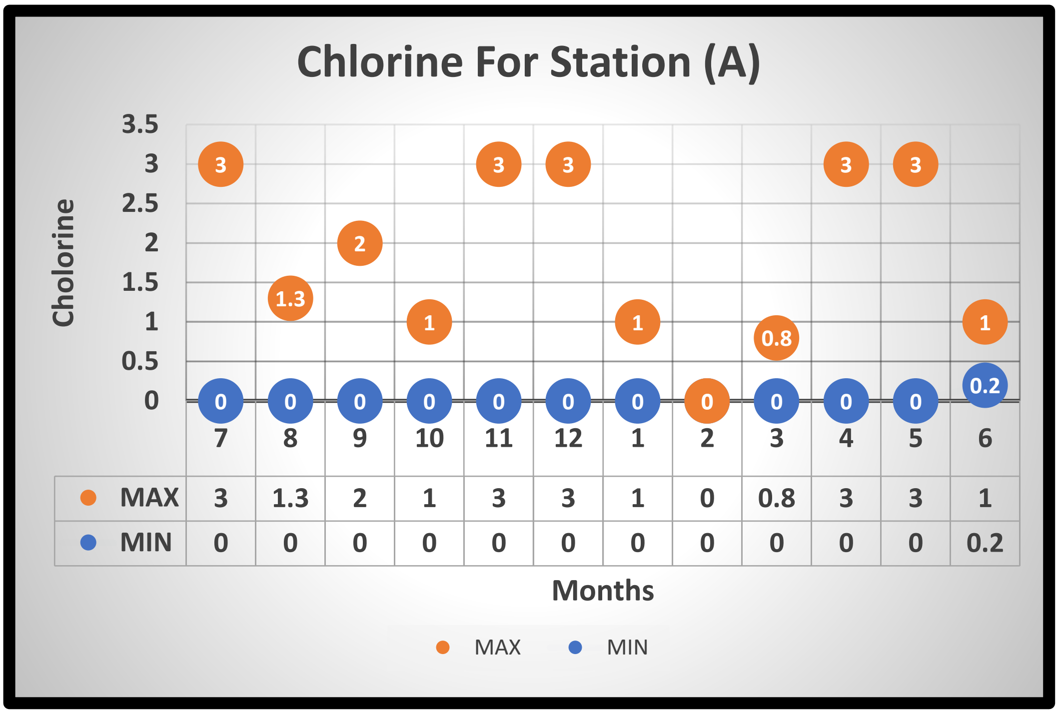
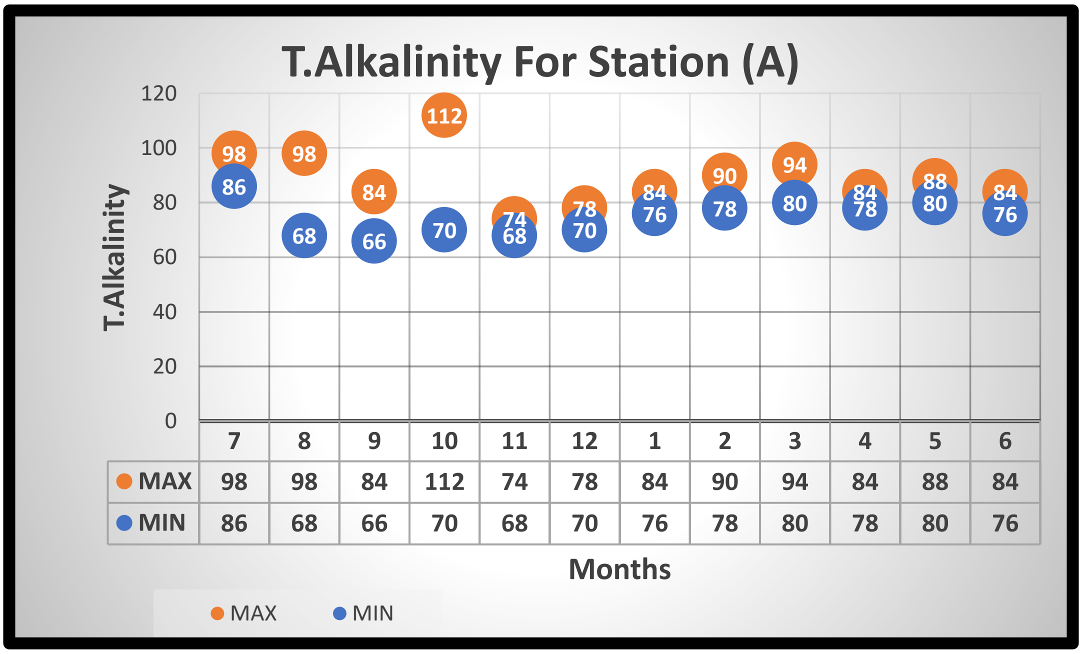


