Addis Ababa University
Africa Center of Excellence for Water Management

Drinking Water Quality and Management Practices from Source to Household: The Case of Kombolcha Town, Ethiopia

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Degree of Master of Science in Water Supply and Sanitation

By

Bezawit Tesfaye Ejigu

June, 2020

Addis Ababa Ethiopia

Addis Ababa University
Africa Center of Excellence for Water Management

Drinking Water Quality and Management Practices from Source to Household: The Case of Kombolcha Town, Ethiopia

A Thesis Submitted to Africa Center of Excellence for Water Management Addis Ababa University in Partial Fulfillment of the Degree of Master of Science in Water Supply and Sanitation

By

Bezawit Tesfaye Ejigu

Advisor: Prof. Dr.-Ing. Esayas Alemayehu
Co-advisor: Dr. Feleke Zewge

June, 2020

DECLARATION

I hereby declare that this thesis submission is my own work towards the master of science and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in text.

Bezawit Tesfaye Ejigu		21/06/2020
	Signature	Date

ADDIS ABABA UNIVERSITY

AFRICA CENTER OF EXCELLENCE FOR WATER MANAGEMENT

SCHOOL OF GRADUATE STUDIES

Thesis Approval Form

The undersigned have examined the thesis entitled 'Drinking Water Quality and Management Practices from Source to Household: The Case of Kombolcha Town, Ethiopia' presented by Bezawit Tesfaye Ejigu a candidate for the degree of Master of Science in Water Management specialization in Water Supply and Sanitation and it is hereby certify that it is worthy of acceptance.

Prof, Dr. Ing. Esayas Alemayehu		21/06/2020
Advisor	Signature	Date (dd/mm/yyyy)
Dr. Feleke Zewge		
Co- Advisor	Signature	Date (dd/mm/yyyy)
Dr. Andualem Mekonnen		
Internal Examiner	Signature	Date (dd/mm/yyyy)
Dr. Adey Feleke		
External Examiner	Signature	Date (dd/mm/yyyy)
Dr. Beteley Tekola		
Chair Person	Signature	Date (dd/mm/yyyy)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

a.s.l: above Sea Level

CSA: Central Statistical Agency

DCI: Ductile Cast Iron

GSP: Galvanized Steel Pipe

HDPE: High Density Polyethylene

KWSSSO: Kombolcha Water Supply and Sewerage Service Office

Mg/d: Milligram per Day

Mg/l : Milligram per Liter

MoFED : Ministry of Finance and Economic Development

NHMRC: National Health and Medical Research Council

NTU: Nephelometric turbidity units

PVC: Polyvinyl Chloride

SR: Service Reservoir

TDS: Total dissolved solid

UNICEF: United Nations International Children`s Emergency Fund

UTM: Universal Transverse Mercator Coordinate system

WHO: World Health Organization

ABSTRACT

This research focuses on investigation of the existing drinking water quality of Kombolcha town from the source to points of household tap in relation to safety and acceptability for users concerning water quality parameters. The town gets its water supply from groundwater sources.

A total of 45 water samples were selected and collected from boreholes, reservoirs, distribution mains and households. The pH, Turbidity, Total Dissolved Solids (TDS), Electrical Conductivity (EC), Temperature, Total hardness, free chlorine residue, Manganese, Nitrate and Iron and Microbiological (Total Coliform and fecal Coliform) parameters were determined. The result was then compared with the WHO and Ethiopian water quality standards.

The results obtained show that for physical analysis except temperature the rest all parameters were within the WHO permissible limit. The results for temperature were found between the ranges of 22.5°C - 26.1°C. Based on laboratory analysis of chemical parameters the result shows that total hardness is above the permissible limit set by the guidelines. Also, all chlorine residual of the samples were found to be below the recommended values of WHO and national guidelines except seven of samples. However manganese, iron and nitrate were within the permissible limit. The result of bacteriological analyses indicated that Fecal coliform of all samples were zero meeting WHO and national guidelines. But Total coliform of nine samples were above the guideline`s limit ranging between 1-4 CFU/100ml.

