



AFRICA CENTRE OF EXCELLENCE FOR
WATER MANGEMENT ADDIS ABABA
UNIVERSTY



**DRINKING WATER QUALITY IN DEBRE BIRHAN
TOWN, AMHARA REGION, ETHIOPIA**

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**A Master's thesis submitted to the Africa Center of Excellence for Water
Management, Addis Ababa University in partial fulfillment of the
requirements for the Degree of Master of Science in Water Management
(Water Quality Management)**

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Declaration

I, Candidate's Name Mr. Nigus Seyum (**GSR/8991/14**), hereby declare that this MSc research thesis titled "**DRINKING WATER QUALITY IN DEBRE BIRHAN TOWN, AMHARA REGION, ETHIOPIA**" has been developed by me and has not been submitted to any other institution for an award of any academic qualification. The content of the proposal has not been plagiarized and where works of other researchers have been used, they have been appropriately cited.

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Acronyms

ANOVA:	Analysis of variance
APHA:	American public health association
BHs:	Boreholes
CSA:	Central statistics agency
DB:	Debre Birhan
DBWSSS:	Debre Berhan water supply and sewerage service
EC:	Electrical conductivity
EDTA:	Ethylene diamine tetra acetic acid
EPA	Environmental Protection Agency
ESA:	Ethiopian standards agency
FC:	Fecal coliform
HH:	Households
M.a.s.l.:	Meter above sea level
MF:	Membrane filtration
MOH:	Ministry of health
MoWR:	Ministry of water resources
NTU:	Nephelometric turbidity unit
SI:	Sanitary inspection
SPSS:	Statistical package for social science
TC:	Total coliform
TDS:	Total dissolved solids
TH:	Total hardness
THMs:	Trihalomethanes
TTC:	Thermotolerant coliform
TW:	Tap water
UN:	United nation
USEPA:	United state environmental protection

Abstract

Water quality is determined by the physicochemical and biological factors that influence the use of water for household purposes. Health problems associated with water are caused by poor drinking water quality. The study was carried out to determine drinking water quality in Debre Birhan town. 41 water samples were taken from various sources i.e. 12 from boreholes, 3 from reservoirs, 13 water taps within the distribution systems and 13 from household containers. Samples were collected from March to May of 2023. The sample collection was performed according to WHO drinking water sampling guidelines and analyzed in the laboratory using a photometer 7100 based on its procedures. The drinking water quality parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), total and fecal coliforms were analyzed onsite by different instruments. Whereas the chemical parameters such as nitrate, total hardness, calcium, chloride, sulfate, phosphate, iron, copper, fluorides and ammonia were analyzed in laboratory. The drinking water for the town came from groundwater might be affected by several industries, lack of sewerage system which influenced have a direct impact for the pollution of groundwater. Per capita consumption was calculated by dividing annual consumption by the number of people in a town, results a daily consumption of 38.44 L per person. Based on the findings, the result for Debre Birhan's drinking water quality were recorded as pH (7.33–7.76), EC (108.5–157.2 μ S/cm), TDS (54.5-79 mg/l), alkalinity (100–180 mg/l), total hardness(65-150 mg/l), calcium (18-47 mg/l), chloride (2-10 mg/l), sulfate (0-9 mg/l), phosphate (0.2-2.80mg/l), iron (0-0.6mg/l), fluorides (0.17-1.2 mg/l) and nitrate (1.77-18.08mg/l). The WQI results at the source were classified as excellent 40%, good 47% and poor 13%. On the other hand, 85% and 77% of tap water and household containers samples respectively were under excellent category with the remaining results found in good class. Based on the sanitary assessment survey, 59% of participants store drinking water in containers, 97% responded that containers have lids, 54% stored water in homes, and 48% wash hands after lavatory use. Moreover, the absence of sewerage line system and poor waste management in the town leads to wastewater accumulation in septic tanks and pit latrines. Then it was transported by vacuum trucks and private vehicles. The finding of this study can provide valuable insights for professional in the water sectors, healthcare providers and government and non-government organizations.

Key words: *Debre Birhan Town, Water Quality Parameters, Water quality index, Water Supply and Sanitation*

1 Introduction

1.1 Background of the study

For life to continue on Earth, water is the most essential liquid. There is only 3% fresh water in the oceans, while the remaining 97% is unfit for human use, 1.97% glaciers and ice caps making up the remaining only 0.3% is available for human use as surface and groundwater (Luvhimbi et al., 2022). Surface water and groundwater resources are interconnected. Groundwater supplies the majority of the flow into many surface streams. On the other hand, groundwater recharge mainly comes from surface stream water. As a result, the two supply sources are linked and using one could have an impact on the amount of water available from the other.

The need for high-quality water for home, recreational, industrial and other uses has consistently increased due to the world's fast industrialization, urbanisation and population rise (Uchechi & Allwell, 2015). The vast majority of people living in undeveloped countries still rely on surface water as their primary source of water and used as their means of waste disposal for it. Population's access to water coming mainly from unprotected or contaminated sources, increases the risk of waterborne disease outbreaks. Moreover a large percentage of the population in developing countries lack access to safe drinking water forcing to use untreated water from additional sources, including springs, streams, rivers, dams and groundwater, for consumption at home and drinking (Welch et al., 2000).

Water is a vital component of life and is needed for industrial, agricultural and other activities, and it is considered one of the most delicate parts of the environment (Wichelns, 2015). In the last few decades, the accelerated pace of industrial development and the progressive growth of the population have caused a great increase in the demand for fresh water, but pure water is currently in shortage in many regions of the world. It will become even more restrictive in the upcoming century as a result of population growth, urbanization and climate change. Although, the issue of drinking water quality has raised concern in the developed world, it has been little debated in developing countries. Unfortunately, in developing countries, the drinking quality of water is continuously contaminated and hazardous for human use due to high population growth, expansion in industries, and the throwing away of wastewater and chemical effluents into canals and other water sources. Ethiopia is faced with inadequate infrastructure for drinking water and sanitation, 36% of the population practices open defecation, while 52.1% of people use inadequate sanitation facilities (Berhanu, 2015). It is believed

that unsanitary and unsuitable water supplies, along with poor hygiene and sanitation practices, contribute to almost 60% of infectious diseases (Berhanu, 2015). Most of health problems affecting children in the country are also caused by infectious diseases that are passed on by contaminated water and poor sanitation. The primary cause of contaminated water is waste from poor sanitation practices, agriculture, and other activities that contaminate water distribution systems (Tabor et al., 2011). In addition, the integrity of the distribution system and the quality of drinking water are typically affected by fractures in the system, fading and incorrect maintenance, and insufficient levels of chlorine. Before now, in order to prevent water-related illnesses, it was necessary to adequately safeguard the water supply from contamination and conduct regular source monitoring. One technique to evaluate the hygienic state of water is to continuously monitor the results of water quality tests based on the identification of indicator organisms (Mengesha, Admasu, 2004). It is generally accepted which physicochemical factors such as turbidity, pH, temperature, nitrate, and others are significant components of drinking water quality. These variables have an impact on human health, disinfection effectiveness, and microbiological quality. Multiple studies conducted in Ethiopia on the physicochemical and bacteriological quality of drinking water from different sources found that pollution indicators including total and faecal coliforms were present in the water. These suggest that our country's water distribution systems have numerous issues with water quality. For municipal water distribution systems, it is necessary for the establishment of a long-term monitoring and assessment system.

Accesses to potable water as well as sanitation are key issues worldwide. People continue to depend on unsafe water sources including rivers, streams, springs, and manually dug wells in developing nations like Ethiopia as a result. These nations have also been negatively impacted by inadequate access to sanitary services. Due to their vulnerability to the environment, these sources are particularly susceptible to pollution from individuals, animals, and birds. A large number of sources are also situated in wetlands where open-area defecation occurs often and flood-washed wastes affect the quality of the water. This study was conducted in addition to assessing the urban growth, water quality index, and wastewater in order to assess the condition of the drinking water quality from sources to houses in Debre Birhan town.

1.2 Statement of the problem

The quality of drinking water is evaluated by examining its physical, chemical, and bacteriological attributes. In many developing nations, subpar water quality serves as an indicator of poverty. Consequently, the United Nations' Sustainable Development Goal (SDG) Target 6 initiatives have placed a high priority on enhancing the provision, quality and sanitation of drinking water while also reducing waterborne infections (The world Bank, food and agricultures organization, WHO, 2018). Nevertheless, various challenges hinder the effort to ensure clean drinking water for the population. These obstacles include rapid urbanization, inadequate sanitation and pollution of water sources due to sewage and industrial effluents (Alemu et al., 2018). This underscores the persistence of waterborne illness transmission despite global activities to supply clean drinking water.

According to the World Health Organization (WHO), nearly 80% of waterborne diseases in underdeveloped countries stem from drinking contaminated water (Adah & Abok, 2013). Furthermore, 3.1% of deaths are attributable to unhealthy water quality (Pawari & Gawande, 2015). Water contamination poses a grave threat to the health and well-being of humans, as well as the surrounding flora and fauna. The most important aspect affecting human health is the quality of drinking water. Access to safe drinking water remains a significant challenge in many developing countries, including Ethiopia.

Ethiopia has witnessed rapid population growth, industrialization, and economic expansion, which have escalated the demand for water for various purposes. However, clean drinking water access remains elusive for a significant portion of the Ethiopian population. The activities of the community, including agriculture, urban development, and industrial usage, utilize a substantial influence on water quality. Furthermore, the water distribution system in Debre Birhan may be contaminated by various pollutant materials.

In the face of a burgeoning population and expanding industries, the pollution of groundwater due to industrial effluent discharge stands out as a critical issue. To safeguard public health and combat waterborne diseases, there is an imperative to prioritize groundwater quality control and prevention. Another pressing concern in the town is the contamination of the Beresa River by sewage from various sources, potentially leading to groundwater pollution (Ermias, 2007)

The distribution of drinking water in the town is also marred by imbalances resulting from a shortage of electrical power. The town's drinking water supply primarily relies on groundwater sources. Consequently, the groundwater is vulnerable to a variety of effluents from various sources, including a brewery factory, a leather plant, a blanket manufacturer, the textile industry, and an industrial park located in the vicinity.

Despite the town's evident water quality challenges, there has been limited research conducted in the past decade on the water source, distribution system, and point-of-use. Consequently, this study provides valuable insights into the parameters influencing drinking water quality at its source, within the distribution system, at consumers' taps, and in household containers, thereby serving as a valuable baseline for further investigation.

1.3 Research question (hypothesis)

- What is the status of the physiochemical and bacteriological quality of drinking water in the town?
- How is the existing drinking water quality as compared to Ethiopian Standard (ESA) and World Health Organization (WHO) standards?
- How adequate is the water supply in terms of quantity
- What is the status of wastewater management initiatives in the town?
- What are the water storages and sanitations practices of the residents during water shortage?
- What recommendations can be made to improve the water quality and wastewater management

1.4 Objectives of the study

1.4.1 General objective

The general objective of this study is to assess the physicochemical and bacteriological quality of drinking water in Debre-Berhan town from source to point of use and valuate management practices.

1.4.2 Specific objectives

- To examine the physicochemical and bacteriological quality of drinking water of Debre-Berhan town from source to point-of-use
- To determine the Water Quality Index (WQI) and evaluate suitability of the water for drinking
- To assess the adequacy of the water supply services in terms of quantity and assess the town's wastewater management practices.
- To investigate water handling and sanitation practices of the community during water shortage
- To recommend best practices for improving water quality challenges

1.5 Significance of the study

The findings of this study will serve as a baseline study and be useful to professionals in the water sector, healthcare providers, and government and non-government groups. Additionally, it can be important to stimulate, motivate, and focus attention on water quality problems, sanitation and hygiene, and water-related health care sectors. In the future, it will be possible to identify the water pollutants and water quality parameters, besides determining if the water is suitable for consumption or the environment. As supplementary reference material, this research will inform drinking water suppliers.

2. Literature review

2.1 The concept of drinking water quality

By 2030, Sustainable Development Goal 6 (SDG 6) aims to end open defecation and guarantee that everyone has access to clean water and sanitation facilities that are managed sustainably (WHO,2019)

Goal 6 of the Sustainable Development Goals (SDGs), which calls for universal access to clean water and basic sanitation, has the support of every nation around the world. Communities in low-income countries like Ethiopia are still affected by the public health burden brought on by contaminated drinking water supplies and insufficient water supplies, notwithstanding significant advances. Drinking water can get contaminated at any point along the supply chain, from the source to the home's water container and polluted water a variety of waterborne diseases (Sitotaw & Nigus, 2021)

Due to relatively poor access to basic water and sanitation facilities, water-related diseases are particularly common in Ethiopia. Over 83 million people live in unhealthful surroundings, with unsafe drinking water coverage at about 66% and access to improved sanitation at only 6.3% of homes (Marlos De Souza,.: Carlos Carrión-Crespo, 2018). Therefore, 60–80% of all illnesses and diseases in Ethiopia are caused by water-related factors (Sitotaw & Nigus,2021).

The water situation in the Amhara region appears in better coverage than other regions as a report of WASH, with 64% of families having access to improved drinking water sources. However, there are still issues in large towns, like the regional capital Bahir Dar, with the consistency of the water supply (24/7) and the distance from the water source to residences (UNICEF Ethiopia, 2022)

Water consumed for all common domestic functions, such as drinking, washing, and preparing food, is referred to as potable or drinking water (WHO, 2004). According to the WHO, drinking water is only considered safe if and only if there are no substantial health concerns present both over the scheme's lifespan and at the time it is consumed. Water supply quality is determined by its physico-chemical and bacteriological characteristics. Water quality is a complex topic that is determined by the physical, chemical, hydrological and biological qualities of the water, which are used by the user to judge the water's acceptability (Adesakin et al., 2020). Decision makers can develop strategies for preventing and controlling water pollution with the help of information about the water quality of specific bodies of water, and only monitoring can yield such reliable information. Water quality monitoring is crucial,

especially in these sections of the country, to maintain the public health, the environment, and the primary supply of freshwater used for drinking in rural and some urban areas (Adah & Abok, 2013). However, it becomes crucial to monitor water quality in order to spot issues and create solutions to prevent further deterioration.

When evaluating access to improved water sources, water quality issues are frequently the most crucial issue. Regarding its physical, chemical and bacteriological criteria, acceptable quality parameters the safety of drinking water (WHO, 2004). All of humanity must have clean drinking water available to them. Around the world, more than a billion people lack access to clean water for drinking. Human health as well as socioeconomic sustainability is directly correlated with water quality. As anthropogenic activity becomes more intense, contaminants, particularly trace elements from various sources, penetrate the aquatic system and endanger people. Among other contaminants, human activities, particularly the care of animals and agriculture, have a significant impact on the pollution of river water. High levels of ammonia, nitrogen, organic and inorganic nitrogen compounds, and harmful microorganisms are found in cattle waste. Consuming water that has been contaminated by microbiological of coliform is danger human, animal. Pathogenic bacteria, viruses, protozoa, and parasitic organisms can be found in faeces (WHO, 2008)

2.2 Drinking water quality Parameters

Water that can be used safely for drinking and cooking is referred to as potable water and must meet certain physical, chemical and microbiological requirements (WHO, 2004). The quality of surface and groundwater is assessed using physical, chemical and biological requirements.

2.2.1 Physicochemical parameters

The physicochemical quality of drinking water is significantly affected by the properties of the water, such as temperature, pH, turbidity, electrical conductivity, taste, nitrate, alkalinity, total hardness, fluoride, chloride, phosphate and colour (WHO, 2008). When water is at its purest, it has no taste or smell. However, as inorganic and organic particles dissolve in it, a taste and occasionally an odour begin to develop. Inorganic salts at the concentration that is typically present in drinking water do not change the taste, in general, alter the flavor (Fawell, 2005). Both taste and odour are produced by the interaction of numerous environmental factors. Temperature is a key determinant of the quality of drinking water. This factor primarily serves as an aesthetic standard for drinking water. Generally, cool

water tastes better than warm or cold water. The turbidity and colour of filtered water may be indirectly influenced by temperature since low water temperatures have a tendency to reduce the effectiveness of water treatment operations by reducing floc formation rates and sedimentation efficiency. Temperature-related increases in chemical reaction rates can result in more severe corrosion of pipes and fittings in closed systems (WHO, 2008).

pH

pH is a key factor in determining the quality of water since it affects many of the chemical and biological processes within a water body as well as all events related to water supply and treatment. pH is dependent on carbon dioxide and carbonate-bicarbonate equilibrium. The pH of most natural water ranges from 6.5 to 8.5, though diluted waters with high organic content can have lower pH values, while eutrophic waters, groundwater brines, and salt lakes can have higher pH values (EPA, 2021). The WHO's recommended allowable limit is 6.5 to 8.5.

Electrical conductivity (EC)

Potable water has a conductivity that typically ranges from 50 to 1500 $\mu\text{S}/\text{cm}$ (Erena, 2015). The EC values indicate that the concentration of dissolved ions in water, for the interaction of rock minerals with groundwater and the nature of geologic formation could affect the ions in water. The ability of water to carry electric current is measured by its electrical conductivity. The accepted maximum acceptable level of EC in drinking water is 1500 $\mu\text{S}/\text{cm}$ (Churniya et al., 2020).

Total dissolved solids (TDS)

The term "total dissolved solids" (TDS) describes the total concentration of dissolved materials in water, which includes organic matter and inorganic salts, minerals, metals of cations, and anions (WHO, 2019). The TDS concentrations are higher than 500 mg/l to be unsafe for drinking water (Longe & Balogun, 2010). TDS frequently contains the inorganic salts carbonates, nitrates, bicarbonates, chlorides, sulphates, magnesium, potassium, and sodium. Sewage, industrial waste, natural sources, urban runoff and chemicals used in water treatment can all be causes of TDS. Water with high TDS levels may taste brackish, harsh, or salty, but it's not always dangerous for your health. But TDS levels greater than 1000 mg/l are considered dangerous which has more than 1000 mg/l (Brian Benham, 2019).

Drinking water becomes significantly and steadily less pleasant at TDS levels greater than about 1000 mg/l. Water with a total dissolved solids (TDS) level less than about 600 mg/l is typically regarded as having good palatability. Due to excessive scaling in water pipelines, heaters, boilers and domestic appliances, the presence of high amounts of TDS may also be unpleasant to customers. For TDS, no proposed health-based recommendation value has been made (WHO, 2011a).

Table 1 TDS recommendation

Level of TDS (mg/l)	Acceptance
< 300	Excellent
300-600	Good
601-900	Fair
901-1200	Poor
>1200	Unacceptable

Odour

The presence of an odour in drinkable water is nearly always a sign of contamination in the water supply or of a problem with distribution or treatment. Assessing potential or current causes of odour is essential part of sanitary surveys and efforts should always be taken to identify the origin of an odour problem. Since there is no way to evaluate odour thoroughly, there is no way to set a maximum allowable limit. While odour is not always a sign of dangerous chemical concentrations, the availability of odorous public water supply may lead people to look for alternative sources that might be contaminated with diseases or unacceptably high levels of hazardous compounds. Thus, the objective is to controls and protects water that possesses unwanted odour (Watson et al., 2001). It might also be the first sign of a dangerous situation if industrial effluent contamination of the water source causes it (WHO, 2011a).