Figure (4-2): The maximum and minimum pH for Station (A)



	7	8	9	10	11	12	1	2	3	4	5	6
MAX	3	1.3	2	1	3	3	1	0	0.8	3	3	1
MIN	0	0	0	0	0	0	0	0	0	0	0	0.2

Figure (4-3): The maximum and minimum residual chlorine for Station (A)



	7	8	9	10	11	12	1	2	3	4	5	6
MAX	98	98	84	112	74	78	84	90	94	84	88	84
MIN	86	68	66	70	68	70	76	78	80	78	80	76

Figure (4-4): The maximum and minimum Total Alkalinity for Station (A)

From the interpretation of the results for station (A), the following observed points emerged:

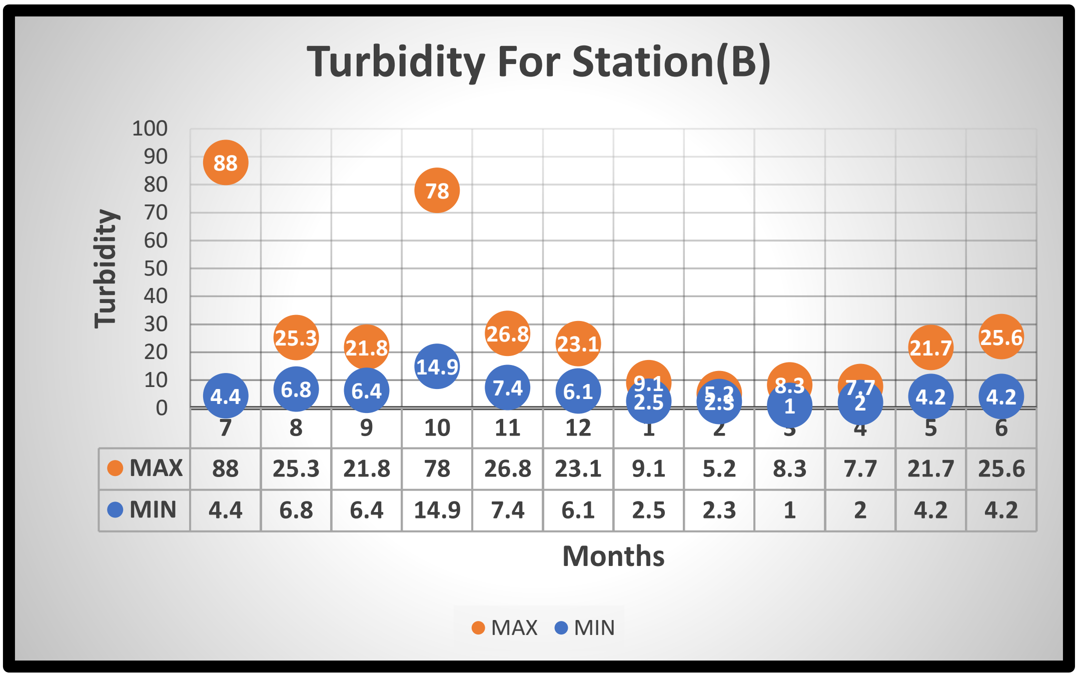
- Figure (4-1) showed that the turbidity of treated water is outside the permissible range (5 NTU) during the months of the year except for February and March. This indicates that treatment is not up to acceptable levels of appropriate operational performance. Plant operators must pay attention to the dosage of coagulants used or sedimentation performance and action.
- Figure (4.2) illustrated the pH linearity for the treated water, which is within acceptable and permissible limits.
- Figure (4-3) revealed fluctuations for residual chlorine in the treated water.
- Figure (4-4) suggests that the total alkalinity of treated water conforms to the specifications and governing properties.