In summary, with regard to the Physico-chemical parameters the water is safe and there is no significant effect on the health of the users. The results of bacteriological analyses have shown that some of the sample points are at risk. To overcome these problems regular chlorination is recommended. It is also recommended that sampling and monitoring at different times is essential and analysis of additional water quality parameters should be undertaken.

Key Words: *Kombolcha town, water supply, WHO standards, water quality*

ACKNOWLEDGEMENTS

I would like to thank the Almighty God and his mother Saint Mary, who brought me to this level by making me strong and patient during the hard times.

My deepest thanks go to my advisors Professor Dr. Ing. Esayas Alemayehu and Dr. Feleke Zewge for their valuable advice and consistent guidance throughout the research period.

This work would not have been completed in the present form without the help and cooperation of different institutions and individuals. Among others the most important ones are Kombolcha water supply and sewerage service office, Dessie water supply and sewerage service office and Wollo University Kombolcha Institute of Technology. I greatly appreciate the support of Mr. Tesfaye, Mr. Hussen Fantawu, Mr. Anwar and other support staff members of both Dessie and Kombolcha water supply and sewerage service office.

I am deeply indebted to my husband Dagmawie Negash, for his continuous support, encouragement and enabling me such an achievement, without him it would have not been possible to complete my study. I am grateful to my family for their understanding, encouragement and support throughout my study.

I am also thankful for all the staffs of ACEWM for their contribution throughout the coursework and also for the completion of this work. I owe great thanks to my friends, colleagues and other people who helped in one way or another for the success of this thesis work.

1 INTRODUCTION

1.1 Background of the Study

Water plays a major role in life existence. Water is one of the most crucial and non substitutable environmental resources that is why we say "water is life". For survival of all living things on the earth water is important. Especially, human beings require water for domestic uses and for development. Even though 75% of earth is covered by water, only 3% of it is available as fresh water, which is found in lakes, rivers, springs, ice and ground water etc. This little amount of fresh water is not found evenly distributed in all parts of the earth. In addition, it could add impurities and contaminated by microorganisms that cause waterborne diseases like typhoid, cholera, bacillary disunity and amoeba. Whereas other water source are contaminated by high concentration of dissolved materials. Therefore, one of the basic needs for human life is adequate quality, safe and affordable supply of drinking water. For many people across the planet it is difficult to have access to safe and adequate water supply services which affects their life in various ways (Yibeltal, 2011).

Water in its evaporation state is nearly pure. Nevertheless, when water possesses the hydrologic cycle it comes in contact with materials in the air, on the earth surface and beneath the surface of the earth leading to the development of impurities. Human activities contribute further impurities in the form of industrial and domestic wastes, agricultural chemicals, and other, less obvious contaminants. It is necessary to have clean, safe, and adequate water for survival of all living organisms and the functioning of ecosystems, communities, and economies. On the other hand, population growth resulting in agricultural and industrial expansion which in turn favors climate change, have a major impact on the quality of the water. Both quality and quantity of clean water supply is significance for the welfare of humanity (Khelif & Abderrahmane, 2018). It is well known that, the human body is mainly made up of water. This body water is crucial for metabolic activities, organ functions, in regulating and transporting of nutrients, waste removal, thermal regulation and digestion. Conversely, if water is fecal polluted it will be a media for diseases transmission between water users (Alhassan & Kwakwa, 2014). Water quality could be also characterized by an optimum level of biophysical or physicochemical parameters such as pH, turbidity, taste, odour, conductivity, and color. Therefore, poor quality of drinking water could result from the water source or ineffective treatment mechanism.

As in other developing towns, a rapid population growth and high rural-urban migration poses many social and environmental challenges for the town of Kombolcha of which inadequacy of water supply and sanitation services are crucial. The high development and expansion of the town is mainly attributed to commercial areas, industrial zones and housing projects either by government and private sectors. The rapid extension of the urban areas in different parts of the town necessitates optimization and upgrading of the water supply and other important infrastructures in order to provide the required services and to protect the health and environment of the targeted population.

One of the issues inviting attention in water quality performance assessment in Kombolcha town is that it is characterized by low quality of water, on which the area faces the problem of water borne diseases.