Turbidity

The turbidity of water bodies is caused by soil erosion, building, road construction, logging and mining, urban runoff, wastewater and septic system effluent, decaying plants and animals (WHO, 1996). Higher turbidity levels are often associated with higher levels of disease-causing

microorganisms such as viruses, parasites and some bacteria (APHA, 2012). For effective disinfection, it is important that the turbidity be as low as possible, preferably less than 0.1 Nephelometric Turbidity Unit (NTU) (John Fawell MBE, 2010).

Hardness

The indicators of calcium and magnesium hardness typically include the formation of soap scum and the requirement for excessive soap usage in order to clean. Changes in hardness are probably noticeable to consumers. The level of water hardness that the general public will tolerate varies greatly from community to community. Depending on the related anion, the taste threshold for the calcium ion ranges from 100 to 300 mg/l, while the taste threshold for magnesium is likely lower than that for calcium. Water with a hardness above 100 mg/l may produce scale deposition in the buildings of treatment plants, distribution systems, pipework and tanks depending on the interaction of other parameters, such as pH and alkalinity (Monarca et al., 2006). Calcium carbonate scale deposits are created when hard waters are heated. Contrarily, water with a hardness of less than 100 mg/l may be soft, although not necessarily cation exchange softened and may have a limited buffering capacity, making it more corrosive to water pipes. Hardness in drinking water has no established health-based guideline value. the supplementary file magnesium and calcium in water for drinking (WHO, 2011a).

Water hardness is an essential consideration in deciding whether it is suitable for domestic and industrial purposes. The primary cations that contribute to hardness are mainly the ions of calcium and magnesium (Venkatesharaju et al., 2016). The maximum permitted limit of overall hardness should not exceed 300 mg/l of CaCO₃, according to WHO guidelines. The types of hardness and softness of water are as follows:

Table 2 Summary of hardness and softness categorize range(WHO, 2011b)

No	Range of concentration(mg/l)	Categorized hardens
1	0-50	Soft water
2	50-150	Moderate water
3	150-300	Hard water
4	More than 300	Very hard water

Calcium (Ca²⁺)

The element of calcium is the most abundant in the Earth of crust, which is essential for the health of human bones and cells. In humans, the majority of calcium is stored in the bones and teeth. In humans, a significant calcium deficit can lead to cardiovascular disorders, rickets, poor blood clotting, fractured bones, and other conditions. The concentration of calcium 75 mg/l is the maximum allowable range in drinking water, under (Cotruvo J, Bartram J, 2009) and ES ISO-7980 standards.

Manganese

Manganese can be found naturally in rocks, soils and water sources. While the body needs a specific amount of manganese for good health, excessive levels in drinking water can have adverse health impacts, especially on memory, attention and movement skills in children and adults (Darji et al., 2022).

High levels of manganese in water can cause learning and behavioural issues in infants in particular. Manganese in water supplies gives beverages a bad taste when levels exceed 0.1 mg/l and stains laundry and hygiene items. Similar to iron, the presence of manganese in drinking water may cause deposits to build up in the distribution system. Most consumers can tolerate concentrations down to 0.1 mg/l. Manganese will frequently develop a coating on pipes even at a concentration of 0.2 mg/l, which may slough off as a black precipitate. This tolerance threshold of 0.1 mg/l is greater than the health-based value of manganese, which is 0.4 mg/l (WHO, 2011a).

Alkalinity

Alkalinity is the water's capacity to resist changes in pH that would make the water more acidic. It is the presence of one or more ions in water, including hydroxides, carbonates and bicarbonates. It can be defined as the capacity to neutralize acid. A moderate concentration of alkalinity is desirable in most water supplies to stabilize the corrosive effects of acidity. However, excessive quantities may cause a number of problems. The WHO standards describe alkalinity only in terms of total dissolved solids (TDS) of 500 mg/l.

The alkalinity of drinking water describes the ability to resist pH changes that would otherwise lead the water to become more acidic or basic. It measures when the water has substances that are bicarbonate, carbonate, or hydroxide (Muller & Ramsburg, 2023). A variety of ions, such as hydroxides, carbonates, and bicarbonates, may be present in water in one or more amounts, contributing to its alkalinity. The recommended alkalinity level for domestic drinking water is less than 100 mg/l (Hemond, 2005). Less than 150 mg/l of alkalinity raises the chance of corrosiveness. Scaling can happen in water with a high alkalinity (more than 150 mg/l) (Stevens Point, 2019). Alkalinity is just regulated by the EPA Secondary Drinking Water Regulations with respect to the amount of total dissolved solids (500 mg/l) and, to a lesser extent, by the pH value (Ignacio et al., 2012).

Nitrate (NO₃⁻) and Nitrite (NO₂⁻)

Nitrate are found in groundwater naturally in small amounts, nitrate levels in drinking water can be raised by man-made sources such fertilisers, sewage discharge and animal waste. Therefore, compared to sources of groundwater for drinking water, the existence of man-made sources of nitrate contamination, such as fertilisers and sewage, might result in higher nitrate concentrations in domestic containers (Cárdenas-Navarro et al., 1999). High nitrate (NO₃⁻) concentrations in drinking water can have serious adverse impacts on people's health, especially for young children. Nitrate is a naturally occurring molecule in food and nature that combines nitrogen and oxygen to cause methemoglobinemia, sometimes known as "blue baby syndrome" in infants. This disorder develops when the body converts nitrate to nitrite, which reduces the blood's capacity to carry oxygen. Because of their less acidic stomach contents, which promote the growth of bacteria that convert nitrate to nitrite, infants are particularly vulnerable. If signs such as blue skin pigmentation are seen in newborns drinking water with nitrate levels more than 10 mg/l, they need to medical attention Furthermore,

certain birth defects and unfavourable reproductive outcomes have been linked to drinking water nitrate exposure. Increased nitrate levels have been linked in studies to an increased risk of preterm birth and certain congenital abnormalities. Even though food is the primary source of nitrates for adults rather than water, drinking water with excessive nitrate contents can still be harmful to health in ways that go beyond "blue baby syndrome." Notably, low nitrate levels in drinking water have been related in certain studies to colorectal cancer and other health issue (Ward et al., 2018).

Nitrate (NO_3^-), also a crucial plant nutrient, is a substance that occurs naturally in the environment. It is a component of the nitrogen cycle and is found in different amounts in all plants. Since nitrate is in a more stable oxidation state than nitrite, nitrite (NO_2^-) is rarely found in substantial proportions outside of reducing environments. It can be produced in vivo by the reduction of ingested nitrate as well as by microbial nitrate reduction. During the stagnation of nitrate-containing and oxygen-poor drinking water in galvanized steel pipes, or if chlorination is employed to give a residual disinfectant, Nitrosomonas bacteria can also chemically produce nitrite. Nitrate can enter surface water and groundwater as a result of agricultural activities, including the excessive use of inorganic nitrogenous fertilizers and manures, wastewater disposal, and the oxidation of nitrogenous waste products in human and animal excreta, including septic tanks. Nitrate concentrations in surface water can change quickly due to fertilizer runoff, phytoplankton uptake, and bacterial denitrification, although changes in groundwater concentrations are often more gradual. Because of natural vegetation's ability to leak into groundwater, some of it may also be contaminated with nitrate (WHO, 2011a).

Sulfate (SO_4^{2-})

The sulfate content of drinking water that is suggested based on aesthetic effects like taste and odour, the secondary maximum contaminant level (SMCL) of 150 mg/l is the recommended concentration of its in drinking water (Bashir et al., 2012). The Environmental Protection Agency (EPA) has made this suggestion, which aims to increase consumer acceptance of water resources. Water with high sulfate content may taste bitter or antiseptic and may also have a laxative effect. Since infants are frequently more sensitive to sulfate than adults are, it is recommended to produce infant formula with water that has fewer sulfates than 150 mg/l. More than 150 mg/L of sulfate can cause the water to taste bitter or like medicine. It can cause plumbing, especially copper pipe, to corrode (Charles Abernathy, David Cole, 2003)

Taste thresholds have been shown to range from 150 mg/l for sodium sulfate to 1000 mg/l for calcium sulfate, depending on the linked cation's nature. At concentrations below 150 mg/l, taste is typically to be negligible. Sulfate has no derived health-based recommendation value (WHO, 2011a).

Phosphate (PO_4^{3-})

Phosphate ions concentration in drinking water is not specifically recommended by the WHO. Phosphates, however, are commonly used in drinking water treatment to maintain water quality while dealing with certain problems with inorganic pollutants. The maximum amount of phosphate that must normally be added to drinking water treatment is 1–5 mg/l, it is a functional recommendation rather than a health or safety guideline (Rosales et al., 2020). Detergents, fertilizers and naturally occurring mineral deposits are the main sources of phosphates in surface water. The concentration of phosphate ions in drinking water varies based on the geographical area and methods used for water treatment. The suggested range for drinking water is 30 to 400 mg/l (ppm). Phosphate content in drinking water under controlled conditions varied from 1.05 to 2.9 mg/l (Rosales et al., 2020).

Drinking water containing excessive phosphate concentrations can be harmful to people's health. Hyperphosphatemia, or too much phosphate in the blood. Symptoms includes inability to breathe, cramps in the muscles, joints and irregular sleep patterns. Furthermore, kidney stones, digestive issues, and diarrhoea can all be caused by consuming too much phosphate. Moreover, excessive phosphate levels may hinder the absorption of some drugs, especially antibiotics. Thus, it is essential for public health to maintain proper amounts of phosphate in drinking water (Appenzeller et al., 2001).

Ammonia (NH_3) and Ammonium ion (NH_4^+)

Unpolluted surface water and groundwater rarely contain ammonia, however water contaminated by sewage, animal faeces, or fertiliser runoff may have high concentrations. Ammonia in drinking water does not have a maximum contamination limit (MCL) set by the US Environmental Protection Agency (USEPA). However, 0.9 mg/l is the health-based limit for ammonia in drinking water established by the (Lewoyehu, 2021). Drinking water with high ammonia levels can taste foul and smell worse. Chloramine, which is which gives drinking water an unpleasant taste and smell, can be produced when ammonia and chlorine are used to disinfect water. Aquatic life is toxic to ammonia in water, although people are not affected by ammonia (WHO, 2003a).

The concentration of ammonium ions in drinking water can vary due to factors such as temperature, pH and the presence of dissolved salts in the water. The presence of ammonium cation in raw water can lead to the formation of nitrites in drinking water through catalytic action or unintentional colonization by ammonium-oxidizing bacteria. Ammonium is a natural component of many food products and is added to foods in small amounts for various purposes. The estimated daily intake of ammonia from food and drinking water is 18 mg/l with minimal exposure through inhalation and smoking. Ammonia is not considered to pose an immediate health hazard at concentrations typical of drinking water and therefore no health guidelines have been established for ammonia concentrations in drinking water. However, exposure to high levels of ammonium salts can cause adverse health effects such as pulmonary edema, nervous system dysfunction and acidosis to kidney damage. Animals exposed to various ammonium salts in drinking water showed physiological adaptations, slight organ changes or increased blood pressure (WHO, 2003a).

In case of pure ammonia is a colourless gas with an unpleasant odour. It is produced from natural gas derived from coal, hydrogen, and nitrogen. In the natural world, microorganisms break down urea and proteins to produce ammonia. It is one of the most popular industrial and home compounds as a result. Ammonia is a gas with the chemical formula NH_3 , indicating that it is made up of three atoms of hydrogen and one nitrogen atom. Ammonia is a great fertilizer since it contains a lot of nitrogen. Ammonium salts are a significant source of nitrogen for fertilizers. Ammonia is one of the most widely used industrial and household chemicals, and like nitrates, it can hasten eutrophication in streams (Sasongko et al., 2018). Both disinfectants may react and change into less chemically active biocides if specific dissolved components are present in the water. The free chlorine reacts in a stepwise manner to form chloramine in the presence of the ammonia nitrogen ion.

Ammonia is often produced through the degradation of nitrogenous organic materials and the release of industrial and municipal waste (A. R. Khan, 2016)

Chloride (Cl)

Chloride is a naturally occurring element that is common in most natural rivers, groundwater and lakes. It usually corresponds to the water's salinity and amount of dissolved minerals 250mg/l, or the concentration at which most people can detect a salty taste when they drink water. It is the recommended limit for chlorides in drinking water for the above amount (WHO, 2003b). Large

concentrations of chloride are not considered to be dangerous to human health, but they can corrode and damage metal pipes and components, break goods in the home. A maximum of 250 mg/L of chloride is the secondary drinking water standard (WHO, 2003b). Although excessive consumption of chloride does not usually cause a health risk, however it can cause hyperchloremia, or high blood chloride levels (Hong et al., 2023).

Chloride concentrations in drinking water for the general public must not be more than 250 mg/l. For sodium, potassium, and calcium chloride, the taste thresholds range from 100 to 300 mg/l, depending on the related cation. Some consumers may grow tolerant to low levels of chloride-induced taste, but concentrations above 250 mg/l are increasingly likely to be noticed by taste. Chloride in drinking water has no established health-based guideline value (WHO, 2011a).

Copper (Cu²⁺)

The majority of copper in drinking water comes from corrosive water leaching it's from copper pipes in construction. In some circumstances, it has been proven that high dissolved oxygen levels speed up copper corrosion. Concentrations can differ greatly depending on how long the water has been in contact with the pipes; for instance, first-draw water is likely to have more copper than a sample that has been completely flushed. High amounts can obstruct the water's ability to be used for residential purposes. Copper concentrations greater than 1 mg/l may stain laundry and hygiene items. Copper also gives water a color and an unfavourable bitter flavor at concentrations above 5 mg/l. Despite the reality that copper can cause a taste, it should be tolerable at the health-based recommended limit of 1 mg/l (WHO, 2011a).

For public water sources, the EPA established a regulated copper concentration action level of 1.3 mg/l (Manne et al., 2022). The WHO is considering adopting a brief copper limit of 1mg/l for drinking water (National Academy of Sciences., 2000).

Fluoride (F⁻)

The minerals fluorspar, cryolite and fluoraptite are containing fluorides. It is a common element that has abundantly dispersed in the Earth's crust. Fluoride concentrations can be found in various types of water, with groundwater often having larger quantities. Well water in some regions with mineral deposits high in fluoride may contain up to 10 mg/l, though far higher quantities can be observed.

There are several locations around the world where fluoride levels are high. Fluorine can be found in almost all foods, at least in trace amounts. Fluoride is a mineral that is absorbed from soil and water and is found in all vegetation. Fluoride levels in tea, for instance, can be very high, with dry tea often containing 100 mg/kg. Fluoride is widely used in dental preparations to combat dental caries, especially in areas where sugar consumption is high. These can be tablets, mouthwashes, toothpaste, varnishes, or gels for topical use. Fluoride may also be added to table salt or drinking water in some countries to protect against dental caries. The amounts added to drinking water are typically such that the final concentrations range between 0.5 and 1mg/l. This will be determined by the fluoride concentration in drinking water, the levels consumed in foodstuffs, and the use of fluoridated dental preparations (Ally et al., 2020).

The WHO recommends the concentration of fluoride in drinking water not exceed 1.5 mg/l (Craig et al., 2015). Fluoride in drinking water can have a variety of negative impacts on health if levels are high. The following are a few common side effects:

- a. Dental fluorosis: This condition, that is characterized by tooth discolouration and can result in other dental problems, can be brought on by excessive fluoride ions in drinking water.
- b. Skeletal fluorosis: This condition, which can result in bone loss, bone loss and muscle damage, also comes on by high fluoride levels in drinking water.

Iron (Fe^{3+})

Iron levels in natural freshwater range from 0.5 to 50 mg/l. The involvement of iron in water containing, the rusting of steel and cast-iron pipes used for water distribution may contribute to the presence of iron in drinking water. Iron is a necessary component of human nutrition. Although the amount of iron in drinking water may vary, however over 0.3 mg/l is usually regarded as unwanted (Intisar El Sharaa, 2020). Although iron is not harmful to health, excessive amounts of it can cause problems like staining, a metallic taste, and unpleasant odours. Iron can be managed and control in a number of ways, such as by using treatment methods or using plastic tubes for water distribution system in different water sources. The type of iron present—ferrous iron, also known as "clear-water iron" or ferric iron, sometimes known as "red-water iron"—determines the appropriate course of action. Experts in water treatment can assist in identifying the most effective way to remove iron from drinking water (Becky Pottratz, 2001).

2.2.2 Bacteriological parameters

Contamination of drinking water, either directly or indirectly widespread health danger related to it by microbes found in faeces and by animal or human waste. Monitoring for particular viruses, bacteria, and protozoa can be challenging, expensive and time-consuming, and it may not always be able to identify the pathogens. Therefore, relatively quick and easy tests for the presence of indicator organisms are used to assess microbiological quality. The three common organisms used as microbial indicators are total coliforms (TC), thermotolerant coliforms (TTC), or alternatively, *E. coli* and *Enterococcus* (R.B. Baird, 2012). An indicator organism for inferring the presence of pathogenic microorganisms in drinking water should usually present in the faeces of humans and animals in large numbers but the absence of in natural water, however to readily detected by simple, inexpensive methods. Faecal coliform (FC) bacteria grow normally at 44.5 °C, while non-faecal coliform bacteria are killed at this temperature. The membrane filter (MF) technique is widely used to measure faecal coliform bacteria in water. The MF consisted of a small, circular, cellulose acetate membrane that retained bacteria on its surface while allowing water to pass through the tiny pores.

The membranes are transferred to a media pad in a sterile plastic container. It is difficult to monitor disease carrying organisms directly, to use the count of FC bacteria as a stand-alone measure and indicator of disease potential. The presence of FC bacteria in water indicates that faecal material from mammals or birds is present, so organisms that cause waterborne diseases may be present as well. The use of finders is attractive because it reduces the complexity and cost of analysing sludge or environmental media (soil, water, or air) for individual pathogens (Sánchez-Alfonso, 2022). Although more accurate measure of faecal pollution is the number of thermotolerant coliform bacteria, while *E. coli* counts are also acceptable. Appropriate confirmatory testing needs to be done when needed. If necessary, proper confirmatory tests must be carried out. TC bacteria are not acceptable indicators of the sanitary quality of water supplies, particularly in tropical areas, where many bacteria of no sanitary significance occur in most untreated supplies. TC includes organisms that can survive and grow in water. Hence, they are not useful as an index of faecal pathogens, but they can be used as an indicator of treatment effectiveness and to assess the clean lines and integrity of distribution systems and the potential presence of biofilms (WHO, 2008)

2.3 Health effect of poor drinking water quality

Low-quality drinking water has major and extensive effects on health. Main health effects from contaminated water can include diarrhoea and other diseases caused by water that can be fatal, particularly in younger children and other people at risk. Drinking water pollution can lead to long-term health problems such as cancer, heart problems, poor reproductive outcomes and neurological development disorders in children. Furthermore, symptoms like nausea, vomiting, diarrhoea, and stomach cramps brought on by poor water quality might interfere with day-to-day activities and perhaps affect children's academic performance (Ford, 1999). Numerous harmful microbes, including bacteria, fungus, viruses, protozoa, and other biological creatures, contaminate water and have been associated with a number of diseases that seriously harm human health. It is commonly known that water has the capacity to spread microbial pathogens to large populations, leading to chronic illness in many nations across all economic development levels.