4-2 Station (B):

Laboratory investigations for the maximum and minimum values at station (B) for the characteristics of turbidity, pH, chlorine, and total alkalinity are presented in Table (4.2) and Figures (4-5) to (4-8).

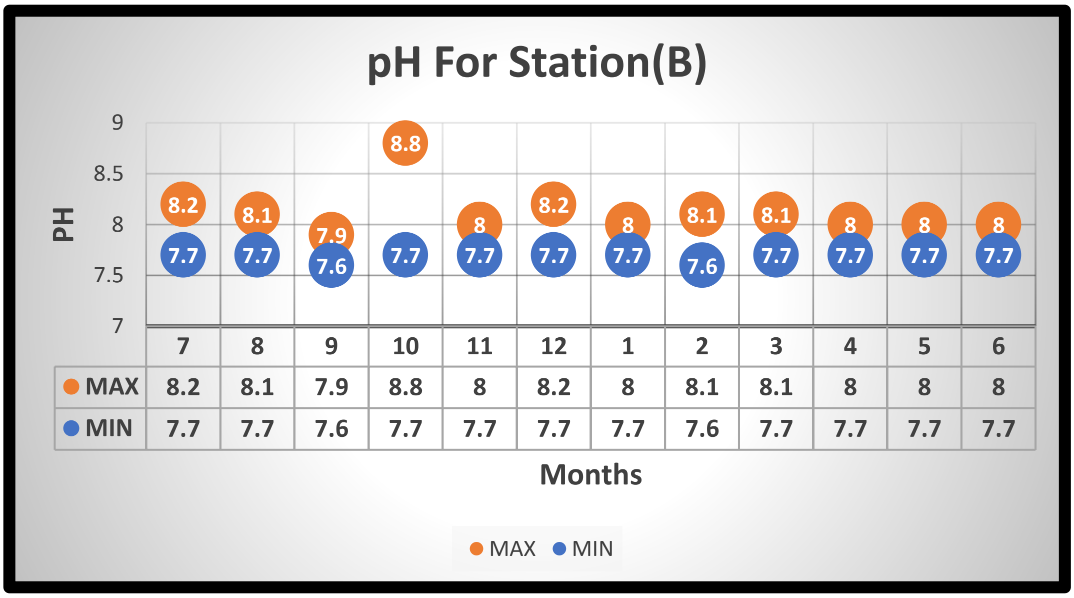
Table (4-2) The maximum and minimum value of station (B)

Months	Station (B)							
	Turbidity		pH		Chlorine		Total Alkalinity	
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
	NTU		-		mg/L		mg/L	
July	88	4.4	8.2	7.7	1	0	98	86
August	25.3	6.8	8.1	7.7	1.2	0	98	68
September	21.8	6.4	7.9	7.6	0.8	0	84	66
October	78	14.9	8.8	7.7	0.4	0	112	70
November	26.8	7.4	8	7.7	1.5	0	74	68
December	23.1	6.1	8.2	7.7	0.6	0	78	70
January	9.1	2.5	8	7.7	0.8	0	84	76
February	5.2	2.3	8.1	7.6	0.8	0	90	78
March	8.3	1	8.1	7.7	0.7	0	94	80
April	7.7	2	8	7.7	0.8	0	84	78
May	21.7	4.2	8	7.7	0.5	0	88	80
June	80	14	8	7.7	1	0	100	80



Months	7	8	9	10	11	12	1	2	3	4	5	6
MAX	88	25.3	21.8	78	26.8	23.1	9.1	5.2	8.3	7.7	21.7	25.6
MIN	4.4	6.8	6.4	14.9	7.4	6.1	2.5	2.3	1	2	4.2	4.2

F igure (4-5): The maximum and minimum turbidity for Station (B)



Months	7	8	9	10	11	12	1	2	3	4	5	6
MAX	8.2	8.1	7.9	8.8	8	8.2	8	8.1	8.1	8	8	8
MIN	7.7	7.7	7.6	7.7	7.7	7.7	7.7	7.6	7.7	7.7	7.7	7.7

Figure (4-6): The maximum and minimum PH for Station(B)