1.2 Research Questions

❖ What are the major factors for low quality of drinking water in Kombolcha town?
❖ Do the drinking water quality parameters fit the guidelines set in the WHO standard and national guideline?
❖ What will be the mitigation measures if the parameter doesn't fall within the standards limit?

1.3 Objectives of the Study

The main objective of this study is to assess the quantitative and qualitative measures of water quality parameters for Kombolcha town referencing to the WHO guidelines and Ethiopian guidelines recommended value.

1.3.1 Specific Objectives

✓ To assess the physico-chemical characteristics of the water such as pH, temperature, turbidity, Electrical conductivity, total dissolved solid, total hardness, free chlorine residue, Manganese, Nitrate and Iron.

- ✓ To determine the microbiological characteristics of water (total coliform and fecal coliform)
- ✓ To characterize the drinking water quality from source to point of distribution up to house hold taps.
- ✓ To identify best practices for improving water quality problems.

1.4 Scope and Limitation of the Study

The thesis focused basically on the investigation of water quality of Kombolcha town that includes different characteristic of water quality parameters such as physical, chemical, and bacteriological parameters. The investigation was performed from sources to household tap. It was specifically focused only on the major standards of water quality parameters of physicochemical and bacteriological aspects such as total coliform and fecal coliform.

The study area is limited to Kombolcha town water supply source, reservoir, selected distribution main, and house hold taps.

2 LITERATURE REVIEW

Water is a liquid at ambient conditions, but it often co-exists on earth with its solid state being an ice, and gaseous state as vapor. The human bodies are approximately 60% water, human blood is consists of at least 50% water and the human brain is made up of 77% water.

Water is a precious natural resource, important to sustain life, to socio-economic development and for environmental protection. Therefore, water could be an important poverty alleviation means through enabling the people towards achieving sustainable allocation of safe and sufficient drinking water and sanitation. On the basis of its occurrence and management one`s access to safe drinking water can be life threatening.

The quality of water which is free from disease causing microorganisms and chemical substances harmful to health is referred to us drinking water quality. Many people in the world are still bringing water manually using human labor or other transport mechanisms due to the absence or unreliable supply of household water connection. This type of facility enforces users to store water in their houses for longer period which create vulnerable environment for disease causing microorganisms development. In some circumstances, though there present fully protected sources and well-managed water supply systems it does not ensure safe water consumption due to the occurrence of fecal contamination during transportation, and storage.

In order for water to be acceptable for drinking there should be a good balance in terms of the physical, chemical and bacteriological qualities of water. Moreover, water should be free from minerals and organic substances which could cause adverse physiological impacts. In addition, disease causing microorganisms should be removed for a water to be taken as healthful drink for human consumption. Also drinking water should be aesthetically acceptable; it should be free from apparent turbidity, color, odor and from any objectionable taste (Temesgen & Hameed, 2015).

2.1 Sources of Water

Water can be grouped into Surface water and Ground water .surface water comprising of oceans, rivers, lakes, reservoirs, lagoons, streams and many others. Surface water frequently contains substances that must be removed before it can be used as drinking water. However groundwater which is considered mostly as purer than the surface water and lastly the rain water which falls as a result of condensation and precipitation of the clouds. Groundwater is the major source of drinking water in Ethiopia. More than 80% of the country's drinking water supply source is from ground water (Nakade, 2013).

2.2 Pollution of Drinking Water

In general, pollutants can be released into the environment as gases, dissolved substances or in the particulate form. Ultimately pollutants reach the aquatic environment through a variety of pathways, including the atmosphere and the soil. Pollution may result from point sources or non-point sources. There is no clear-cut distinction between the two, because a non point source on a regional or even local scale may result from a large number of individual point sources, such as automobile exhausts (Werner et al., 2009). An important difference between a point and a non point source is that a point source may be collected, treated or controlled (non point sources consisting of many point sources may also be controlled provided all point sources can be identified). The major point sources of pollution to freshwaters originate from the collection and discharge of domestic wastewaters, industrial wastes or certain agricultural activities, such as animal husbandry (WHO/UNICEF, 2014). Most other agricultural activities, such as pesticide spraying or fertilizer application, are considered as diffuse sources. The atmospheric fall-out of pollutants also leads to diffuse pollution of the aquatic environment.