Drinking water quality can be affected by the undulating nature of the country's topography; water sources often occur in challenging environments, requiring people to travel a great distance on a continuous, incline that is both short and long. This resulted in longer waiting times, inadequate supply, a lack of income, and a lack of quality, which were the characteristics of many improved schemes (Mengesha Admasu, 2004). These factors led to less access to the water needed by the household for consumption and forced households to seek out alternate, unimproved, and unhealthy nearby water sources due to reluctance to use improved sources. It is widely recognized that individuals who utilise contaminated drinking water sources are more exposed to illnesses spread by water.

Most people living in developing countries lack access to any kind of sanitation facilities or clean water. As a result, trachoma, skin conditions, diarrhoea, and other illnesses associated with sanitation, hygiene, and access to water affect millions of people. The consumption of water contaminated with human or animal excrement or urine carrying dangerous bacteria or viruses can result in water-borne illnesses such as cholera, typhoid, bacterial dysentery, viruses such as a retrovirus, and other disorders. Furthermore, water from different sources could also contain dissolved organic and inorganic materials that could harm the community's health. Moreover, diarrheal diseases represent a major health problem in developing countries, and some estimates suggest that the global death toll from diarrheal diseases is about two million per year. Worldwide, the death toll due to diarrheal diseases ranks third among all

infectious diseases (WHO, 2011a) Water pollution directly affects drinking water in lakes, rivers, and oceans in different parts of the world, which consequently harms human health and the natural environment. Poor water quality includes waste water and sewage, marine dumping, oil pollution, atmospheric deposition, underground storage and leakages, radioactive waste, global warming, industrial waste, etc. The contaminated water may cause waterborne diseases. Most children are widely affected due to the consumption of poor-quality groundwater and open channels. The WHO predicts that within developing nations, drinking contaminated water is the cause of roughly 80% of infections (D. N. Khan et al., 2013) and approximately 3.1% of deaths are caused by polluted, low-quality water (Pawari & Gawande, 2015) The contaminated and low quality of the water has been a factor in approximately 3.1% of deaths in recent years. The global public's emphasis has focused on the health risks associated with low water quality. The majority of microorganisms found in drinking water are heterotrophs, indicating they need certain organic nutrients to flourish, like phosphate and nitrate, as well as other organic matter that supports their growth in an environment that is favourable. The growth of heterotrophic bacteria is significantly accelerated by the addition of nutrients to our drinking water since these limiting nutrients, like phosphorous, have a significant ecological significance in nature, are necessary for the growth of microbes, and are less abundant than carbon.

The bacteriological safety of drinking water is assessed using surrogate indicator microorganisms. However, it has been suggested that over 30% of cases of water-borne gastroenteritis have drinking water that fulfills the legislated quality requirements based on bacterial indicators. In this situation, the disease is caused by viruses and protozoa (Fewtrell & Bartram, 2001). Since bacterial indicators do not give information relating to viruses and protozoa, and the methodologies applied to the direct detection of enteric viruses and protozoa are difficult and expensive, other indicators for semi-microorganisms are necessary. The improvement of drinking water quality for human consumption and agriculture depends on reliable analytical measurements. Thus, the analytical tests of colour, odour, EC, pH, flavor, turbidity, bicarbonate, alkalinity, carbonate, magnesium, calcium, water hardness, potassium, sodium, chloride, sulfate, phosphorus, TDS, and nitrate are very important water quality parameters and play a significant role.

2.4 Sanitary Assessments

Sanitary survey means qualified individuals' on-site evaluation of present and potential contamination hazards and directions in and around water supply systems. When using protected wells and springs as

well as protected water connection systems as groundwater sources, it is possible to achieve very low levels of contamination, according to the WHO. However, bacterial contamination of many protected water sources can occasionally occur for a number of reasons (WHO, 2011a).

Sanitary assessments focus on sources of contamination from nearby industries or agricultural activities that pose microbiological and chemical risks. The main risk factors for water system pollution are the existence of pit latrines close to shallow point sources or stagnant surface waters. Pathways are the locations where pollution might occur; such as through fractured well aprons or leaky pipelines. Hazards and channels for contamination might be indirect or sporadic, such as a broken door that allows animals inside well enclosures or erosion that reveals underground pipelines (UNICEF and WHO, 2021). The general sanitation of the sources, the drainage system and reservoir, the physical condition of the protective platform, the location of the outlet and overflow pipe, domestic faucets and the materials that the users used to fetch water are all included in the sanitary assessment process (Amenu et al., 2013).

2.5 Water Quality Index (WQI)

The Water Quality Index (WQI) gives a single number that represents the overall water quality at a specific location and time. Since it has been determined that using individual water quality variables to represent the water quality for the general public is not easily accessible, WQI is essentially a mathematical approach of calculating a single number from many collections of results.

WQI's goal is to transform complicated water quality data into information that can use and understand. Additionally, WQI can be used as a tool to compare the water quality of various sources and provides the general understood with an overview of potential water-related issues in a certain area (Oboh & Egun, 2017).

The Water Quality Index (WQI) as a measure to assess the water quality in groundwater, rivers and streams. Massive amounts of water quality data have been simplified into a single "score" between 1 and 100, where higher scores represent water that is good or poor by depending on water quality index used. The index is based on accepted standards and guidelines for water quality that address the physical and chemical characteristics of the water bodies, including the quantity of dissolved oxygen in the water, temperature (Griffiths et al., 2012). There are a number of water quality index. These are

National Sanitation Foundation Water Quality Index (NSFWQI)

Brown et al. used the Delphi technique to construct the water quality index, which involved carefully choosing the criteria, creating a standard scale, and giving the parameters weights. The National Sanitation Foundation (NSF), which also goes by the name NSFWQI, supported this index. Because it is the most thorough work, it has been written in numerous works (Sutadian, 2016). Assessment forms are created based on the conclusions of experts to assign values for variations in the quality of the water resulting from different levels of each of the chosen issues.

Using established rating forms and related weights, like the Additive index, among can calculate a water quality index.

$$WQI = \sum_{i=1}^n W_i Q_i$$

$$I = \sum_{i=1}^n I_i W_i$$

Equation 1 National Sanitation Foundation Water Quality Index

Where, $\sum_{i=1}^n W_i = 1$, I_i = Sub-index of each parameters, W_i = Weighting factor, Q_i = is the rating value of parameter i and n = Number of sub-indices.

Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI)

The Canadian Council of Ministers of the Environment (CCME) has created a water quality index to make complicated and technical water quality statistics easier to understand. A science-based communication tool called the CCME WQI compares multi-variable water quality data to user-specified benchmarks for water quality. Scope, frequency, and magnitude are the three measures of variation that the WQI computationally integrates to create a single unit-less value that indicates the overall water quality at an address in relation to the selected benchmark (e.g., the safeguarding of aquatic life) (Rosemond et al., 2009). The final result is shown as a single, unitless number between 0 and 100, where 100 means the variables were either below or similar to the chosen benchmarks. To make things easier, the CCME created a calculator that is a water quality parameters that has been preprogrammed with mathematical equations

$$WQI = 100 - \sqrt{(F1 + F2 + F3) / 1.732}$$

Equation 2 the Canadian Council of Ministers of the Environment (CCME)

Where:

F₁ represents Scope: The percentage of variables above the guideline

F₁= [No. of variables whose objectives are not met /Total no of variables]*100;

F₂ represents Frequency: The frequency by which the objectives are not met

F₂= [No of tests whose objectives are not met /Total no of tests]*100;

F₃ represents Amplitude: The range to which the failed tests are above the guideline

The constant, 1.732, is a scaling factor (square root of three) to ensure the index varies between 0 and 100.

Weight arithmetic water quality index (WAWQI)

The technique of categorizing water quality according to quality is accomplished by utilizing the most commonly measured water quality variables to compute of the selected known standards the water, use quality index, which is determined by the weighted arithmetic index. The four essential typical procedures used by the indices for developing a WAWQI technique are as follows:

- a) Parameter selection;
- b) Obtaining the sub-index value;
- c) Establishing weights; and
- d) Sub-index aggregation to determine the value of the final index. The WAWQI formulas as follows

Step 1 to determine $K = \left(\frac{1}{\frac{1}{s_1} + \frac{1}{s_2} + \frac{1}{s_3} + \frac{1}{s_4} + \dots} \right) = \frac{1}{\sum 1/s_n}$

Equation 3 Weighted Arithmetic Water Quality index

The unit weight $W_n = K/S_n$

S_n standard of water quality values at nth parameter

Step II $Q_p = (V_p - \text{ideal value}) / (\text{WHO standards} - \text{ideal value}) \times 100$

Vp is the mean concentration values of selected parameter

The ideal value most parameters are 0 except pH= 7 and DO are 14

Table 3 Water Quality Index (WQI) and Status of water quality (Satish Chandra et al., 2017)

Water Quality Index Level	Water Quality Status
0-25	Excellent Water Quality
26-50	Good Water Quality
51-75	Poor Water quality
76-100	Very poor Water quality
> 100	Unsuitable for drinking

2.6 Guidelines for Water Quality Parameters

Drinking water should be as secure as possible and every measure should be taken to make it safe. Additionally, safe drinking water is required for everyday activities, including consuming food, cooking and maintaining personal cleanliness (ESA, 2013). Guidelines as well as recommendations for drinking water vary regionally or from one nation to another, and it is not expected that there will be a single set of standards that applies to all countries for a variety of reasons. The ability of the regulatory body to set and enforce standards must also be taken into account, as must any present or future legislation pertaining to water, health and other related issues. Parameters are evaluated based on the corresponding tested values, as shown in the tables below for comparison, in accordance with the WHO recommendations and the national water quality requirements of Ethiopia (WHO, 2011a).

Table 4 WHO and Ethiopian physical water quality guidelines

Parameters	WHO Guidelines	Ethiopian Guidelines
Temperatures	<15 ⁰ C	
Electrical conductivity	1200 µs/cm	
Total dissolved solids	< 1000 mg/l	< 1000
Turbidity	< 5 (NTU)	< 5

Table 5 WHO and Ethiopian Chemical water quality guidelines

Parameters	WHO Guidelines	Ethiopian Guidelines
Aluminium as Al ³⁺	0.2 mg/l	0.2
Fluoride as F ⁻	1.5 mg/l	1.5
Nitrate (as NO ₃ ⁻)	50 mg/l	50
Chloride as Cl ⁻	250 mg/l	250
Copper as Cu ²⁺	2 mg/l	2
Phosphate as PO ₄ ³⁻	-	-
Total Iron as Fe ³⁺	0.3 mg/l	0.3
Alkalinity as CaCO ₃	500 mg/l	200
Total hardness as CaCO ₃	500 mg/l	300
Ammonia as (NH ₃ and NH ₄ ⁺)	1.5 mg/l	1.5
Sulphate as SO ₄ ²⁻	250 mg/l	250
Calcium as Ca ²⁺	200 mg/l	75

Sources(WHO, 2011b)(ESA, 2013)

Table 6 WHO and Ethiopian Biological water quality guidelines

Parameters	WHO Guidelines	Ethiopian Guidelines
Total coliform	Must not detectable in any 100 ml samples	Must not detectable in any 100 ml samples
Faecal coliform	Must not detectable in any 100 ml samples	Must not detectable in any 100 ml samples

2.7 Current Status of the Groundwater and Water Distribution System in the Town

Since the late 1960s when the water delivery infrastructure is constructed, Debre Birhan town depended on groundwater as a source of drinking water (Timotewos et al., 2023). However, Debre

Birhan lacks a centralised sewage system, and all facilities are on-site (Pippa Scott and Lucia Henry, 2018). The area's highland and moderately-gently sloping plains receive the majority of their groundwater recharge from rainfall, suggesting that precipitation may have an effect on this process. Groundwater serves as the main source of water supply for Debre Birhan town along with the water distribution system.

Moreover, the ultimate assessment of its wastewater system points to the need for sanitation stakeholders to work together better and make better decisions, as it is important for the town's general water management (Vidal et al., 2019). Both the quantity and the quality of the water in the surrounding area have been observed to be impacted by the manufacturing processes in Debre Birhan town. Studies investigated how industrial and municipal discharges affect the Beressa River's water supply in the town, and the results show that these discharges contributed to shortages of water and pollution (Awgchew et al., 2015).

2.8 Adequacy of the water supply

Water supply adequacy is an essential consideration for numerous sectors, including industrial, agricultural, and municipal users. Because of a rapid increase in both population and economy, effective management of water resources is becoming increasingly critical (Hunter et al., 2010). According to national and international guidelines, the quantity of water available to all people should be 50–100 liters per person per day, or an absolute minimum of 10 liters per person per day, according to the World Health Organization, for maintaining health, hygiene, and all home uses (Gleick, 1996).

The per-capita residential water demand varies for different demand categories based on the size and development of the town, the kind of water distribution system, the socioeconomic status of the town, and the local climate. Based on the fundamental human needs for water for various activities in the demand group, the per capita water demand for an adequate supply level must be determined (Rata & Brook, 2018).

The residential homes mostly required water for drinking, cooking, washing, bathing, laundry, toilet flushing, home cleaning, home maintenance and others. However, not all households have these demands. The characteristics of the various categories of water needs are largely self-governing, with each category existing simultaneously and generally not overlapping with the others. Growth in the economy is unable to be separated from water because it is essential to production. The basis of

ecology is water. Water is essential to the conservation of the ecological environment (Hou et al., 2019).

From the above assumption, there are many different things that people accomplish with water. The significance of certain types of water varies. For instance, drinking a few liters of water each day is more crucial than utilizing water for personal care or laundry, but people still wants to wash to prevent many diseases and conditions and fulfill other physiological needs. Additional uses of water have the following health and other benefits, including the figure 1 (Reed & Reed, 2013).

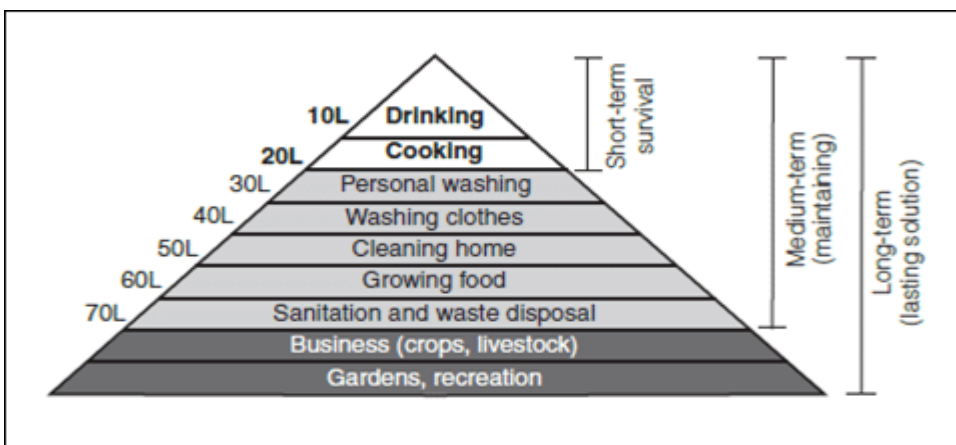


Figure 1 The Hierarchical Drinking water needs

The per-capita residential water demand varies for different demand categories based on the size and development of the town, the kind of water distribution system, the socioeconomic status of the town, and the local climate. Based on the fundamental human needs for water for various activities in the demand group, the per capita water demand for an adequate supply level must be determined (Rata & Brook, 2018).

3. Methodology

3.1 Study area

Debre Birhan is the zone town of North Shewa in Amhara region state, situated in central Ethiopia, 130 Km to the northeast of Addis Ababa. The town is located an average elevation range of 1765-2850 m above sea level (m.a.s.l.) in latitude $9^{\circ}41'N$ and longitude $39^{\circ}32'E$. historically the town served as the capital of the Shewa kingdom. Currently, the town is an administrative center for the North Shewa Zone in the Amhara Regional State.

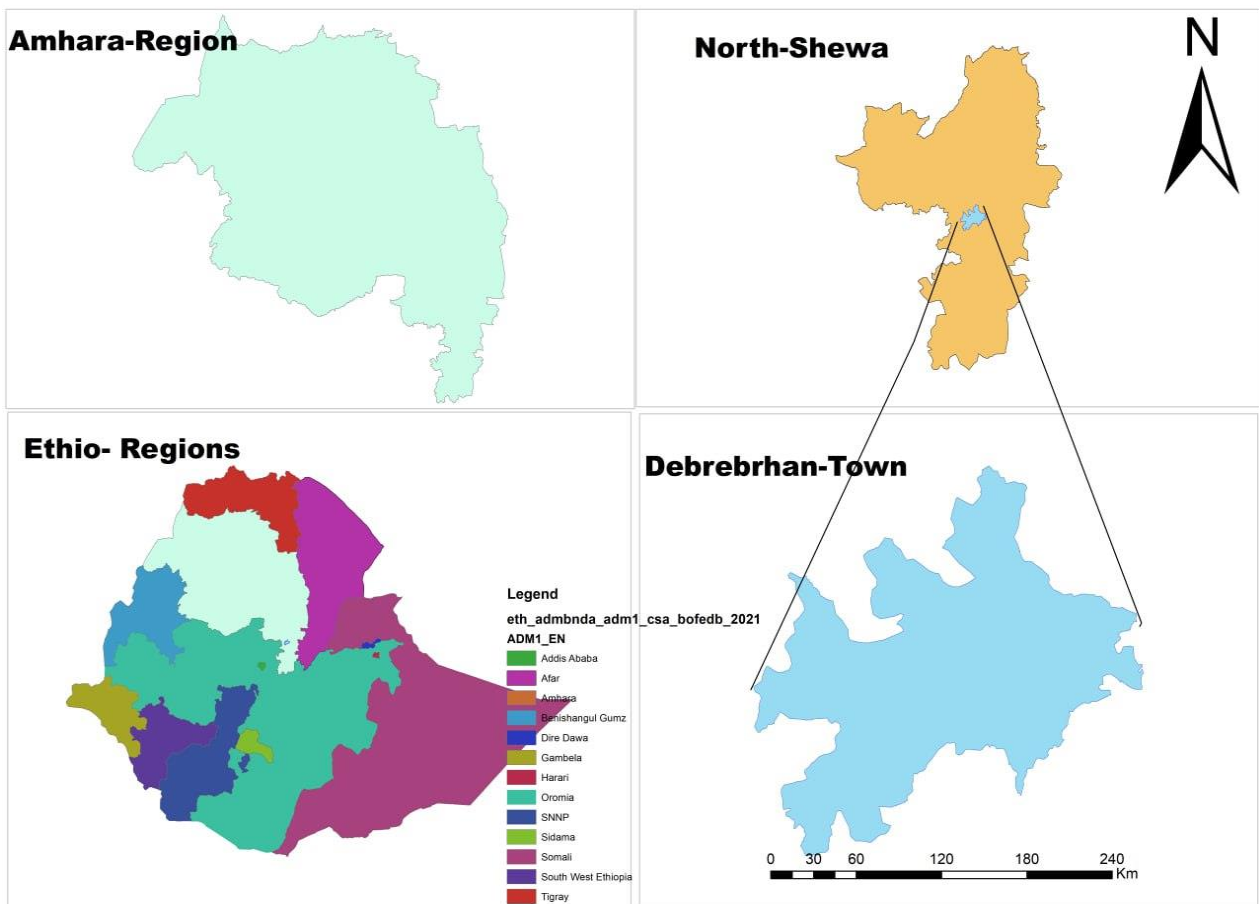


Figure 2 map of the study area

3.2. Assessing the Adequacy of Water Supply System in the Town

Field observations and informal interviews were employed with the employees of the authority and end users. To assess the current status and adequacy of the water supply in the city. Secondary data on

demography and current production capacity of the boreholes were collected from the authority to estimate the adequacy of water supply.