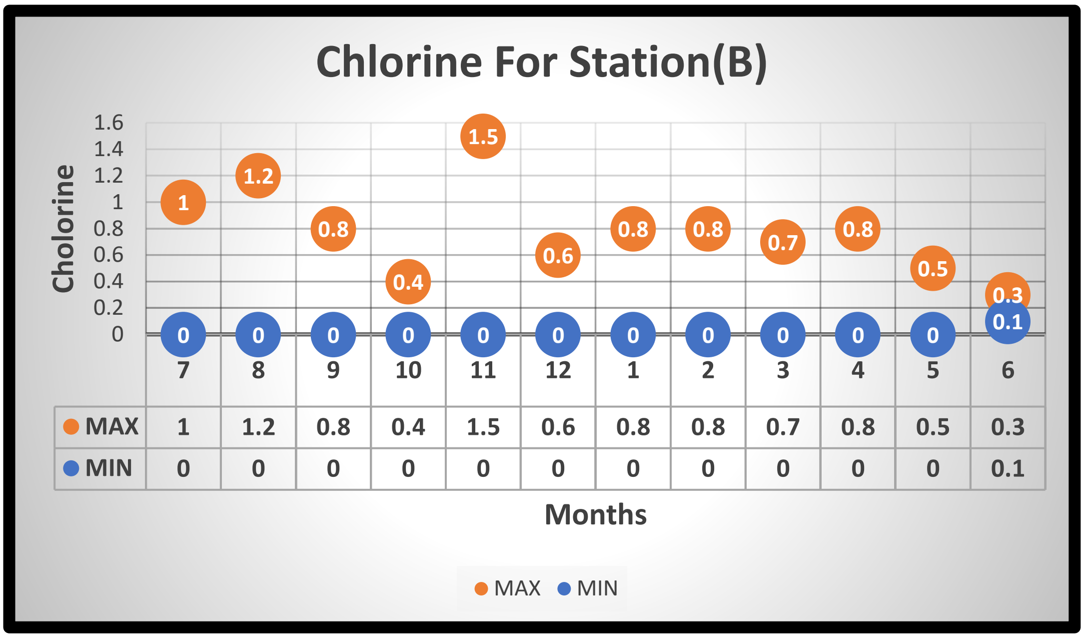


Figure (4-7): The maximum and minimum residual chlorine for Station(B)

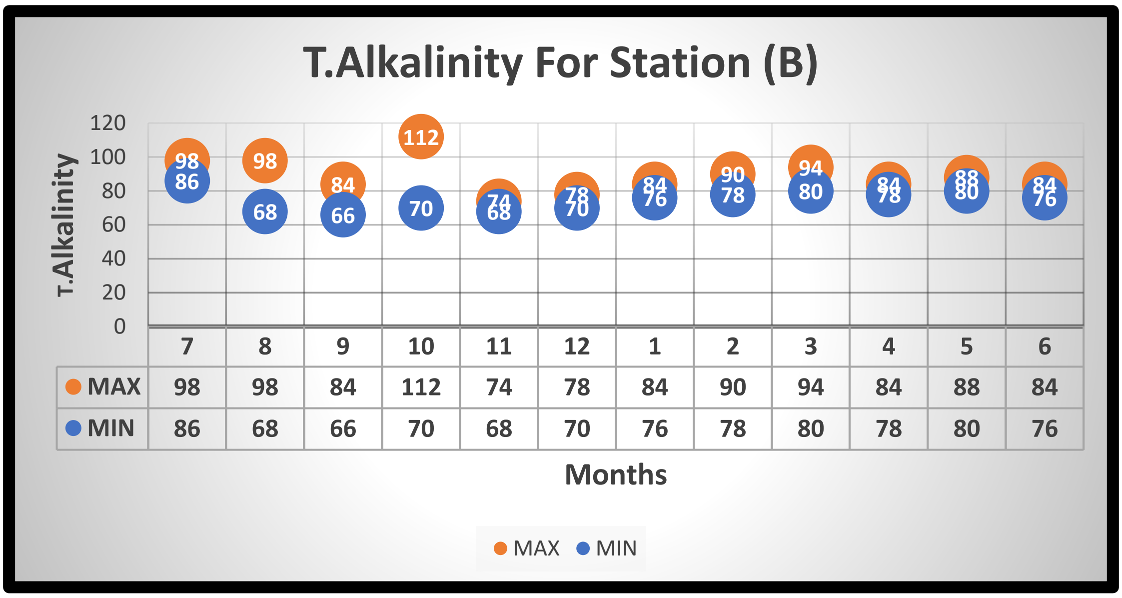


Figure (4-8): The maximum and minimum Total Alkalinity for Station(B)

The following observations were made as a result of the analysis of the results for station (B):

- Figure (4-5) showed that the turbidity of treated water is outside the permissible range (5NTU) during the months of the year.
- Figure (4-6) indicated that the pH of treated water is acceptable and in harmony with standards.
- Figure (4-7) outlined that the residual chlorine of treated water is in an unstable state.
- Figure (4-8) showed that the total alkalinity of treated water conforms to the specifications.