2.3 Millennium Development Goals

To address the problem water sanitation and health Ethiopia has committed to the Millennium Development Goals (MDGs) by adopting the Universal Access Plan to achieve 100% water and sanitation coverage at national level. However, the overall progress has been slow and there is a disparity in development between urban and rural areas. The WHO/UNICEF (2015) report on the progress on water supply and sanitation showed that in 2015, 57% of the population have access to improved water sources (compared to 13% in 1990) and 28% of the population have access to improved sanitation services (compared to 3% in 1990). It is clear that sanitation coverage is lagging far behind water supply coverage. There should be more concerted and coordinated actions to meet the Sustainable Development Goal (SDG) 6 which aims to ensure access to water and sanitation for all. Unless efforts to increase access to clean water supply and sanitation services are intensified and implemented in conjunction with the promotion of proper hygiene practices, communicable diseases will continue to remain a major cause of child morbidity and mortality in rural Ethiopia (WHO/UNICEF, 2015).

2.4 Drinking-Water Quality and Health

Waterborne Diseases are caused by pathogenic microorganisms that most commonly are transmitted in contaminated fresh water. Infection commonly results during bathing, washing, drinking, in the preparation of food, or the consumption of food thus infected. Various forms of waterborne diarrheal disease probably are the most prominent examples, and affect mainly children in developing countries. The lack of access to water and sanitation infrastructure is the disconcerting from a public health perspective (Fewtrell et al., 2007).

Water has a profound effect on human health both as a means to reduce disease and as a media through which disease causing agents may be transmitted. The impact of water on health derives principally from the consumption of water containing pathogenic organisms or toxic chemicals and the use of inadequate volumes of water that lead to poor personal and domestic hygiene (Howard et al., 2012). Water contaminated with microbiological and chemical constituents can cause a variety of diseases and thus water intended for human consumption should be safe, palatable and aesthetically pleasing.

Poor hygiene practices may result from the use of inadequate volumes of water and therefore water quantity is also important in controlling infectious diarrheal diseases. Diarrhea diseases are a leading cause of morbidity and mortality in less developed countries, particularly among young children (WHO/UNICEF, 2008).

Water and sanitation-related diarrheal disease is among the top three causes of all deaths in Ethiopia, and Amhara region is one of the regions that have faced this life threatening challenge for many years. In Ethiopia over 60 % of the communicable diseases are due to poor environmental health conditions arising from unsafe and inadequate water supply and poor hygienic and sanitation practices (MoH, 2005).

Ethiopia has one of Africa's lowest rates of access to water supply, sanitation, and hygiene despite abundant surface and groundwater resources. According to the government report (MoWRD, 2006) 40% of the population had access to safe water; however, according to the World Health Organization (WHO/UNICEF, 2008) and local nongovernmental organizations, the figure was closer to 22 percent. The WHO estimated that only 13 percent of the population had access to sanitation. Ethiopia's Millennium Development Goals (MDGs) for improved water and sanitation access are 70 percent and 56 percent respectively. To reach the MDG targets, the government will need to help ensure local water supply and sanitation (WSS) service providers continue to develop their capacity to manage operations. The government will also need to encourage consumer advocacy and hygiene awareness.

In most developing countries, especially in Sub- Saharan Africa (SSA), the basic causes of more than 80% of the diseases are inadequate and unsafe water supply, and improper disposal of waste. Ethiopia is among the poorest countries in the world, ranking 170 out of 177 in the UN human development index and is the second most populous country in Africa. Yet, Ethiopia's rural populations are among the least served with rural water supply and sanitation access at only 24% and 8% respectively (ADF, 2005).