3.3 Study Design

The research was accomplished using cross-sectional and descriptive study designs. A cross-sectional study method was used to assess the physicochemical and bacteriological quality of drinking water at sources (boreholes), reservoirs, taps and household containers.

3.3.1 Water Sampling Method and Size

For the study, stratified sampling methods were applied to collect water samples from taps and household water containers. The number of water samples from household containers was determined by a simple random selection method. On the other hand, purposive sampling technique was conducted for boreholes and reservoirs. The number of samples for sanitary inspection questioner in each kebele was decided based on the number of populations within each of them by the stratified methods.

The selected sampling sites in Debre Birhan town are indicated in Figure 3 showing the representative sample areas. The water samples were collected from 12 boreholes (BHs), 3 reservoirs, 13 taps, and 13 household (HH) containers. Sampling spots were indicated by the GPS (Entrix, Garmin, Taiwan) coordinate system.



Figure 3 Water samples collection points

3.3.3 Water Sample collection procedure

Procedure for water sample collection was carried out as per WHO guidelines at selected sampling place of boreholes, reservoirs, taps and household containers. Polyethylene bottles (500 ml) were used to collect the water samples. The sample bottles were rinsed first three times and properly labeled before the sampling. Then the sample were taken and were preserved at 4 °C by using ice box (ISO 5667, WHO, 2022) prior to analysis. The physical parameters such as pH, EC, were analyzed onsite whereas the chemical analysis was performed at water quality laboratory located at ACEWM and Ministry of Water and Energy. The water samples for bacteriological analysis were collected by using thermally sterilized glass bottles. The tap was burned by a cotton pad with alcohol and the water was allowed to run for two minutes prior to sampling. Finally, the sample was taken and the analysis was done onsite using bacteriological test kits.

3.3.4 Water Sample storage and transportation

The water samples were stored and preserved at temperature of 4 °C by using ice box and transported to laboratory following the WHO drinking water guideline. The chemical analysis was performed at the water quality Laboratory located at ACEWM and Ministry of Water and Energy.

3.4 Water sample analysis

3.4.1 Physicochemical analysis

Temperature, EC, TDS and pH were measured using a multi-parameter portable probe instrument. EC and TDS was measured using a conductivity meter, which was first calibrated by immersing the probe meter in 0.01N potassium chloride and setting it to 1413 μ /cm at 30 °C. Before pH analysis the pH meter was also calibrated using a buffer standard of pH 4 and pH 7.

The determination of total alkalinity, total hardness, calcium (Ca^{2+}), ammonia (NH_3), nitrate (NO_3^-), sulfate (SO_4^{2-}), aluminum (Al^{3+}), phosphate (PO_4^{3-}), fluoride (F⁻), copper (Cu^{2+}) and iron (Fe^{3+}) for the collected water samples was done using a photometer following their reaction times and analytical reagent procedures.

Table 7 Analytical instruments

No	Parameters	Test method
1	pH	Electrochemical
2	Electrical conductivity	Electrochemical
3	Total dissolved solids	Electrochemical
4	Alkalinity	Colorimetric
5	Total Hardness	Colorimetric
6	Iron (Fe ³⁺)	Colorimetric
7	Copper (Cu ²⁺)	Colorimetric
8	Nitrate (NO ₃ ⁻)	Colorimetric
9	Sulphate (SO ₄ ²⁻)	Colorimetric
10	Ammonia (NH ₃)	Colorimetric
11	Aluminium (Al ³⁺)	Colorimetric
12	Fluoride(F ⁻)	Colorimetric
13	Chloride (Cl ⁻)	Colorimetric
14	Calcium (Ca ²⁺)	Colorimetric
15	Phosphate (PO ₄ ³⁻)	Colorimetric
16	Bacteriological	Membrane filtration

Total hardness was determined first by adding hardicol No. 1 and No.2 tablets to 10 ml of the water sample, crushed and mixed until completely dissolved. Sample for Sulfate analysis was treated by adding one crushed sulfate Turb pill to the test tube with 10 ml of the water sample and stirring to dissolve it. For fluoride analysis was measured using fluoride No. 1 and No. 2 tablets and for

phosphate analysis, Phosphate LR No. 1 and Phosphate No.2 tablets were added to the water samples then to analysis by instruments. Alkalinity was measured using one alkaphot tablet and iron was examined by adding one Iron HR tablet to a test tube with 10 ml of water. Ammonia was analyzed using ammonia No. 1 and 2 tablets and the concentration of aluminum was measured by crushing and stirring to dissolve the crushing tablets. Chloride was analyzed by crushing and stirring one Acidifying CD tablet and one Chloridol tablet. Then all the sampled were tested using Photometer at specified wavelength and the results were displayed recorded as mg/l. Finally, the results of this analysis was compared with WHO guidelines

3.4.2 Bacteriological analysis

Microbial analysis was conducted using the Aquasafe WSL25 Plus bacteriological test kit. The bacteriological analysis includes total and faecal coliform determination. The American Public Health Association's (APHA) Standard Methods for the Examination of water were implemented and the membrane filtration method was used. Total and fecal coliform in water was detected by Membrane filtration and coinciding detection (m-coli blue 24 broth)

A water sample's total and faecal coliform bacteria concentrations were been determined using the membrane filtering method. All experimental items, such as forceps, petri dishes and the filter funnel device, were first sterilized using a flame. First, a Petri plate with a liquid bacterial growth media was evenly covered with a sterile pad. A 45 µm membrane filter was used to filter a 100 ml water sample, using sterile forceps; the filter paper was transferred to the pad in petri dish holding the M-coli Blue 24 broth growth media. After that, the Petri dish was incubated for 24 hours at 37 °C to adjust of total and fecal coliform. Finally, calculate the total coliforms (red and blue colonies) and fecal coliform (blue colonies) per 100 milliliters of drinking water using the formula below. Finally, the results of this analysis were compared against WHO guidelines.

$$\text{Fecal coliform /100mL} = \frac{\text{Number of blue colonies}}{\text{Volume of sample filtered/1(mL)}} \times 100$$

$$\frac{\text{TC}}{100\text{mL}} = \frac{\text{Number of fluorescent colonies} + \text{Number of blue, non - fluorescent colonies(if any)}}{\text{Volume of sample filtered (mL)}} \times 100$$

Equation 2 coliform counts

Table 8 Water quality counts per 100ml and the associated risk (Source: Michael,2006)

Water quality Counts per 100ml and the associated risk count per 100ml	Category of risk
0	In conformity with WHO guidelines
1-10	Low risk
11-100	Intermediate risk
101-1000	High risk
>1000	Very high risk

3.5 Water Quality Index

The methods for water quality index were calculated for its determination using weighted arithmetic water quality index. The procedures were the following

- a) to selected the parameters to measures the quality analysis
- b) The quality ratings were scaled for each parameter, $Q_p = 100 \{ (V_p - \text{ideal values}) / (\text{WHO standards} - \text{ideal value}) \}$. Whereas Q_p = calculated value of the n^{th} parameter of the given sampling sites. V_p = the averages of measured values of n^{th} parameter in samples sites. The ideal values of most parameters are zero except pH and dissolved oxygen.
- c) Calculated proportionality constant “K” using the formula $k = \left(\frac{1}{\frac{1}{s_1} + \frac{1}{s_2} + \frac{1}{s_3} + \frac{1}{s_4} + \dots} \right) = \frac{1}{\sum 1/s_n}$
- d) Calculated the unit weight for the n^{th} parameters $w_n = k/s_n$
- e) Calculated the weighted arithmetic index a formula $(\sum w_n Q_p / \sum w_n)$.

3.6 Sanitary Inspection Survey

On the other hand, the sanitary condition of the study area was examined using the descriptive study design in Debre Birhan town from March to May 2023. The town’s sanitary conditions were assessed using a checklist of questionnaire. The survey checklist for questionnaire was adopted from WHO

(WHO, 2016) and modified in accordance with the objective of the study. During the sample period, a sanitary inspection was conducted at each site. The structured questionnaire based on all wells unique condition was used for the sanitary inspections (WHO, 2011a). The questionnaires employed are shown in Annex 1.

For the sanitation survey, the sample size for the was determined by the following formula (Krejcie et al., 1996).The number of households (HH) was determined by a 50% proportion, which leads to the highest possible sample size. However, using the level of maximum variability (P = 0.5), the proportion generally produced a more conservative sample size. The determination was made with a 5% margin of error and a 95% confidence interval.

$$n_o = \frac{Z^2 \times p \times (1 - p)}{e^2}$$

Equation 4 Sample Size

Where z = z value (1.96 for 95% confidence interval)

p= percentage picking a choice, expressed as decimal (0.5)

e = margin of error (0.05)

n_o= initial sample size

Substituting numbers, n_o value obtained was 384. But the population is finite and n_o corrected to new sample size (n) by the formula:

$$n = \frac{n_o}{1 + (n_o - 1/N)}$$

Where N= population (206,226 residents of the town)

Accordingly, the total numbers of household (n) to be interviewed were determined to be 382 households.

3.7 Statistical data analysis

To evaluate the physicochemical quality variations among the drinking water sources and residential water taps, the results of the experiment was analyzed using software including SPSS, Microsoft Excel Version 2010 and AquaChem4.0.

3.8 Quality control and quality assurance

Only containers specifically designated for water samples were used. These containers were never employed for storing other chemicals or solutions. For bacteriological testing, sterilized sample containers were utilized to prevent contamination. Containers for physicochemical analysis were kept clean, clearly labeled, and handled with care. Before opening sample bottles, personnel washed their hands or avoided touching the inside of the bottles.

Instruments used for measuring physical parameters were calibrated using appropriate chemicals. During chemical analysis, strict adherence to procedures was followed. Each sample underwent chemical analysis three times (triplicate analysis of the same sample). A blank reagent was prepared to detect any contamination and prevent false results. The expiration dates of chemicals and reagents used during were checked prior to analysis.

4. RESULTS AND DISCUSSION

4.1 Current Status of the Groundwater Supply and Water Distribution System the Town

Based on field observations, discussions with relevant personnel, and feedback from consumers, the current state of the town's water supply system revealed several critical gaps. Addressing these gaps is crucial for ensuring a sustainable and safe water supply for the community.

- The community's increasing demand for water exceeded the capacity of the existing supply, resulting in shortages.
- Some houses and industries were constructed directly above groundwater sources, which were shallow and insufficient for meeting the town's drinking water needs.
- Private companies drilled boreholes to meet their own demands, leading to excessive groundwater extraction.
- Boreholes located outside the town, near Ankober roads and the Beressa River, raised concerns about contamination from various industries and the town's sewerage system.

The supply and coverage of the water consumption depends numbers of population the amounts of water, it was determined by consumed for different consumption of the residences. Water is one of the most crucial characteristics that determine a town's drinking water coverage per capita. The Ministry of Water and Energy states that category I towns and cities (those with populations between 100,000 and 1,000,000) have a minimum per capita water demand of 80 l/c/day. However, the actual per capita demand for this town was only 38.44 l/c/day (Ministry of Water, 2022). The value was indicated that insufficient the current water distribution system in comparison to the Ethiopian Ministry of Water and Energy's standards and some per capita demand studies .Thus, constructed additional deep wells and reservoirs to increase the water supply in the town.

4.3 The Physicochemical characteristics of drinking water

The physicochemical characteristics determine whether a drinking water is suitable for human use. These variables were used to assess the quality of drinking water. The laboratory results of physicochemical parameters of boreholes, reservoirs, tap water and household containers were summarized tables 9, 10, 11 and 12.

Table 9 Physicochemical analysis of BHs water samples

No	Name of boreholes	EC	TDS	pH	T ⁰ C	PO ₄ ³⁻	NO ₃ ⁻	TH	Ca ²⁺	Cl ⁻	Alk	CO ₃ ²⁻	HCO ₃ ⁻	SO ₄ ²⁻	Fe ³⁺	Cu ²⁺	NH ₃	NH ₄ ⁺	F ⁻	Al ³⁺
1	DA-BH4	140	69.8	7.45	21.2	2	2.74	75	43	5.8	130	75	155	4	0	0.08	0.28	0.30	0.84	0.02
2	DA-BH 1	108.5	54.5	7.53	23.2	0.7	3.65	75	35	7	145	90	180	0	0.10	0.08	0.18	0.19	0.82	0.02
3	DABH-Ex1	110	55.4	7.51	22.9	1	3.46	65	30	2	115	70	145	2	0.18	0	0.21	0.22	0.95	0.05
4	DA-BH6	138	68.3	7.53	25.3	0.47	14.25	95	45	2.3	130	80	160	1	0.05	0	0.25	0.27	0.83	0.05
5	DA-BH2	120.6	60.5	7.51	19.8	2.1	3.63	130	29	6.1	150	90	180	7	0.55	0.06	0.19	0.21	0.84	0.01
6	DA-BH-Ex2	138	68.3	7.51	22.3	0.76	3.35	95	30	2.1	130	75	155	2	0.25	0.06	0.18	0.19	0.86	0.06
7	DA-BH7	136.7	68.4	7.50	20.4	0.28	2.86	115	28	2.7	120	70	145	5	0.20	0.05	0.25	0.27	0.81	0.03
8	BE-BH2	116.1	58.8	7.45	23.6	1.75	1.77	85	20	5	150	90	180	5	0.30	0.06	0.18	0.19	0.92	0.04
9	BE-BH4	127.1	63.8	7.48	23.4	1.75	2.98	95	31	6.3	140	85	170	2	0.60	0.04	0.23	0.25	0.81	0.01
10	BE-BH5	122.4	61.5	7.47	22.5	1.90	2.95	150	36	6.4	135	80	165	9	0.25	0.04	0.19	0.21	0.82	0
11	DT-BH1 New	125	62.6	7.51	23	2.80	3.60	100	32	6.6	160	95	195	4	0.25	0.05	0.25	0.27	0.88	0.02
12	DT-BH2 New	135.8	68.2	7.53	19	2.45	2.76	75	28	7.8	155	95	190	6	0.06	0.07	0.35	0.39	0.92	0.04

Table 10 Physicochemical analysis of Reservoirs water samples

No	Code	pH	EC	TDS	T ⁰ C	Alka	CO ₃ ²⁻	HCO ₃ ⁻	PO ₄ ³⁻	NO ₃ ⁻	Cu ²⁺	NH ₃	NH ₄ ⁺	SO ₄ ²⁻	Cl ⁻	Fe ³⁺	TH	Ca ²⁺	F ⁻	Al ³⁺
1	R1	7.43	127.5	63.8	20.6	115	70	140	1.35	2.85	0.02	0.25	0.27	4	9.4	0.05	75	25	0.79	0.06
2	R2	7.55	122.4	66.5	16.5	105	60	125	1.38	4.05	0	0.28	0.30	9	9.7	0.06	90	22	0.97	0.04
3	R3	7.35	132.8	66.7	18	112	55	135	1.95	2.82	0.03	0.29	0.32	8	10	0.10	105	28	0.98	0.05

Table 11 Physicochemical analysis of Tap water (TW) samples

No	Code	pH	EC	TDS	T ⁰ C	Alka	CO ₃ ²⁻	HCO ₃ ⁻	PO ₄ ³⁻	NO ₃ ⁻	Al ³⁺	NH ₃	NH ₄ ⁺	Cu ²⁺	Cl ⁻	F ⁻	SO ₄ ²⁻	Fe ³⁺	TH	Ca ²⁺
1	TW1	7.52	135.6	68.7	15.5	105	60	125	1.95	2.82	0.02	0.25	0.27	0.04	10	0.80	9	0.10	105	30
2	TW3	7.43	127.9	64.3	13.1	100	60	125	1.45	1.78	0.02	0.17	0.17	0.01	5.5	0.83	4	0.10	85	24
3	TW5	7.47	153	76.7	15.3	170	105	210	0.24	3.25	0.05	0.18	0.19	0.01	2.3	1.20	0	0.35	75	22
4	TW6	7.42	145	73.4	13.2	160	95	195	0.24	3.19	0.04	0.19	0.21	0.04	2.7	1.15	4	0.30	90	27
5	TW14	7.50	130.9	65.5	14.7	145	90	180	0.89	3.21	0.02	0.18	0.19	0.04	2.6	0.57	2	0.25	75	18
6	TW17	7.41	125.7	62.9	13.6	135	80	165	0.35	3.63	0.01	0.19	0.21	0.06	6	0.86	7	0.15	85	23
7	TW19	7.48	127.4	63.9	13.8	125	75	155	0.37	3.60	0.06	0.31	0.34	0.04	7.4	0.88	6	0.35	80	22
8	TW21	7.53	138.1	68.3	14.5	180	130	275	0.72	3.98	0.04	0.18	0.19	0.02	2.3	0.17	2	0.10	130	35
9	TW23	7.47	110	55.6	15.3	120	75	150	0.76	3.27	0.04	0.18	0.19	0	2	0.86	7	0.40	75	30
10	TW26	7.33	120.4	60.3	14.3	110	65	135	0.61	3.98	0.04	0.19	0.21	0.02	2.4	0.25	2	0.10	90	46
11	TW28	7.46	145.8	72.6	14.9	135	85	170	2.200	2.74	0.02	0.25	0.27	0.08	6.1	0.87	4	0.23	75	28
12	TW31	7.49	133.7	66.8	13.7	165	100	200	0.28	2.86	0.03	0.25	0.27	0.06	2.7	0.84	5	0.25	75	29
13	TW33	7.51	125.8	63	14.8	175	115	225	0.27	2.89	0.02	0.18	0.19	0.08	2.9	0.81	3	0.19	85	24