4-3 Station (C)

Table (4.3) and Figures (4-9) to (4-12)exhibit laboratory investigations for the maximum and minimum values at station (C) for the characteristics of turbidity, pH, chlorine, and total alkalinity.

Table (4-3) The maximum and minimum value of station (C)

Months	Station (B)							
	Turbidity		pH		Chlorine		Total Alkalinity	
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
	NTU		-		mg/L		mg/L	
July	100	6.7	8.2	7.7	0.5	0	98	86
August	36.4	10.5	8.1	7.7	0.8	0	98	68
September	33	9	8	7.7	0.7	0	84	66
October	97.9	20.1	8.2	7.6	0.6	0	112	70
November	30	11.3	7.9	7.7	2	0	74	68
December	24.6	6.3	8.1	7.6	1.2	0	78	70
January	11.2	3	8	7.7	1	0	84	76
February	6	2.8	8	7.7	0.8	0	90	78
March	5.4	1.9	8.1	7.7	0.8	0	94	80
April	21.5	2.6	8.1	7.7	0.8	0	84	78
May	21.3	5	8	7.7	0.8	0	88	80
June	22	4	8	7.7	1	0	100	84

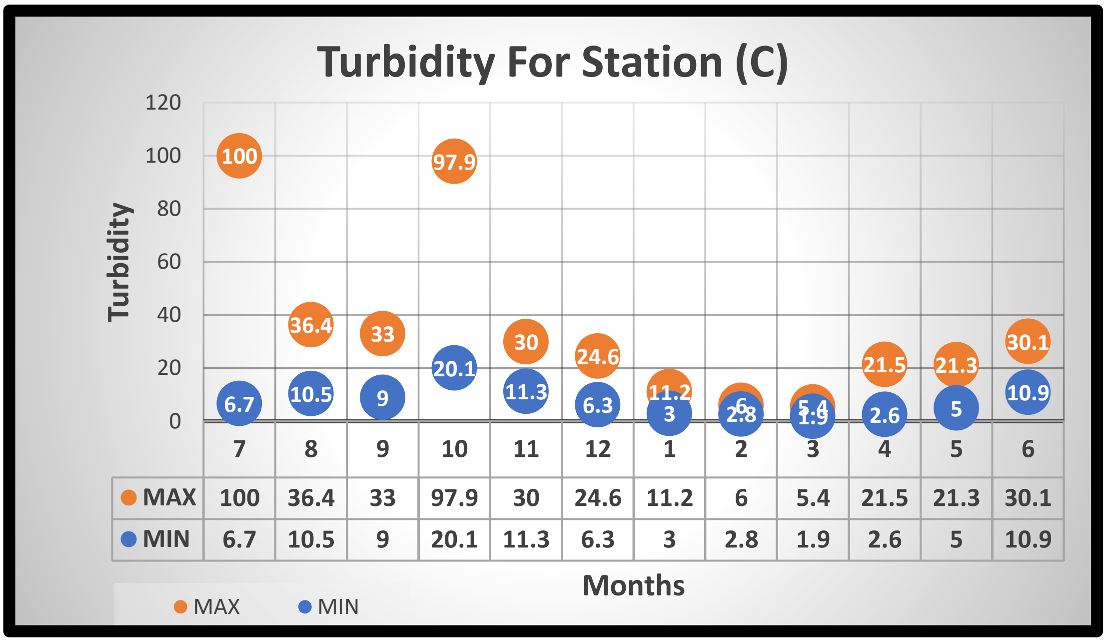


Figure (4-9): The maximum and minimum turbidity for Station (C)