2.5 Water Quality

Water quality refers to the water`s suitability for a number of uses or processes in a sustainable way. For improved public health, it is important to have a good quality of drinking water. Different types of pollutants which deteriorates the quality of drinking water threaten human health (Dessalew & Yonas, 2018). In order to ease the process of water quality evaluation, WHO international guidelines as well as Ethiopian national guidelines are available. Thus, these guidelines are helpful to assess different water quality parameters and to compare with the guidelines limit preventing water acceptability issues and health impacts.

Water quality deterioration can be caused by different factors. Some of these factors include pollutants joining to the supply system through pipe leaks, mixing of urban runoff to supply sources, pollution from industrial and urban wastes, intrusion of flood water to the supply systems, faulty sewerage line connection to water supply pipe line, etc. According to WHO drinking water quality may be controlled through a combination of protection of water sources, control of treatment processes and management of the distribution and handling of the water (WHO, 2010).

In developing countries, one of the major concerns with regard to water quality is microbiological contamination. In addition, inorganic contaminants that negatively influence health and aesthetic aspects of water could be available in drinking water. In this regard, Fluoride and arsenic are causes of health problem in a international context (Sabrina et al., 2013). It is always a challenge to distinguish the reasons of variability of water quality due to the limited availability of data, as well as theoretical and methodological system (Qing et al., 2014).

Our country manifests water quality degradation problem. Major cities and towns which have access to water supply with better performance in comparison to the rural system experience high degree and extent of water pollution resulting from high population growth and industrialization causing to contaminate surface water like rivers as well as the ground water system. The natural processes facilitate the degradation of water quality together with the anthropogenic or human activities limiting the expected use of drinking water. Generally, it can be seen that water quality deterioration for both surface and ground sources becomes the combination effect of urbanization, industrialization, poor sanitation, high growth of population, and less developed waste disposal techniques.

Safe drinking water could be defined as the water with microbial, chemical and physical characteristics that meets the WHO or national water quality guidelines. Access to safe drinking water refers to the proportion of people using improved drinking water sources: household connection; public standpipe; borehole; protected dug well; protected spring; rainwater (WHO, 2010). According to WHO (2010), about 2.6 billion people – half the developing world – lack even a simple 'improved' latrine and 1.1 billion people have no access to any type of improved drinking water source. This is not much different in many parts of Ethiopia. In general, it is necessary to protect quality of water to be supplied in areas vulnerable to water pollution. Moreover, provision of access to safe drinking should be citizen`s right.

During water quality standards development and implementation, it is important to take in to account existing legal aspects as well as future plans associated to water, health and local government and the capacity of regulatory body in the country. As there is no one direct approach towards achieving the water quality standards and its implementation, there might be variation in terms of the nature as well as forms from country to country. Approaches that may work in one country or region will not necessarily transfer to other countries or regions (WHO, 2011). In this specific study, WHO and Ethiopian guidelines values for drinking water quality were used to compare the results of the water quality analysis.

2.6 Water Quality Analysis

As pointed earlier, pollution at the source of water or the inadequate treatment methods used are the major reasons behind poor quality of drinking water. In most cases, water for drinking purposes in Ethiopia is sourced from either groundwater or surface water sources. While it is widely applicable in practice to use sophisticated treatment methods such as slow sand filtration or addition of chlorine for treatment purposes, the quality of these sources might be affected due to anthropogenic activities and/or pollution from industrial activities. In contrast, pathogens and high concentration of harmful substances should be avoided for water to safe for drinking. In most countries, contamination of drinking water with fecal matter is the worst water quality problem (CSA, 2017).

Water quality monitoring and assessment is the most important part of the water quality management. Consequently, in recent years regular measurements of surface as well as ground water quality parameters had been practiced in order to improve quality through monitoring and evaluation of the system (Shamsur et al., 2017).

In Ethiopia, there is a low level of access to safe drinking water quality services to the people. According to the report from the Ministry of Finance and Economic Development (MoFED, 2014) of Ethiopia the national coverage of improved water sources becomes 82.4% in urban areas and 66.3% rural areas. Although the above report of MoFED shows larger success rate, nowadays acute watery diarrhea becomes one of the major water born diseases in concern in the countries' context and it has been manifested that, diarrhea which was resulted due to poor quality of water was the second largest cause of under five years child mortality resulting 88 deaths out of 1000 live births and morbidity of 31% based on the report by (CSA, 2011) as stated by (Tadesse et al., 2017).