Table 12 Physicochemical of household containers water samples

No	Code	pH	EC	TDS	T ⁰ C	Alka	CO ₃ ²⁻	HCO ₃ ⁻	PO ₄ ³⁻	NO ₃ ⁻	NH ₃	NH ₄ ⁺	F ⁻	Cl ⁻	TH	Ca ²⁺	SO ₄ ⁻²	Cu ²⁺	Fe ³⁺	Al ³⁺
1	HH2	7.71	138.9	70.1	14.4	160	95	195	0.61	4.05	0.21	0.22	0.94	9.7	85	26	9	0	0.22	0.03
2	HH4	7.75	126.7	62.6	16.3	120	70	145	0.40	3.50	0.22	0.23	0.81	5.9	130	40	0	0.04	0.35	0.03
3	HH7	7.48	121.2	60.7	15.3	145	85	175	0.39	18.08	0.17	0.18	0.85	2	70	21	4	0.08	0.40	0.02
4	HH18	7.63	148.9	75.6	14.8	175	100	250	0.35	3.63	0.25	0.27	0.86	2.5	85	23	4	0.06	0.35	0.02
5	HH20	7.54	157.8	79	13.9	125	75	135	0.37	3.60	0.31	0.34	0.88	3.8	80	22	6	0.06	0.35	0.03
6	HH22	7.76	133.9	67.3	14.1	155	100	190	0.92	4.17	0.16	0.17	1.10	2.2	90	29	5	0.02	0.25	0.03
7	HH24	7.54	156.6	78.4	13.8	165	100	200	0.45	2.89	0.24	0.26	0.57	3	100	33	3	0.08	0.10	0.02
8	HH25	7.45	131.3	65.7	15.2	160	95	195	1.21	1.96	0.17	0.18	0.97	2.4	75	22	3	0	0.23	0
9	HH27	7.67	125.8	63.2	14.6	120	75	150	0.72	3.27	0.18	0.19	0.72	2	70	19	7	0	0.12	0.04
10	HH29	7.54	129.6	64.9	14.7	125	75	150	1.00	3.35	0.18	0.19	0.70	2.1	130	46	5	0.06	0.17	0.05
11	HH30	7.75	147.8	74.2	15.2	120	70	145	1.80	2.18	0.18	0.19	0.84	7.2	90	36	7	0.06	0.20	0.03
12	HH32	7.60	143.4	71.8	14.2	145	90	180	0.84	8.20	0.021	0.22	1.05	2.2	100	35	2	0.02	0.10	0.04
13	HH34	7.48	112.7	56.8	14.9	135	80	160	0.34	3.97	0.19	0.21	0.86	6	150	47	8	0.04	0.20	0.02

NB; TH=Total hardness, T= temperature

Table 13 Descriptive Statistics for BHs and Reservoirs

Parameters	Unit	Minimum	Maximum	Mean		Std. Deviation	Variance
					Std. error		
pH	-	7.35	7.55	7.49	0.01	0.05	0.00
EC	μS/cm	108.50	140.00	126.73	2.63	10.19	103.76
TDS	mg/l	54.50	69.80	63.81	1.26	4.87	23.74
Alka	mg/l	105.00	160.00	132.80	4.40	17.02	289.74
TH	mg/l	65.00	150.00	95.00	5.94	23.00	528.57
Fe ³⁺	mg/l	0.00	0.60	0.17	0.05	0.18	0.03
Cu ²⁺	mg/l	0.00	0.08	0.04	0.01	0.03	0.00
NO ₃ ⁻	mg/l	1.77	14.25	3.85	0.76	2.93	8.58
SO ₄ ²⁻	mg/l	0.00	9.00	4.53	0.74	2.85	8.12
NH ₃	mg/l	0.18	0.35	.243	0.01	0.05	0.00
Al ³⁺	mg/l	0.00	0.06	0.03	0.01	0.02	0.00
F ⁻	mg/l	0.79	0.98	0.88	0.02	0.07	0.01
Cl ⁻	mg/l	2.00	10.00	5.95	0.70	2.71	7.35
Ca ²⁺	mg/l	20.00	45.00	30.80	1.76	6.83	46.60
PO ₄ ³⁻	mg/l	0.28	2.80	1.55	0.21	0.82	0.67

Table 14 Descriptive statistics for TW

Parametrs	Unit	Minimu m	Maximum	Mean		Std. Deviation	Variance
				Std. error			
pH	-	7.33	7.53	7.46	0.02	0.06	0.00
EC	μS/cm	110.00	153.00	132.25	3.19	11.51	132.38
TDS	mg/l	55.60	76.70	66.31	1.58	5.71	32.63
Alka	mg/l	100.00	180.00	140.38	7.67	27.65	764.42
TH	mg/l	75.00	130.00	86.54	4.36	15.73	247.44
Fe ³⁺	mg/l	0.10	0.40	0.22	0.03	0.11	0.01
Cu ²⁺	mg/l	0.00	0.08	0.04	0.01	0.03	0.00
NO ₃ ⁻	mg/l	1.78	3.98	3.17	0.16	0.59	0.35
SO ₄ ²⁻	mg/l	0.00	9.00	4.23	0.70	2.52	6.36
NH ₃	mg/l	0.17	0.31	0.21	0.01	0.04	0.00
Al ³⁺	mg/l	0.01	0.06	0.03	0.00	0.01	0.00
F ⁻	mg/l	0.17	1.20	0.78	0.08	0.30	0.09
Cl ⁻	mg/l	2.00	10.00	4.22	0.70	2.52	6.37
Ca ²⁺	mg/l	18.00	46.00	27.54	1.98	7.14	50.77
PO ₄ ³⁻	mg/l	0.24	2.20	0.80	0.18	0.67	0.44

Table 15 Descriptive statistics of HH

Parameters	Unit	Minimum	Maximum	Mean		Std. Deviation	Variance
				error	Std.		
pH	-	7.45	7.76	7.61	0.03	0.11	0.01
EC	μS/cm	112.70	157.80	136.51	3.84	13.8	190.42
TDS	mg/l	56.80	79.00	68.48	1.94	7.00	48.96
Alka	mg/l	120.00	175.00	142.31	5.39	19.43	377.56
TH	mg/l	70.00	150.00	96.54	6.99	25.20	634.94
Fe ³⁺	mg/l	0.10	0.60	0.26	0.04	0.16	0.02
Cu ²⁺	mg/l	0.00	0.08	0.04	0.01	0.03	0.00
NO ₃ ⁻	mg/l	1.96	18.08	4.83	1.18	4.25	18.08
SO ₄ ²⁻	mg/l	0.00	9.00	4.85	0.71	2.54	6.47
NH ₃	mg/l	0.16	0.31	0.20	0.01	0.04	0.00
Al ³⁺	mg/l	0.00	0.05	0.03	0.00	0.01	0.00
F ⁻	mg/l	0.57	1.10	0.86	0.04	0.14	0.02
Cl ⁻	mg/l	2.00	9.70	3.92	0.69	2.49	6.18
Ca ²⁺	mg/l	19.00	47.00	30.69	2.66	9.60	92.06
PO ₄ ³⁻	mg/l	0.34	1.80	0.80	0.19	0.67	0.44

Table 16 Correlations of BHs and Reservoirs

	pH	EC	TDS	Alka	TH	Fe	Cu	NO ₃ ⁻	SO ₄ ²⁻	NH ₃	Al ³⁺	F ⁻	Cl ⁻	Ca ²⁺	PO ₄ ³⁻
pH	1														
EC	-0.17	1													
TDS	-0.11	0.96	1												
Alka	0.26	-0.13	-0.24	1											
TH	-0.10	0.10	0.09	0.11	1										
Fe	1.02	-0.23	-0.28	0.28	0.43	1									
Cu	-0.03	0.09	-0.01	0.66	0.03	0.13	1								
NO ₃ ⁻	0.33	0.26	0.22	-0.08	0.01	-0.21	-0.46	1							
SO ₄ ²⁻	-0.28	0.07	0.22	-0.18	0.55	0.02	-0.10	-0.35	1						
NH ₃	-0.10	0.55	0.64	-0.17	-0.03	-0.05	-0.11	0.06	0.30	1					
Al ³⁺	-0.14	0.23	0.24	-0.49	-0.54	-0.44	-0.42	0.22	-0.21	0.22	1				
F ⁻	-0.06	-0.04	0.07	-0.24	-0.23	-0.19	-0.21	-0.17	0.28	0.20	0.50	1			
Cl ⁻	-0.37	-0.10	0.03	-0.09	-0.01	-0.19	0.02	-0.35	0.54	0.44	-0.10	0.07	1		
Ca ²⁺	0.12	0.32	0.20	0.12	0.08	-0.22	0.09	0.59	-0.41	0.01	-0.28	-0.42	-0.35	1	
PO ₄ ³⁻	-0.18	0.04	0.06	0.53	0.08	0.02	0.32	-0.39	0.46	0.43	-0.33	0.17	0.53	-0.15	1

Table 17 Correlation of TW

	pH	EC	TDS	Alka	TH	Fe	Cu	NO ₃ ⁻	SO ₄ ²⁻	NH ₃	Al ³⁺	F ⁻	Cl ⁻	Ca ²⁺	PO ₄ ³⁻
pH	1														
EC	0.22	1													
TDS	0.21	1	1												
Alka	0.43	0.47	0.44	1											
TH	0.24	0.11	0.09	0.15	1										
Fe	0.15	0.05	0.07	0.22	-0.62	1									
Cu	0.18	0.19	0.18	0.29	-0.12	-0.13	1								
NO ₃ ⁻	-0.16	-0.12	-0.15	0.27	0.33	0.07	-0.12	1							
SO ₄ ²⁻	0.12	-0.40	-0.04	-0.53	0.01	-0.02	0.16	-0.16	1						
NH ₃	0.21	0.11	0.11	-0.20	-0.14	0.20	0.38	0.03	0.47	1					
Al ³⁺	-0.04	0.10	0.10	0.15	0.03	0.55	-0.50	0.46	-0.26	0.27	1				
F ⁻	0.05	0.36	0.41	0.07	-0.59	0.61	0.14	-0.45	0.21	0.16	0.06	1			
Cl ⁻	0.14	0.06	0.08	-0.57	0.11	-0.28	0.27	-0.29	0.68	0.63	-0.26	0.18	1		
Ca ²⁺	-0.44	-0.23	-0.24	-0.19	0.05	-0.42	-0.24	0.41	-0.05	-0.07	0.18	-0.62	-0.18	1	.
PO ₄ ³⁺	0.14	0.13	0.13	-0.55	0.11	-0.37	0.09	-0.48	0.30	0.20	-0.44	-0.11	0.59	0.09	1

Table 18 Correlation of HH

	pH	EC	TDS	Alka	TH	Fe	Cu	NO ₃ ⁻	SO ₄ ²⁻	NH ₃	Al ³⁺	F ⁻	Cl ⁻	Ca ²⁺	PO ₄ ³⁻
pH	1														
EC	-0.17	1													
TDS	-0.11	0.96	1												
Alka	0.26	-0.13	-0.24	1											
TH	-0.10	0.10	0.09	0.11	1										
Fe	0.02	-0.23	-0.28	0.28	0.43	1									
Cu	-0.03	0.09	-0.01	0.66	0.03	0.13	1								
NO ₃ ⁻	0.33	0.26	0.22	-0.08	0.01	-0.22	-0.47	1							
SO ₄ ²⁻	-0.28	0.07	0.22	-0.18	0.55	0.02	-0.10	-0.35	1						
NH ₃	-0.10	0.55	0.64	-0.02	-0.28	-0.52	-0.11	0.06	0.30	1					
Al ³⁺	-0.14	0.23	0.24	-0.49	-0.54	-0.44	-0.42	0.22	-0.21	0.22	1				
F ⁻	-0.06	-0.04	0.07	-0.24	-0.23	-0.19	-0.21	-0.17	0.28	0.20	0.50	1			
Cl ⁻	-0.37	-0.10	0.03	-0.09	-0.01	-0.19	0.02	-0.35	0.54	0.44	-0.10	0.07	1		
Ca ²⁺	0.12	0.32	0.20	0.12	0.08	-0.22	0.09	0.59	-0.41	0.01	-0.28	-0.42	-0.35	1	
PO ₄ ³⁻	-0.18	0.04	0.06	0.53	0.08	0.02	0.03	-0.39	0.46	0.43	-0.33	0.17	0.53	-0.15	1

Temperature

In this study, the water samples temperature range in selected sites were 13.1 °C to 23°C (Table 9, 10, 11, and 12). It indicated that from the listed tables these values were within a normal range and had comfortable for drinking water. Based on the following table, the temperature values were below the standard limit.

	Max	Min	Mean
Temperature (°C)	25.3	13.1	16.39

pH in drinking water

As shown in the above laboratory analysis, all of the samples was met the WHO and Ethiopian drinking water standards' safe limits. The result of pH for collected samples ranges between 7.35 - 7.55 for BHs (Table 9 and 10), 7.33-7.53 for TW (Table 11) and 7.45-7.76 for HH (Table 12). Its averages value for BHs, tap water and household were 7.49, 7.60 and 7.61 respectively. The correlation of pH in BHs was positive with alkalinity, Fe^{3+} , Ca^{2+} and NO_3^- . However with EC, TDS, TH, Cu^{2+} , Al^{3+} , SO_4^{2-} , F^- , Cl^- and PO_4^{3-} , it had negative correlation. In case of tap water, it had positive correlation with EC, TDS, alkalinity, TH, SO_4^{2-} , F^- , Cl^- and PO_4^{3-} but negative correlation with NO_3^- , Al^{3+} and Ca^{2+} . The pH value for HH were positively correlated with Ca^{2+} , NO_3^- , and Fe^{3+} but negatively correlated with EC, TDS, TH, Cu^{2+} , Al^{3+} , SO_4^{2-} , F^- , Cl^- and PO_4^{3-} . According to figure 6, the pH values found between WHO guidelines range 6.5 to 8.5. Due to this, drinking water in the study area was considered safe and appropriate for consumption.

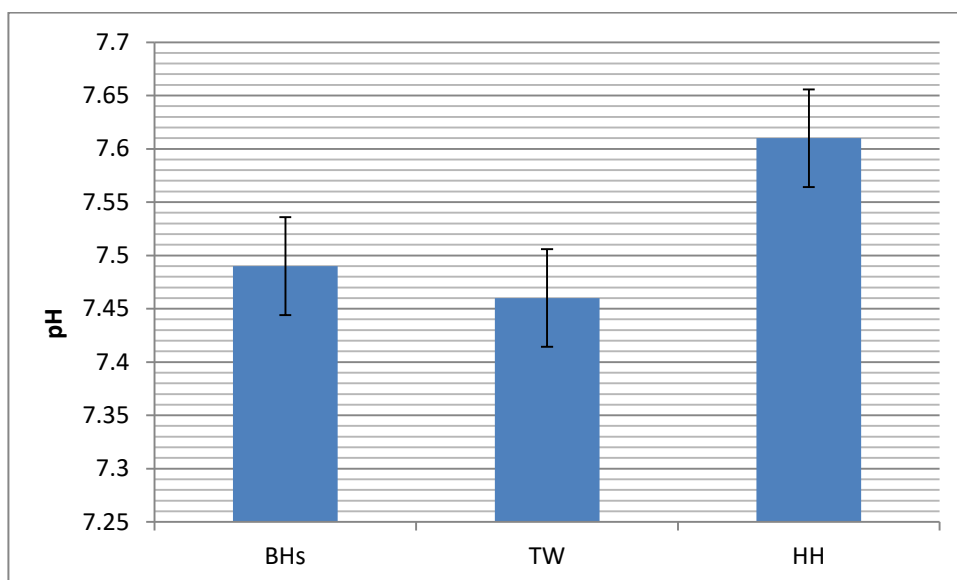


Figure 4 the average concentration of boreholes (BHs) tap water (TW) and household containers (HH) of pH

Electrical Conductivity

The findings of EC values in the current study were ranges 108.5-140 $\mu\text{S}/\text{cm}$ for BHs (Table 9 and 10), 110-153 $\mu\text{S}/\text{cm}$ for tap water (Table 11) and 112.7-157.8 $\mu\text{S}/\text{cm}$ for HH (Table 12). The mean value of EC in BHs, tap water and HH was 126.73, 132.53 and 136.51 $\mu\text{S}/\text{cm}$ respectively. The positive correlation was observed between EC and TDS, TH, Cu, Al^{3+} , SO_4^{2-} , NO_3^- , Ca^{2+} and PO_4^{3-} in BHs and

reservoirs. Whereas, the negative correlation was occurred between EC and SO_4^{2-} , F, Cl^- , alkalinity and Fe^{3+} . The investigation indicated that all the water samples were within the WHO's acceptable drinking water standard and it was likely safe to consume. According to figure 7, total dissolved solids and electrical conductivity had highly positive relationship.

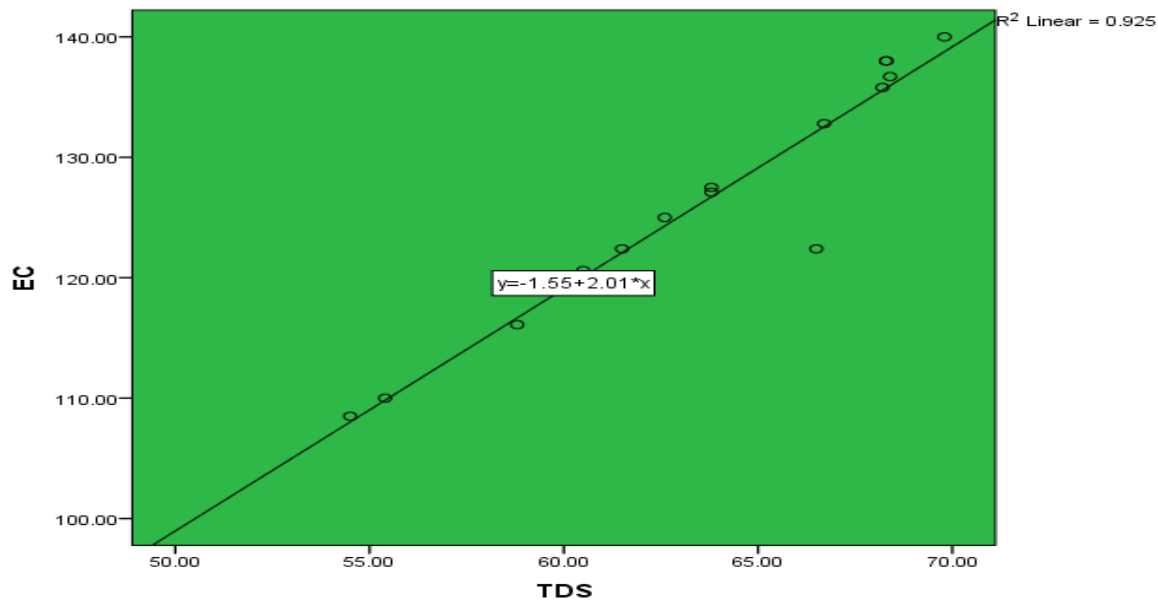


Figure 5 Correlations of TDS and EC

Total Dissolved Solids (TDS)

The TDS value for BHs and reservoirs was 54.5-69.80 mg/l (Tables 9 and 10), tap water 55.6- 76.70 mg/l (Table 11) and HH 56.8 – 79.00 mg/l in (Table 12). Based on this, the results were shown under WHO detection threshold limit. The average value of TDS level was 63.81, 66.31 and 68.48 mg/l respectively indicated in tables (13, 14, and 15) as well as the concentration of TDS in figure 8 was also indicated below standards. Considering the outcome of analysis, the water is safe and suitable for human consumption.