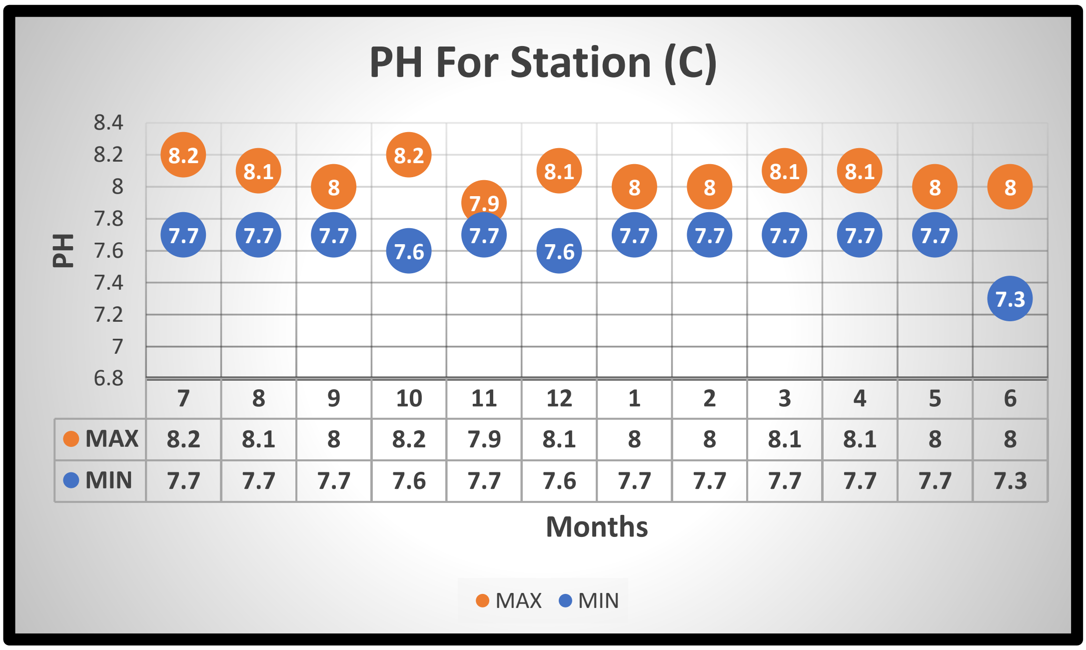


Figure (4-10): The maximum and minimum PH for Station (C)

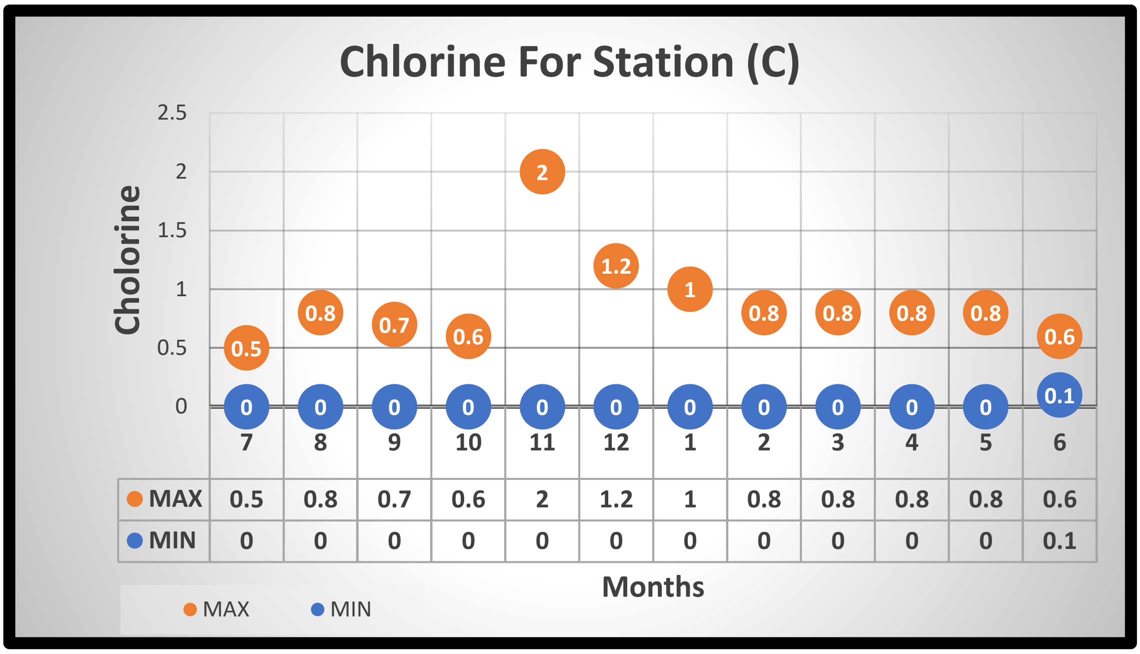


Figure (4-11): The maximum and minimum residual chlorine for Station (C)