Ensuring a good quality of drinking water is a foundation for the prevention and control of waterborne diseases as well as to control the adverse impacts of different chemicals and physical parameters. The most widely used water quality standards or guidelines values in our country is the WHO guidelines for drinking water. Similarly, as drinking water quality is an important measure of safety, the WHO standards for drinking water quality become the basis for most countries in the world. The WHO produces international norms on water quality and human health in the form of guidelines that could be used as the basis for regulation and standard settings in developing and developed countries. Thus, it is essential to provide safe water for drinking purposes through meeting water quality standards in national as well as international level. Therefore, these water quality analysis is mainly comprised of the assessment of the physical, chemical, and biological characteristics of water which. When they present in drinking water above the expected limit, the different quality measurement aspects could be detrimental for human health.

2.7 Water Quality Parameters

In general, on the basis of the of the water quality guidelines and standards water quality parameters could be categorized as physical, chemical, and biological characteristics. The degree of safety of water quality for drinking purpose could be directly related to these three major parameters classes. Therefore, a single water body could be assessed for its suitability for different uses on the basis of these water quality parameters. Therefore, the water quality parameter standards could also well be used to assess the quality of water for drinking purpose (Guptaa et al., 2009).

2.7.1 Physical parameters

Drinking water is supposed to be free from objectionable taste, odor, color and suspended materials which are also known as aesthetic parameters. These parameters include those which are detectable by the senses such as turbidity, color, taste, and odor. Poor monitoring of these parameters might result in the water supply to be rejected or unconventional possible poor quality sources to be adopted. These physical parameters are generally important to achieve good aesthetic value of water and as the same time they are simple and inexpensive for monitoring.

The physical parameter of water includes also parameters like that of hardness, pH, salinity, and TDS. In some instances, the physical quality of water could also be influenced by the chemical water quality. The measurable characteristics that determine these largely subjective qualities are true color which is the color that remains after any suspended particles have been removed, turbidity which could be interpreted as the cloudiness caused by fine suspended matter in the water, hardness which indicates the reduced ability to get a lather using soap, total dissolved solids (TDS), pH, temperature, taste, odor and dissolved oxygen (NHMRC, 2011). While using or drinking water, people could experience the taste, odor, feel and appearance of water. This could be used as a measure of quality from users' perspective. For instance, the physical characteristics of water could be used to indicate the presence of corrosion and encrustation in pipes or fittings.

High turbidity enables bacterial growth by means of inhibiting the effects of disinfection against micro-organisms. Therefore, turbidity should be low, in particular where disinfection is done to keep the quality of the water. Safe drinking water should be colorless. It is common that the presence of colored organic matter or minerals causes drinking water color. Though, odors may result from many factors such as industrial pollution and biological activities organic substances also result in water odor. Water taste problems could be indicators of changes in water sources or treatment process (NHMRC, 2011). The inorganic compounds that could be detected by the taste of water include substances magnesium, calcium, sodium, zinc, iron and copper.

2.7.1.1 PH of pure water

The pH of pure water refers to the degree of acidity and alkalinity of solutions with respect to hydrogen and hydroxide ions. PH refers to the measure of the potential hydrogen ion H^+ existing in water. Therefore, pH is expressed by numbers ranging in between 0 and 14. In general, neutral water is the one having a pH value of 7. Water is considered as an acidic when the pH value lower than 7 occur and a pH value greater than 7 is taken as basic. Generally, the pH value of drinking water ranges between 6 and 8.5. Moreover, water with low pH value is known to be toxic and with high degree of pH, it tends to show bitter taste (Hoko, 2008).

2.7.1.2 Temperature

Temperature directly impacts many of the physical and biological characteristics of water. During the physical analysis of temperature, it is a common practice to express it in degree Celsius. The analysis of temperature should be done on site immediately after collecting the water sample. Cool water is commonly more pleasant than warm water. Furthermore, variation in temperature impacts the degree of tolerance to various inorganic constituents as well as chemical pollutants which commonly affect the taste of drinking water. Therefore, according to (WHO, 2008) water temperature should be kept lower than 15°C for drinking purpose.