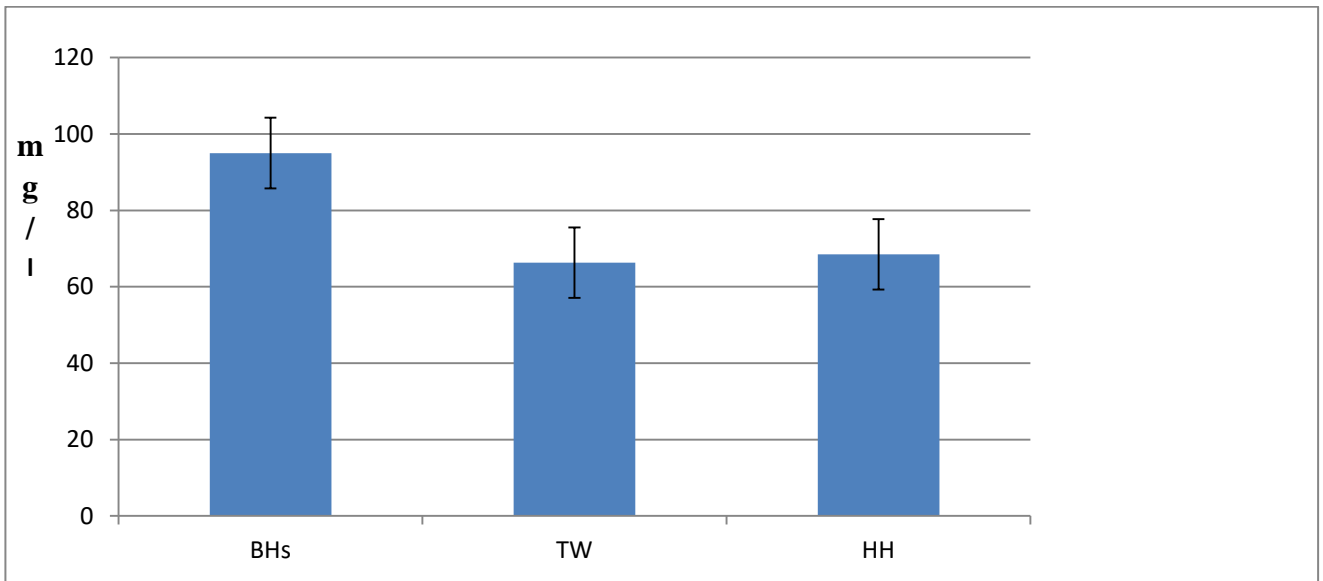


Figure 6 the average concentration of boreholes (BHs), tap water (TW) and household containers (HH) of TDS

Alkalinity

In the study area, the total alkalinity of BHs and reservoirs were between 105 - 160 mg/l (Table 9 and 10), tap water 100 - 180 mg/l (Table 11) and HH 120 - 175 mg/l in (Table 12) as CaCO_3 in mg/l. In some selected taps, the value was high compared to other sources due to corrosion of metal. However, all results were below 500 mg/l shown in figure 9. The alkalinity of drinking water for research location was found between 100 mg/l -180 mg/l, it was indicated that, the water's alkalinity level was safe to drink. Due to the fact that alkalinity present in a specific amount, it acts as a buffer against pH fluctuations and was reduced the corrosiveness of water. The pH of the measured values were around 7, the dominant species are bicarbonate, their pH concentrations lies in the ranges of 6.33 to 10.3, which have high amounts bicarbonate ion. Total alkalinity within range usually means that the water was safe. These results were directed that total alkalinity concentrations were below the EPA allowed limit for all location.

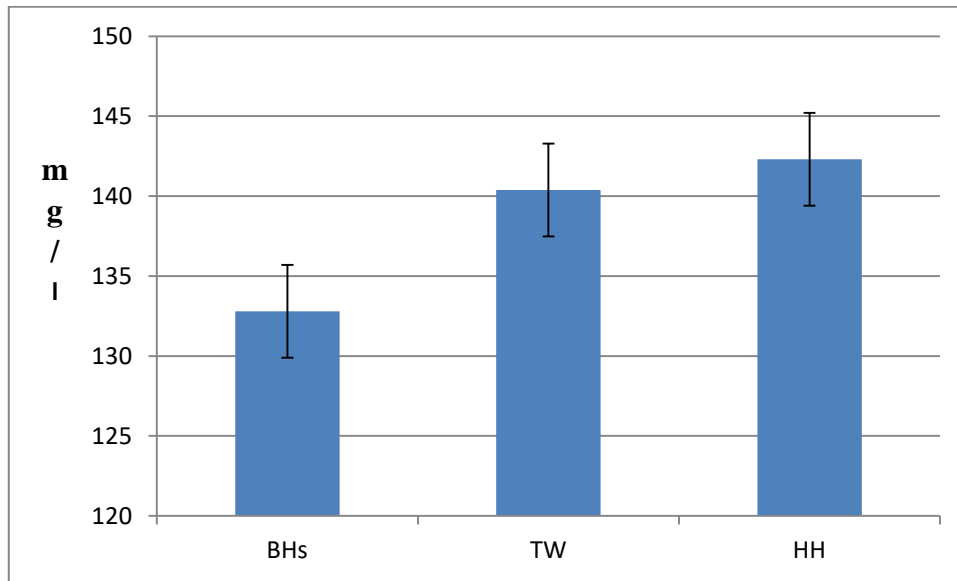


Figure 7 the average concentration of boreholes (BHs), tap water (TW) and household containers (HH) of alkalinity

Total hardness

The total hardness concentrations of Debre Birhan town water supply system in selected places were between 65 - 150 mg/l. The mean values of BHs and Reservoirs, tap water and HH were 95 mg/l, 86.54 mg/l and 96.54 mg/l respectively. Based on table 16, the relation was a positive correlation between some parameters, it was indicated that one parameter tends to increase along with the other. The parameters which had positive relationships with total hardness were calcium, phosphate, sulfate, total alkalinity, EC (electrical conductivity) and TDS (total dissolved solids). On the other hand, total hardness of the water quality parameter with pH, ammonia, aluminum and fluoride was negatively correlated, indicated inverse interaction between these parameters in the water supply.

In considering the result and based on figure 10, the values were found within the WHO's recommendations standards limit. Therefore, these concentrations in drinking water were safe for human use. The hardness level was categorized as moderately hard.

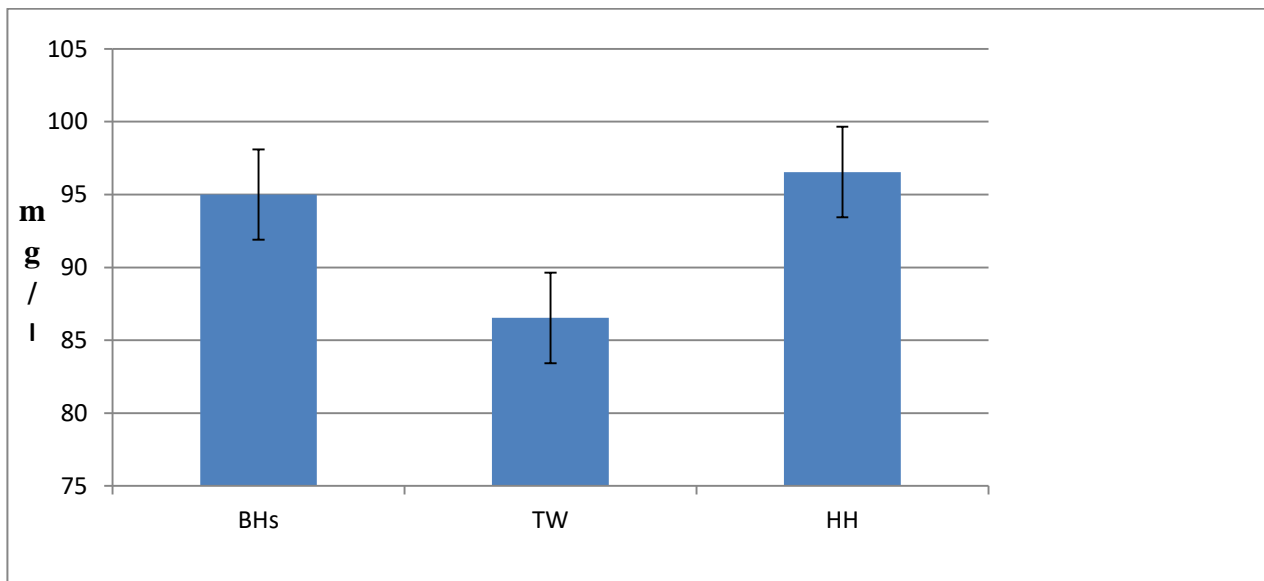


Figure 8 the average concentration of boreholes (BHs), tap water (TW) and household containers (HH) of total hardness (TH)

Iron (Fe^{3+})

The WHO and the Ethiopian national drinking water standards suggested that iron levels be kept at 0.3 mg/l. However, iron concentration in some selected sites were above WHO guidelines such as DA-BH2, BE-BH4, TW5, TW19, TW23, HH4, HH7, HH18 and HH20, which were above 0.3 mg/l.

The samples collected in study areas for iron concentrations were 0–0.6 mg/l in tables 9, 10, 11 and 12 values. High iron concentrations in drinking water samples listed above was due to a number of factors such as corrosion of iron-containing pipes and equipment in water distribution system and point of use, the industrial pollution, natural geological factors and agricultural runoff might increase the sources of iron. But the average levels of Fe^{3+} in BHs and reservoirs, TW and HH were below standard limit.

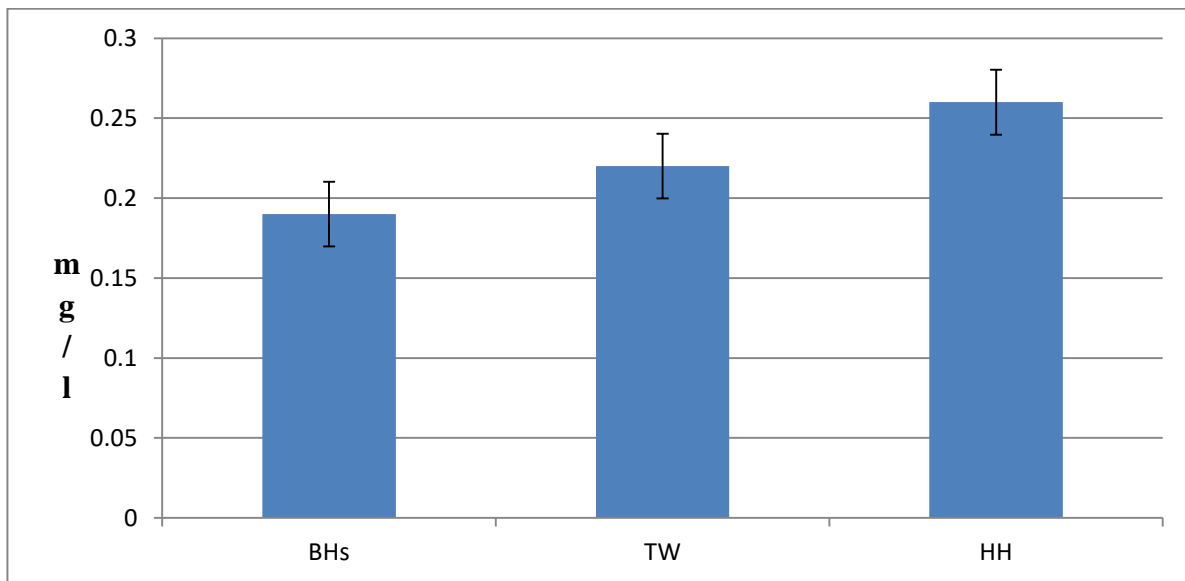


Figure 9 the average concentration of boreholes (BHs), tap water (TW) and household containers (HH) of ferric ions

Copper (Cu^{2+})

The samples copper (Cu^{2+}) value in the town were between 0 to 0.08 mg/l. In general, by considering its concentration, the water could be drinkable. Copper levels in drinking water might occasionally was zero mg/l, meaning that it was not traceable. Based on figure 11, the mean value was 0.04 mg/l and there was no any health risks depends on the study.

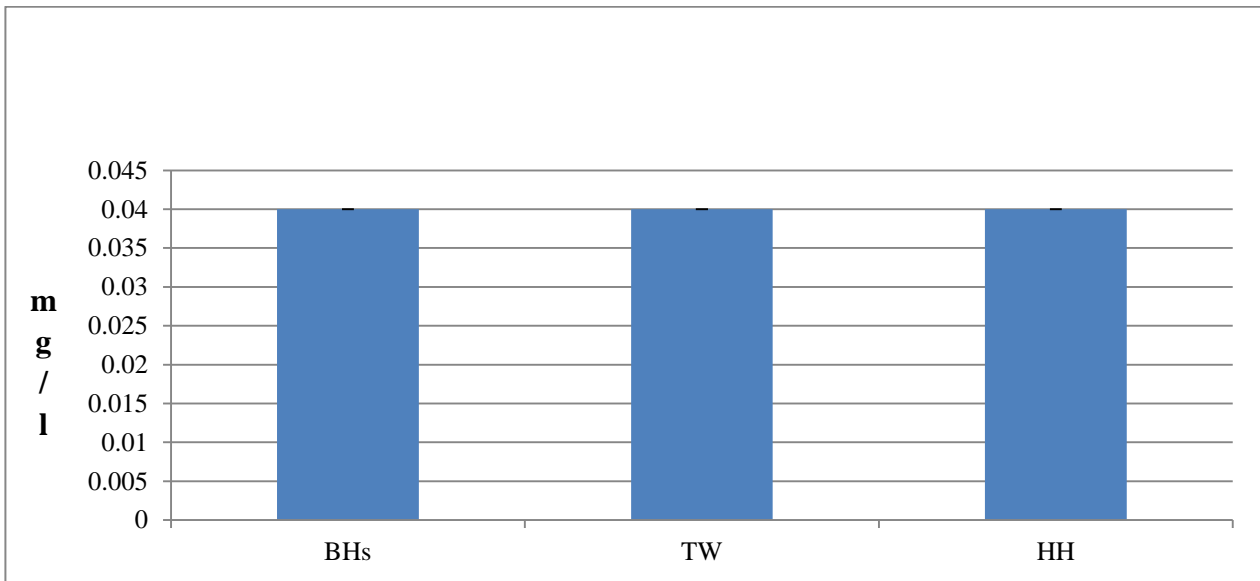


Figure 10 the average concentration of boreholes (BHs), tap water (TW) and household containers (HH) of copper (II) ions

Nitrate (NO₃⁻)

The outcome of this research was showed that, the nitrate concentration of BHs and reservoirs was between 1.77 - 14.25 mg/l, tap water 1.78 - 3.98 mg/l and HH 1.98 - 18.08 mg/l. The average values of nitrate levels were below 50 mg/l, which is under WHO standards. According to table 16, nitrate was a positive correlation with total hardness; ammonia, aluminum and calcium in water, typically correspond with rising nitrate concentration as well as the increasing of these parameters. In other way nitrate content was affected various chemical parameters such as iron, copper, sulfate, fluoride, chloride, and phosphate. An increase in nitrate content might lead to decrease in the listed parameters concentration because of their negative correlation.

These findings were suggested that their values were in the range of allowable limit proposed by WHO. As indicated by figure 13, it was permissible for drinking purpose in water supply of the town.

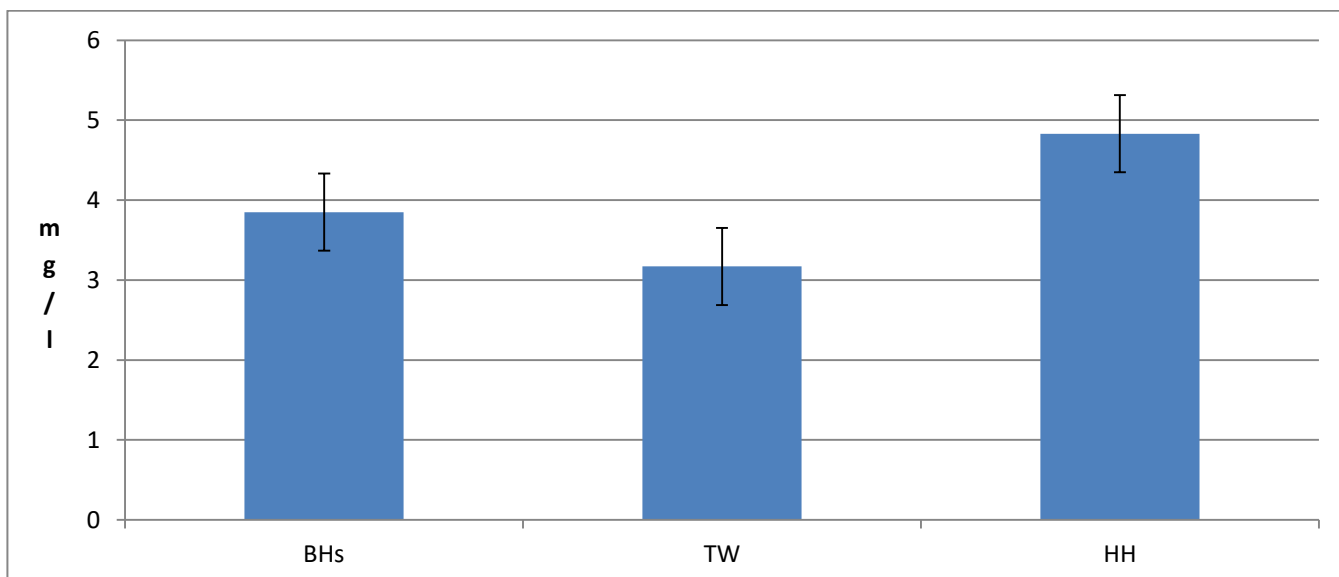


Figure 11 the average concentration of boreholes (BHs), tap water (TW) and household containers (HH) of nitrate ion

Sulfate (SO₄²⁻)

According to the laboratory results of this research, the concentrations of sulfate were far below the WHO maximum permissible limit. Its values in research areas were found between 0 - 9 mg/l. Based on table 16, the sulfate levels was shown a positive correlation with water quality parameters such as EC, TDS, total hardness, iron, fluoride, chloride and phosphate. As sulfate levels was higher, the higher also these parameters. Sulfate concentration had been shown also a negative correlation with water quality indicators such as pH, alkalinity, copper, nitrate, and calcium. When sulfate concentration increased, then the decreased copper, pH, alkalinity, nitrate and calcium levels were recorded.

As a result, it was evident from the investigation that there had not been impact on the health of consumers.

Ammonia (NH₃) and ammonium ion (NH₄⁺)

The concentrations of ammonia in study area were between 0.15 to 0.31 mg/l, and the ammonium concentrations were 0.18 to 0.34 mg/l respectively. Based on the results obtained from the laboratory analysis, NH₃ and NH₄⁺ had no health impact in the consumer. In general, ammonia concentration between the above ranges were considered to be safe for human consumptions, but in order to maintain water quality reduce pollutant on the environment and concentration of ammonia levels be regularly monitored and

managed. In the case of ammonium ion, its concentration in drinking water supplies typically indicates low to moderate levels of ammonium contamination of the drinking water. Therefore, it was essential to keep a check on the amount of ammonia and ammonium water quality parameters.