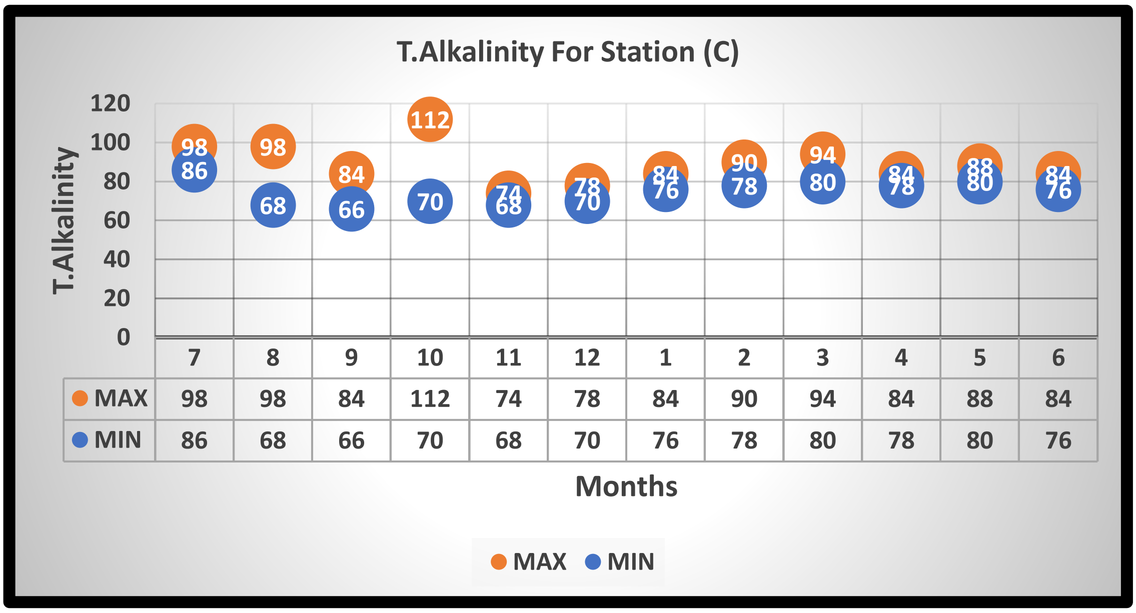


Figure (4-12): The maximum and minimum Total Alkalinity for Station (C)

As a consequence of the examination of the station (B) results, the following conclusions were drawn:

- Figure (4-9) clarified that the turbidity of treated water is outside the permissible range (5 NTU) during the months of the year. This may be attributed to properties of incoming raw water or concentrations of added chemicals during treatment
- Figure (4-10) confirmed that the pH of treated water is acceptable.
- Figure (4-11) reflected that the residual chlorine of treated water is in an unstable state.
- Figure (4-12) showed that the total alkalinity of treated water conforms to the specifications.

Table (4-4) offers a general summary of monthly laboratory experiments of chemical elements as compared to the WHO guidelines and Sudanese national standards.

Bahri station needs maintenance of chlorine addition systems, and periodic washing of water tanks, and the station's SCADA (Supervisory control and data acquisition) system hardly works; Which impairs the quality of the operation and monitoring.

Parameter	Months												Max	SSMO 2007	WHO 2004	Check
	7	8	9	10	11	12	1	2	3	4	5	6				
Appearance	turbid	clear	turbid	-	clear	clear	clear	clear	clear	clear	turbid	turbid	Turbid	Clear	Clear	-
Turbidity	13.1	23.1	10.6	-	12.4	24	4.8	3.1	3.9	4.2	19	6.6	23.1	5 NTU	5 NTU	NOT
Colour	0	0	0	-	0	0	0	0	0	0	0	0	0	15 TCU	15 TCU	OK
Odor	0	0	0	-	0	0	0	0	0	0	0	0	0	Acceptable	Acceptable	OK
PH	8	7.9	7.9	-	7.8	7.9	7.9	7.8	8	7.8	7.7	7.9	8	6.5 - 8.5	6.5 - 8.5	OK
Temperature	26.6	24.3	27.5	-	27.3	27.5	29	28.2	23.7	28.6	28.8	27.7	28.8	Acceptable	Acceptable	OK
Conduct	223	240	194	-	206	226	220	221	186	194	211	225	240	-	-	OK
TDS	132	144	116	-	124	135	132	113	101	110	127	115	144	1000 mg/l	1500 mg/l	OK
T. Alkalinity	82	78	80	-	74	76	76	80	82	80	86	86	86	-	-	OK
T. Hardness	86	92	94	-	94	80	98	80	88	82	64	100	100	-	-	OK
Phosphate	0.37	0.28	0.87	-	0.54	0.16	0.54	0.31	0.21	0.35	0.47	0.16	0.87	-	-	OK
Chloride	11	6.6	4	-	5.2	12	10	7.2	6.2	10	6.8	8.4	12	250 mg/l	250 mg/l	OK
Fluoride	0	0	0.76	-	0.02	0.13	0.02	0.98	0	0.13	0.18	0	0.98	1.5 mg/l	1.5 mg/l	OK
Sulphate	12	26	13	-	16	11	16	7	5	11	1	8	26	250 mg/l	250 mg/l	OK
Ammonia	0	0	0	-	0	0	0	0.11	0.19	0	0	0.07	0.19	1.5 mg/l	1.5 mg/l	OK
Nitrite	0.027	0.034	0.006	-	0.015	0.035	0.031	0.031	0.046	0.031	0.024	0.019	0.046	2 mg/l	2 mg/l	OK
Nitrate	1.3	10	3	-	5.1	7.5	5.1	3.1	4.3	2.5	2.1	2.5	10	33 mg/l	50 mg/l	OK
Iron	0	0.03	0.07	-	0.09	0.05	0.09	0	0.06	0.03	0.03	0.02	0.09	0.3 mg/l	0.3 mg/l	OK
Calcium	23.2	24.8	22.4	-	23.2	24	23.2	25.6	24	24	21.6	24	25.6	250 mg/l	250 mg/l	OK
Magnesium	6.72	7.2	9.12	-	9.6	4.8	9.6	3.84	6.72	5.28	2.4	9.6	9.6	250 mg/l	250 mg/l	OK
Sodium	9	6.8	3	-	5	10	4	7.1	3.6	3.6	14.95	2.5	14.95	250 mg/l	250 mg/l	OK
Potassium	3.7	3.4	2	-	2.6	2.5	2.6	2	2.6	2.6	3.1	2.5	3.7	250 mg/l	250 mg/l	OK
Manganese	0.008	0.02	0.023	-	0.007	0.009	0.54	0.003	0.009	0.012	0.011	0.015	0.54	0.27 mg/l	0.1 mg/l	OK

Table (4-4): Monthly laboratory experiments of chemical elements

Chapter Five

Conclusion and Recommendations

5-1 Conclusion:

The main goal of this study was to evaluate the water quality at Bahri water purification plant, from the beginning of July 2021 to the end of June 2022. Because it is the largest water-producing station in the Republic of Sudan, which produces roughly 300,000 cubic meters of water per day.

The data was analyzed and compared with WHO guidelines and Sudanese standards. The study concluded that the station suffers from a lack of sufficient quantities of PAC and chlorine gas, which is reflected in the water quality of the station. The turbidity of the treated water in October 2021 reached (106 NTU). Often the residual chlorine in the treated water at the plant is (0 mg/l). Bacteria were frequently detected in tests. As for the rest of the chemical and physical parameters conform to the specifications, this is due to the nature of the Blue Nile.

5-2 Recommendations:

1) Provide the necessary quantities of chlorine gas and PAC.
2) Activate the SCADA system at the station.
3) Exploring the potentiality of adding other primary sedimentation basins to the treatment plant to reduce the turbidity of the waters of the Blue Nile.
4) Maintaining relevant apparatus and electronic units and devices used in the plant to add both chlorine and PAC.
5) Periodic cleaning and monitoring of the ground tanks to prevent increasing the turbidity of the treated water.

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