Aluminum (Al^{3+})

In the current investigation, the aluminum levels in water samples for BHs, reservoirs and HH was 0 to 0.05 mg/l (tables 9, 10 and 12), in tap water 0.01 to 0.06 mg/l (table 11). When considering aluminum concentration in range from table 9-12, it is within permissible ranges as per the different standards.. To maintain this amount had to take regulations and managed any potential sources of contamination continues monitoring and management of aluminum levels was sustained to be important.

Depending on (Mazrura et al., 2010) the maximum allowable value is 0.2 mg/l. So, there was no health impact of the society.

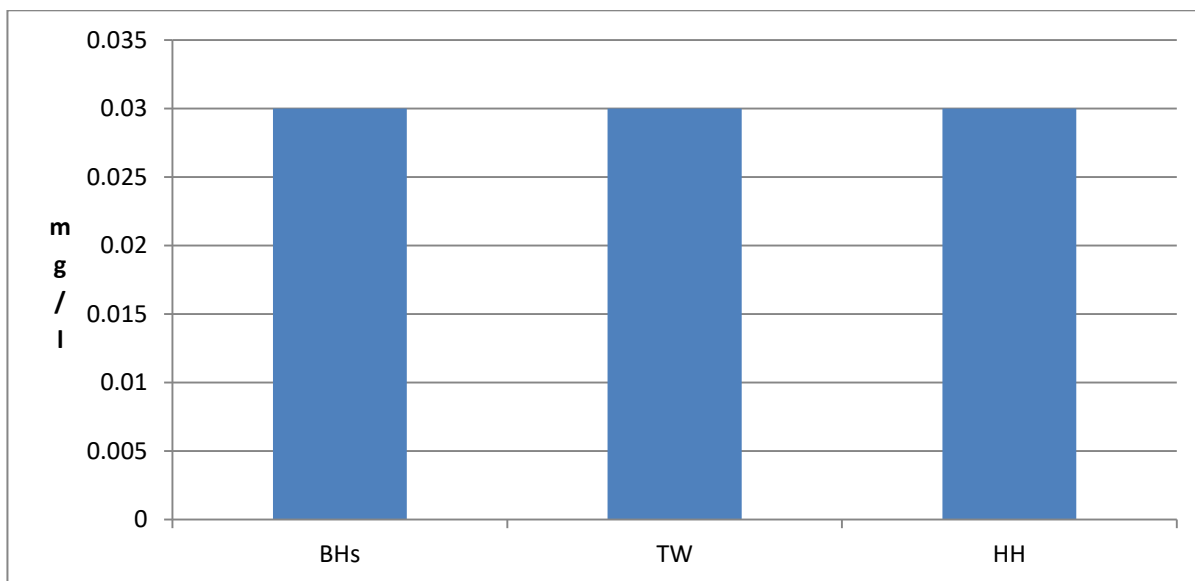


Figure 12 the average concentration of boreholes (BHs), tap water (TW) and household containers (HH) of aluminum ions

Fluoride (F^-)

The fluorides concentrations in study area were between 0.17 - 1.15 mg/l. In the following figure, the concentration of the F^- was underneath WHO standards. Depending on table 16 for the results were

appeared to be positive relationship between the concentration of fluoride with aluminum, sulfate, ammonia and total dissolved solids. This was suggested that parameters levels were raised, which was directly proportional to fluoride concentration. Also the amount of fluoride was negatively correlated with pH, EC, total hardness, iron, copper and nitrate. These parameters tended to decrease with increased fluoride concentration and vice versa.

Therefore, the concentration of fluoride was below the WHO recommendation and Ethiopia standard level and has no side effects on the health of the community that drink this water.

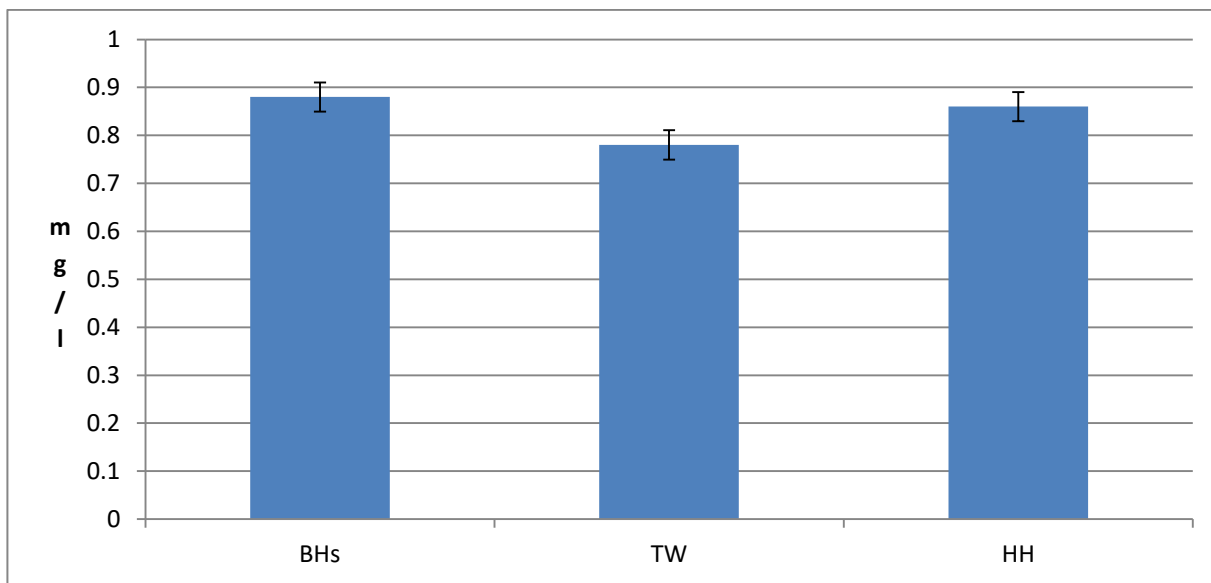


Figure 13 the average concentration of boreholes (BHs) , tap water (TW) and household containers (HH) of fluoride ion

Chlorides (Cl⁻)

Chloride concentration in the study area was between 1 - 10 mg/l. Based on this result, chloride in water did not have serious health problems depending on the laboratory results. Its standard consider acceptable for drinking water. Typically, the amount of chloride present in table 9, 10, 11, 12 and figure 16 was below WHO standard set for drinking, i.e. it was safe for human consumption. Therefore, no health problems by the concentration of chloride in the water supply.

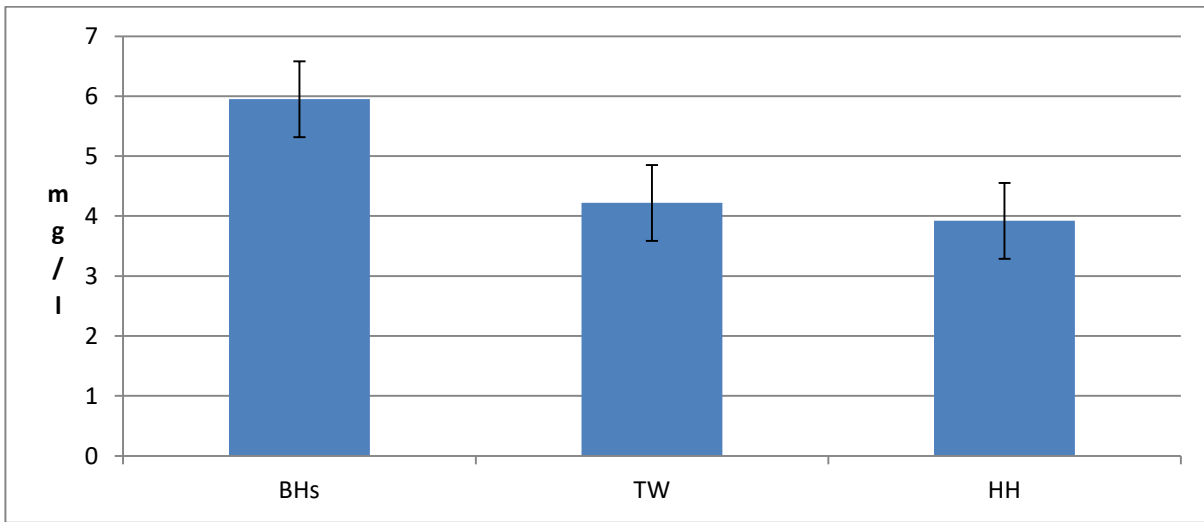


Figure 14 the average concentration of boreholes (BHs), tap water (TW) and household containers (HH) of chloride ion

Calcium ions (Ca^{2+})

The calcium concentration in the Debre Birhan water supply, as determined by laboratory investigation stands between 18 - 47 mg/l, which is less than 200 mg/l as indicated by figure 17 and table 9, 10, 11 and 12. The calcium analysis result had lower than the recommended level of WHO. In consideration of these concentrations the whole values in all sites were safe to consumers.

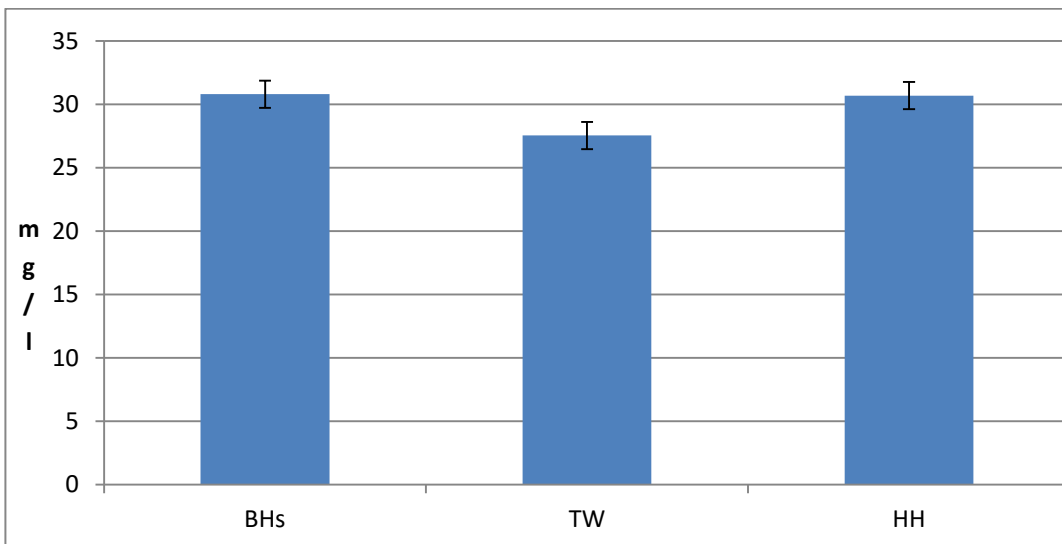


Figure 15 the average concentration of boreholes (BHs), tap water (TW) and household containers (HH) of calcium ions

Phosphate (PO_4^{3-})

According to the average value of phosphate analysis (Table 13, 14, 15 and Fig. 17), the assessment of 41 sample sites was not greater than 1.55 mg/l. The concentration of phosphate ion in study areas range was from 0.24 mg/l to 2.80 mg/l. Some sites were high due to ground water phosphate levels was increased by geological factors of minerals and rocks naturally; agricultural activity, as result of runoff from agricultural chemicals from detergents, cleaning supplier and manufacturing process were frequently found in wastewater in from residential and commercial properties. By regarding of the above outcome laboratory investigation was not harmed for the source and point use of drinking water.

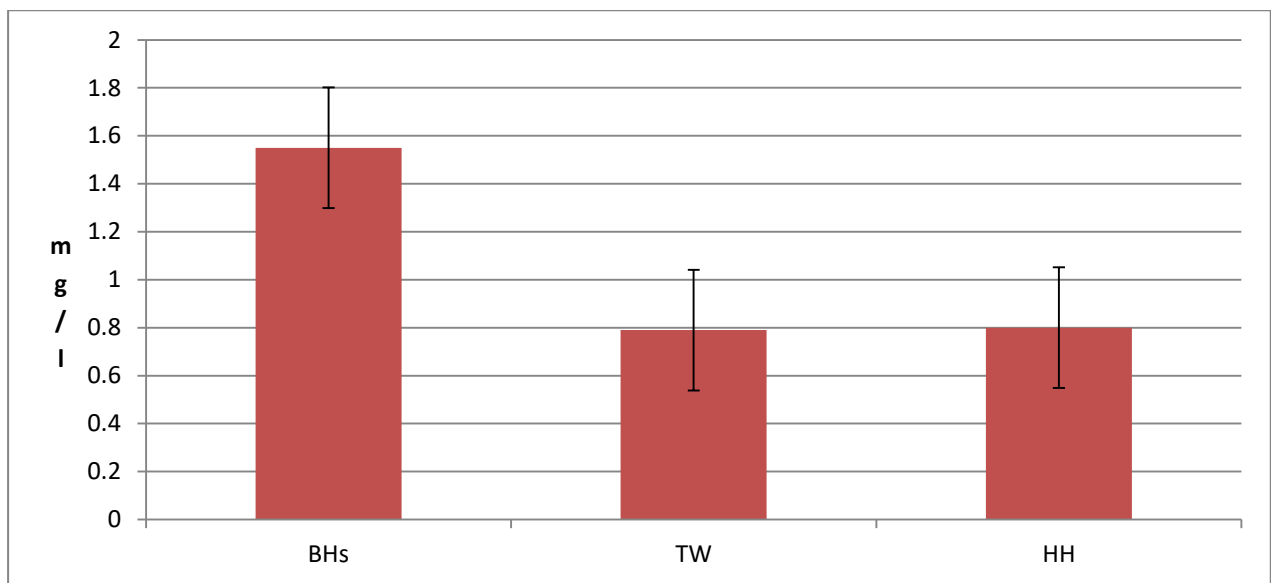


Figure 16 the average concentration of boreholes (BHs), tap water (TW) and household containers (HH) of phosphate ions

4.4 Bacteriological analysis

For this research, counts per plate from 100 ml water samples were used to report all bacteriological result. As the typical CFU/100 ml concentration, all values were expressed as 100 CFU/ml.

4.4.1 Bacteriological analysis at Sources

Procedures for microorganisms from the WHO and the Federal Democratic Republic of Ethiopia, Ministry of Water and Energy, both recommend zero total coliforms and faecal Coli CFU/100 ml at the source and point of use.

At the source level, tests for bacteria in source water reveal were not seen bacteria in the boreholes and reservoirs. The boreholes and the reservoir contained 100 CFU/100 ml of had not total and 100 CFU of E. coliform.

In general, to explained that there was no problem of bacteriological contamination at the source level for water supply system in the study area and fit for human consumption by considering of this analysis.

Table 19 Bacteriological water quality result for boreholes and reservoir

Samples Site	Total coliform 100ml/ CFU	Fecal Coliform 100ml/CFU	Risk Category
DA-BH4	Nil	Nil	No risk
DA-BH 1	Nil	Nil	No risk
DABH-Ex1	Nil	Nil	No risk
DA-BH6	Nil	Nil	No risk
DA-BH2	Nil	Nil	No risk
DA-BH-Ex2	Nil	Nil	No risk
DA-BH7	Nil	Nil	No risk
BE-BH2	Nil	Nil	No risk
BE-BH4	Nil	Nil	No risk
BE-BH5	Nil	Nil	No risk
DT-BH1 New	Nil	Nil	No risk
DT-BH2 New	Nil	Nil	No risk
R1	Nil	Nil	No Risk
R2	Nil	Nil	No risk
R3	Nil	Nil	No Risk

4.4.2 Bacteriological analysis Point-of use (tap water and household).

The bacterial test resulted that had no fecal coliform to detect in tap water 13 water samples site distribution system of water supply. However, in household containers 13 water samples fecal coliform was detect in 2 sites.

They also lack water treatment practices in household for some sites and the residences were unawareness that waterborne disease could spread in the household containers. The experiments support this finding by showing 50% decreases in both faecal and total coliform bacteria in the water stored in covered containers compared to open containers.

Table 20 Bacteriological water quality result for tap water

Samples site	Total coliform 100ml/CFU	Fecal Coliform 100mlCFU	Risk category
TW1	Nil	Nil	No risk
TW3	Nil	Nil	No risk
TW5	Nil	Nil	No risk
TW6	Nil	Nil	No risk
TW14	Nil	Nil	No risk
TW17	Nil	Nil	No risk
TW19	Nil	Nil	No risk
TW21	Nil	Nil	No risk
TW23	Nil	Nil	No risk
TW26	Nil	Nil	No risk
TW28	Nil	Nil	No risk
TW31	Nil	Nil	No risk
TW33	Nil	Nil	No risk

Table 21 Bacteriological water quality at household

Sample site	Total coliform 100ml/CFU	Faecal Coliform 100mlCFU	Risk category
HH2	Nil	Nil	No risk
HH4	Nil	Nil	No risk
HH7	Nil	Nil	No risk
HH18	Nil	Nil	No risk
HH20	Nil	Nil	No risk
HH22	6	Nil	Low risk
HH24	Nil	Nil	No risk
HH25	8	Nil	Low risk
HH27	7	2	Low risk
HH29	Nil	Nil	No risk
HH30	8	2	Low risk
HH32	Nil	Nil	No risk
HH34	5	Nil	Low risk

The summarized result of the household sites was presented in Table 21 the average total coliform count in this study was a little higher than the levels recommended by the WHO and Ethiopian Standards Risk Classification. Especially the total coliform counts were higher in household water samples compared to those of water from reservoirs, boreholes, and tap water.

To remove the presence of total coliform in drinking water, it is necessary to establish in place proper sanitation procedures, enhance storage conditions, make sure that there are particular containers for storing water, clean these containers on a regular basis and utilize efficient water treatment techniques to lower the amount of coliform in household water.

4.5 Water Quality Index (WQI)

WQI was determined for water supply of drinking water in the town physicochemical structures in on its calculation assessment result. Tables 23, 24 and 25 were shown the values of some water quality parameters used in the WQI computation. Furthermore, to summarize the WQI value from for all selected parameters, which was determined to be within the range of excellent, good and poor water quality under used the calculation weight arithmetic water quality index.

Calculation of weight arithmetic water quality index

Table 22 Water quality Standards

Water quality parameters	WHO values (mg/l)
pH	8.5
EC	1500
TDs	500
TH	300
NO ₃ ⁻	50
Al ³⁺	0.9
F ⁻	1.5
Fe ³⁺	0.3
Cl ⁻	250

Step 1 to determine $K = \left(\frac{1}{\frac{1}{s_1} + \frac{1}{s_2} + \frac{1}{s_3} + \frac{1}{s_4} + \dots} \right) = \frac{1}{\sum 1/s_n}$

Equation 5 Weighted Arithmetic Water Quality index procedures

The unit weight $W_n = K/S_n$

S_n standard of water quality values at n^{th} parameter

Step II $Q_p = (V_p - \text{ideal value}) / (\text{WHO standards} - \text{ideal value}) \times 100$

Vp is the mean concentration values of selected parameter

The ideal value most parameters are 0 except pH and DO

Table 23 Water quality index for BHS and reservoirs

Sample Id	WQI values	Water quality status
DA-BH4	8.28	Excellent
DA-BH 1	29.37	Good
DABH-Ex1	48.04	Good
DA-BH6	19.68	Excellent
DA-BH2	39.85	Good
DA-BH-Ex2	31.46	Good
DA-BH7	33.70	Good
BE-BH2	72.81	Poor
BE-BH4	60.67	Poor
BE-BH5	45.72	Good
DT-BH1 New	19.29	Excellent
DT-BH2 New	22.23	Excellent
R1	19.34	Excellent
R2	22.69	Excellent
R3	31.16	Good

From the calculations 40% of the water quality index was rated as "Excellent," it generally indicates that a significant portion of the measured parameters or indicators satisfy high-quality requirements. This was concluded such parameter levels of pH and others minimal pollution levels and other

qualities that support high-quality water. Whereas regarding the 47% of measurements that were classified as "good," this was shown that a considerable proportion of the water samples satisfy the requirements for good quality, as determined by the particular limits or standards applied to each parameter. However, a 13% water quality index indicates poor water quality index, due to the presence of the parameters for iron concentrations were high and their amounts had the implication in harm to human health. When iron concentration was raised above certain threshold, the overall quality of the water might be significantly lowered its quality, perhaps giving the water a "poor" category on index.

Table 24 Water quality index values for TW

Sample ID	WQI values	Water Quality Status
TW1	29.19	Good
TW3	29.29	Good
TW5	22.63	Excellent
TW6	13.43	Excellent
TW14	16.64	Excellent
TW17	25.07	Excellent
TW19	11.73	Excellent
TW21	24.36	Excellent
TW23	17.41	Excellent
TW26	5.71	Excellent
TW28	21.23	Excellent
TW31	19.14	Excellent
TW33	16.57	Excellent

In tap water (TW) in calculation of WQI thought excellent quality category was 85%. The conclusion was generally positive, indicating that the water met the requirements and was appropriate for many

kinds of applications including drinking, recreational activities, agricultural and maintaining aquatic ecosystems. The remaining 15% was found under good category for water quality index. Therefore, depending on the assessments that most of the water samples were considered to be of high quality based on for weighted arithmetic water quality index ranks.

Table 25 Water Quality index for HH

Sample ID	WQI values	Water Quality Status
HH2	14.00	Excellent
HH4	21.40	Excellent
HH7	19.09	Excellent
HH18	17.18	Excellent
HH20	19.56	Excellent
HH22	13.30	Excellent
HH24	27.27	Good
HH25	11.02	Excellent
HH27	33.42	Good
HH29	29.08	Good
HH30	13.19	Excellent
HH32	12.91	Excellent
HH34	12.75	Excellent

According to the calculation of an assessment of a in using water quality index, which was implied by the summarization, 77% of the samples was found excellent water quality, while the remaining 23% had been good water quality.

4.6 Water types in the study area

A graphical technique was used in hydrogeology and hydro geochemistry in particular to analyses the chemistry of water to use the Piper plot. It was employed to categories water samples according to the ionic composition of those samples. To show the magnesium, calcium, sulfate chloride and

carbonate/bicarbonate ions concentrations in the graph situation. Using their percentages as a guide, it could interpret the values as follows:

The piper graph was shown Ca_Mg at 80% and CO₃-HCO₃ at 100% based on the information that was provided. Regarding on the sample's location, water types could be determined using the Piper plot. Whereas the anion triangle stands for Cl, CO₃-HCO₃ and SO₄, the cation triangle was representative of Ca, Mg, Na and K. The water type can be categorized as Ca-Mg-HCO₃, which was represented by the lower left corner of the diamond in the Piper plot, according to the information provided (El-Aziz, 2017). Given that the information is 100%, it appears that bicarbonate ions (HCO₃) predominate in this particular kind of water.

The water type based on the piper plot was Ca-Mg -HCO₃. In this study, the major cations and anions (Ca²⁺ and HCO₃⁻) were plotted in piper diagram.

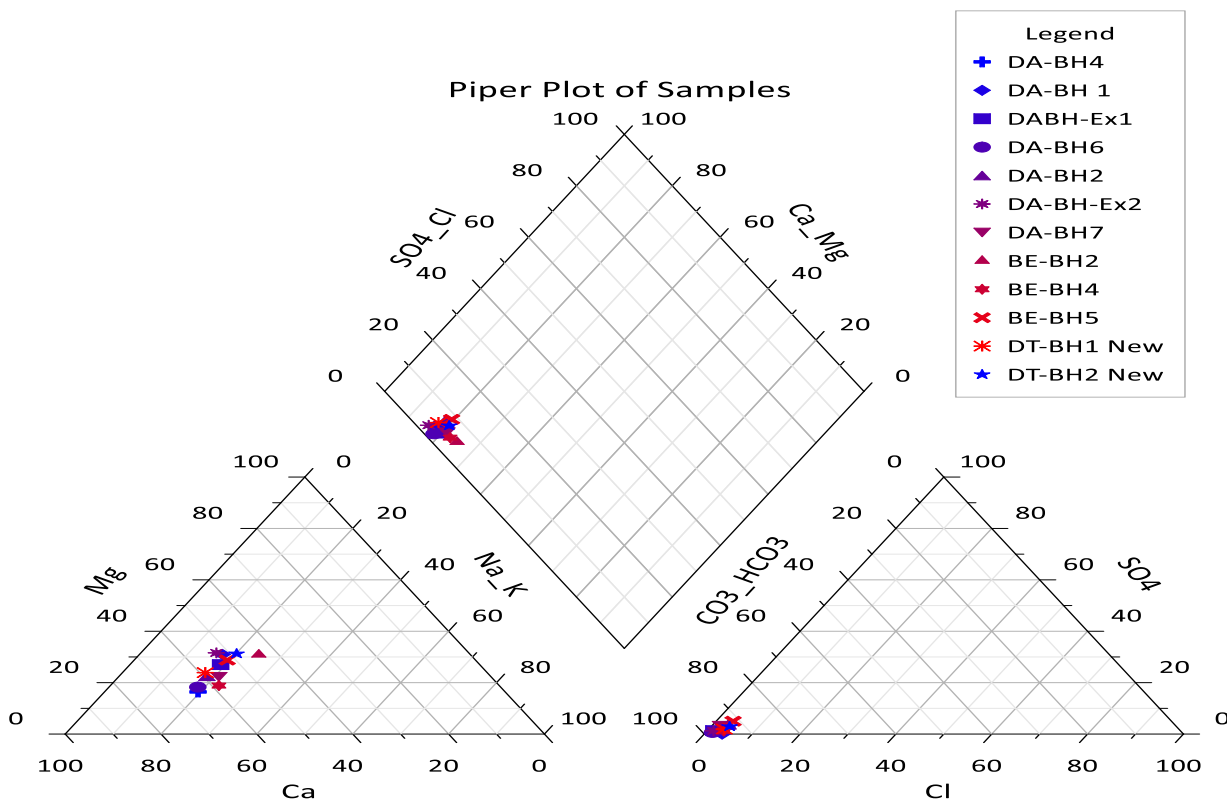


Figure 17 Piper diagram of 12 groundwater water samples.

4.7 Sanitary Inspection Analysis at Source and Household.

4.7.1 Sanitary inspection analysis at source (boreholes)

In a water supply facility was inspected on-site to determine the actual and possible cause of contamination of the drinking water in the town. External environmental elements (such the location of the latrine) and the system's functional and physical structure were assessed. The appropriate question was used to apply the situation of the sources.

The check list was prepared based on WHO standards (UNICEF, 2018). All upcoming and current sources of drinking water should undergo sanitary inspections and routine monitoring. After that, an appropriately asked and observed individual selected site should conduct inspections using an easy-to-understood reporting form. These forms were comprised a collection of questions with a choice of responses of "yes" or "no." The questions were designed in such a way that "yes" responses denote a contamination risk, while "no" responses denote the absence of that particular risk. Every "yes" response receives a single point, whereas every "no" response receives zero points. The points were added up at the conclusion of the inspection, as indicated in the table, WHO guidelines provided the basis to develop the checklist. In order to assess the sanitary situation of the water sources in the study area, the checklist was consisted of 9 questions. According to the WHO, there are 9 risk categories: 0–2 is low risk, 3-6 is medium risk, and 7-9 is very high risk. A set of questions with "yes" or "no" responses make up these forms. One point is given for every "yes" response, and zero points are given for each "no" response. The points are totaled at the conclusion of the inspection, and as indicated in table 26, if to have the larger the overall number of dangers found and the higher the risk of contamination. Based on the response from below table, at sources of water supply had low risk in 12 boreholes.

Table 26 Sanitary inspection at the source

No	Checklists at source	DA-BH4	DA-BH1	DAB H-Ex1	DA-BH6	DA-BH2	DA-BH-Ex2	DA-BH7	BE-BH2	BE-BH4	BE-BH5	DT-BH1 New	DT-BH2 New
1	Is there a latrine within 10m	No	No	No	No	No	No	No	No	No	No	No	No

	borehole?												
2	Is a toilet located above the well?	No	No	No	No	No	No	No	No	No	No	No	No
3	Is there any pollutant source within 50 m?	Yes	Yes	Yes	yes	Yes	No	No	Yes	No	No	No	No
4	Is the water around the well ponding or stagnant?	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
5	Is the fence broken or lacking?	No	No	No	No	No	No	No	No	No	No	No	No
6	Is the drainage around pump house faulty?	No	No	No	No	No	No	No	No	No	No	No	No
7	Is damage in fence allow animals to enter?	No	No	No	No	No	No	No	No	No	No	No	No
8	Is that unsanitary to unseal a well?	No	No	No	No	No	No	No	No	No	No	No	No
9	Is there any leaking of water due to improper cover of well?	No	No	No	No	No	No	No	No	No	No	No	No
Risk category		Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk

4.7.2 Sanitation and hygiene at household and pipeline

The survey results indicate that 59% of respondents answered “yes,” stating that they kept drinking water in a separate container. In contrast, 41% responded “no,” indicating that they did not have an isolated container for storing drinking water. Approximately 84% of participants reported that their drinking water containers were kept above ground and away from pollutants. However, 16% of those who answered “no” did not follow this practice. Regarding the narrowness of water containers, 45% disagreed with the majority opinion (55%) that water containers had a narrow mouth. On the topic of container lids or coverings, 97% (370 respondents) confirmed that their containers had a covering, while 3% (10 respondents) believed otherwise.

When it comes to water transportation, 93% of respondents stated that water pipes were protected during transport. However, 7% expressed that they did not expect water lines to be covered, leading to potential leakage during distribution.

Regarding water availability at home, 54% of respondents (204 individuals) indicated that they stored water at home, while 176 respondents answered “no.” As for hygiene practices, 47% of participants reported frequently washing their water collection containers, while 53% did not follow this practice.

In terms of toilet availability, 60% of respondents confirmed having a toilet in their households. However, 40% either did not respond or answered “no.” Lastly, based on the collected data, 48% of participants (183 individuals) reported washing their hands with soap after using a toilet, while 52% did not follow this practice.

Table 27 sanitary inspection at household

No	questionnaires for pipeline and household WASH	Response	
		Yes	No
1	Is there a separate container used to store drinking water?	223(59%)	157(41%)
2	Is the container of drinking water kept above ground and away from contaminants?	319(84%)	61(16%)
3	Is water container has a narrow mouth?	209(55%)	171(45%)
4	Do containers have a covering or lid?	370(97%)	10(3%)

5	Do water collect form around taps?	380(100%)	-
6	Are the water lines covered while being transported?	355(93%)	25(7%)
7	Do you have water on reserve at home?	204(54%)	176(44%)
8	Do you often wash the containers that use to collect water?	177(47%)	203(53%)
9	Do you home have a toilet?	227(60%)	153(40%)
10	Do you wash your hands with soap after using the toilets?	183(48%)	197(52%)

4.8 Wastewater management and Sanitation system

In the town, there is no proper liquid waste management system. Wastewater accumulates in septic tanks and pit latrines, and it is transported by vacuum trucks. These trucks are used to remove and transfer wastewater from homes and institutions. The waste is then disposed of in a garbage drying bed near the solid waste dumping site. Unfortunately, private vacuum dumping at this location is prohibited by the water office. As a result, wastewater is illegally disposed of on uncontrolled land, posing a significant health risk to the community. The municipality should collaborate with the water office to find a solution that benefits everyone and addresses this environmental issue.

Additionally, various institutions, including apartment buildings, a prison camp, a factory, and a university, contribute to poor wastewater management. For instance, Debre Birhan University's effluent discharges directly into the Beresa River, further polluting the environment.

5. Conclusions and Recommendations

5.1 Conclusions

In this study, Debre Birhan town water supply system had identified gaps due to rising demand, insufficient capacity, and shallow groundwater sources. Private companies drilled boreholes, which were located outside the town and near Beressa river. This activity could reduce the source of groundwater and affect the supply of drinking water in the town. The study analyzed the average daily water consumption in a town using a population of 206,226 and drinking water daily consumption of 2,893,720 m³ per year from 3 reservoirs. Due to this, the calculated per capita consumption in the town is equals 38.44 L/c/d.

The town's drinking water arises from groundwater and 19 private organizations drill boreholes for their purposes. The Debre Birhan water supply office doesn't control these boreholes, while regional and zonal water offices issue drilling-controlled mandates and they establish regulations to permit and control groundwater extraction.

The physicochemical parameters like pH, EC, TDS, alkalinity, nitrate, sulfate and fluoride was within the national and WHO guidelines for most samples except for a few boreholes (DA-BH2 and BE-BH4), tap water (TW5, TW19 and TW23) and households (HH4, HH7, HH18 and HH20) which had high iron concentration. The bacteriological analysis showed no detection of total coliform and fecal coliform in any of the samples from boreholes, reservoirs and tap waters. This indicates no contamination from source to point of use. However, some household samples showed presence of total coliform, suggesting potential contamination during storage and handling.

The water quality index calculation classified most sources as excellent quality except for a few boreholes with high iron. Tap water and household samples fell in the excellent and good category.

Based on piper diagram, major cation was Ca²⁺-Mg²⁺ and anion HCO₃⁻ with the dominant water type Ca-Mg -HCO₃.

A majority of respondents reported that they keep drinking water in separate containers (59%) and 84% of them suggested they put the container above ground that reduce the risk contamination. Most respondents had water on reserve at home. However, most residents did not wash the containers before

they collect water and did not wash their hands with soap after using the toilets. In this case the hygienic practice of the society leads them vulnerable for health problems.

Overall, the drinking water was within permissible WHO guidelines for physicochemical parameters but bacteriological quality was a concern at household level due to poor sanitation and hygiene practices during water collection, storage and use. To summarize, this study evaluated the water quality from sources to households, identified quality issues and their causes to recommend interventions for sustained water quality supply.

The town lacks a sewer line system for liquid waste management leading to wastewater storage in septic tanks and pit latrines. Then the waste transported by vacuum trucks and private vehicles. Finally, it disposed of in a garbage drying bed maintained by the water office. This results in water pollution and endangering community health.

5.2 Recommendations

Based on the information provided, the following recommendations were made:

- The research was carried out over one point sampling. It is recommended that additional research should be carried out over seasonal variation by considering various characteristics related to water quality such as heavy metal concentrations and trace organic compounds.
- Further work/research needs to be conducted on groundwater quality should include a thorough evaluation of the undertaking's physical, chemical and biological components, customized according to the groundwater specific objectives and legal requirements.
- Preparation of guidelines for proper use of groundwater by private company to avoid groundwater depletion, set criteria for sustainable groundwater extraction rates. Put precautions in place to reduce the amount of pollution that enters groundwater, such as safe chemical handling and storage, adequate waste disposal procedures, and pollution monitoring. Promote water conservation measures in the business's operations, such reusing water or putting in place water-saving equipment. Encourage the use of substitute water sources whenever possible to lessen dependency on groundwater.

- Creating awareness of the community about water handling practices to make brochures, leaflets or advertisements with information about safe water handling practices and hand them out door-to-door or through community centers, schools and local businesses. Conduct demonstrations on methods of water purification, such as boiling, filtering, or using water purification tablets. Show residents how to properly disinfect water to make it safe for drinking.
- Construct industrial areas away from the groundwater base to prevent groundwater pollution. Chemicals and other materials that have the potential to leak into the ground and contaminate groundwater are frequently factors of factories effluents. The probability that these pollutants will penetrate into and contaminate groundwater is increasing by locating industrial locations from groundwater sources. For many populations, groundwater is an essential supply of drinking water. Groundwater basins are best served by keeping industrial activity away from them in order to maintain the water source's quality and keep it safe for drinking and other uses. Groundwater contamination can have detrimental effects on the environment that impact not just human health but also the ecosystem. Industrial areas are constructed away from groundwater resources to reduce the pollution of environmental for groundwater bases.
- To provide enough water deliveries to the community depends on the estimated population numbers, design water supply system taking in to consideration growth in the commercial, industrial educational, social and administrative sectors.
- Proper management of both liquid and solid waste is indeed crucial for maintaining environmental health and public hygiene. A comprehensive waste management strategy involves efficient collection, transportation, treatment, and disposal of waste materials. Enhancing garbage collection services is imperative to ensure that waste is promptly removed from residential areas, commercial zones, and public spaces. Regular and reliable garbage collection schedules help prevent the accumulation of waste, which can lead to environmental pollution and health hazards.

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Annex

Annex-I. Sanitary inspection at the source

- | | | |
|---|--------|-------|
| 1. Is there a latrine within 10m borehole? | A. Yes | B. No |
| 2. Is a toilet located above the well? | A. Yes | B. No |
| 3. Is there any pollutant source within 50 m? | A. Yes | B. No |
| 4. Is the water around the well ponding or stagnant? | A. Yes | B. No |
| 5. Is the fence broken or lacking? | A. Yes | B. No |
| 6. Is the drainage around pump house faulty? | A. Yes | B. No |
| 7. Is damage in fence allow animals to enter? | A. Yes | B. No |
| 8. Is that unsanitary to unseal a well? | A. Yes | B. No |
| 9. Is there any leaking of water due to improper cover of well? | A. Yes | B. No |

Annex II: Questionnaires used to obtain household inspection on drinking water quality from Debre Birhan town

1. Is there a separate container used to store drinking water? A. Yes B. No
2. Is the container of drinking water kept above ground and away from contaminants?
A. Yes B. No
3. Is water containers have a narrow mouth? A. Yes B. No
4. Do containers have a covering or lid? A. Yes B. No
5. Does water collect form around taps? A. Yes B. No
6. Are the water lines covered while being transported? A. Yes B. No
7. Do you have water on reserve at home? A. Yes B. No
8. Do you home have a toilet? A. Yes B. No
9. Do you wash your hands with soap after using the toilets? A. Yes B. No