Generally, the growth of microorganisms could be facilitated due to high water temperature resulting in unpleasant taste, odor, color and create pipe corrosion problems. Therefore, it is a good practice to keep the temperature of water within the limits of the guidelines. Keeping the temperature within the standard range protects the development of mesophilic pathogenic bacteria (Garoma et al., 2018).

2.7.1.3 Total Dissolved Solids (TDS)

A wide variety of inorganic and organic mineral deposits like that of calcium, magnesium, potassium, sodium, or salts such as chlorides, bicarbonates, sulfates can be dissolved in water as water is a strong solvent.

Undesirable tastes and color changes in the appearance of drinking water could occur due to the above listed minerals or salt contents. Moreover, in drinking water the presence of total dissolved solid (TDS) could arise from industrial wastewater and sewage. Therefore, the general quality of water can be evaluated from the TDS test results (Mohammed et al., 2013).

2.7.1.4 Electrical Conductivity (EC)

The ability of a substance to conduct electric current is referred to as electrical conductivity. is the conductivity of a body of unit length and unit cross-section at a specified temperature is called specific electrical conductance and it is mostly expressed in ms/cm (micro Siemens per centimeter). At 25 °C, only a few hundreds of micro Siemens per centimeter conductance is available in pure water. When the temperature of a solution increases the specific electrical conductivity also increases. Thus, temperature has direct relationship with electrical conductivity.

Availability of charged ionic particles in water solution results in an increase in conductivity of the solution. Therefore, measurement results of electric conductivity are indications of the presence of ionic concentration hence, as the ionic concentrations increases conductance of the solution is also increases.

The addition of coagulants for turbidity removal and chlorine-based chemicals for disinfection purpose contributes to the increase of electric conductivity. The addition of Coagulants and chlorine substances enhances the concentration of dissolved solids thereby increasing the electric conductivity of the water. Therefore, the higher the dissolved solids in the water, the higher its electric conductivity and it increases from raw to treated water (Tadesse et al., 2017).

2.7.1.5 Turbidity

The measure of suspended and colloidal matter in water is known as turbidity. The suspended or colloidal matters could be finely divided organic and inorganic matters, clay, silts, soluble organic compounds, plankton, and other microscopic organisms causing the water to change its color from its original and acceptable purity level. On the other hand, turbidity can be also expressed as the optical property that causes light to be scattered and absorbed. In this regard, it is difficult to establish a relation between the turbid property of water and the weight concentration of suspended or colloidal matter due to the fact that the light scattering properties of these matters are dependent on the size, shape and refractive index of the particles.

Turbidity is one of the important parameters of water quality as it helps to address the drinking water acceptability issues to users and it is also helpful in decision making to decide on the treatment methods to be used and its efficiency. In this regard, for instance the efficiency of chlorination or addition of chlorine could be anticipated by chlorine demand as it defends microorganisms (disinfection), or it might stimulate the growth of bacteria (WHO, 2011). On the basis of the WHO guidelines, turbidity of 0.5 NTU is recommended to have effective disinfection in drinking water treatment. However, 5 NTU could be taken as acceptable to the users.

2.7.2 Chemical parameters

It is difficult to find naturally existing pure water as most of the water sources have chemicals naturally that have leached from the surrounding environment. Most of the time, there is a little or no adverse impacts imposed from the naturally occurring chemicals. Even, some of them could be beneficial for human health. On the contrary, water could be contaminated resulting in deterioration of its quality due to human made chemicals. These chemicals could be sourced from one of the following or the combination of industrial effluents, municipal solid waste as well as sewage flows, agricultural effluents, or runoff from urban and towns.

The presence of highly toxic substances in drinking water could result in either acute or chronic health effects. According to the reports, the prolonged exposure of chemicals in drinking water for extended periods might result in a health concern (WHO, 2010). Therefore, the type of chemical and its concentration, as well as the length of exposure are the critical factors to evaluate severity of these health effects. As the lower limits of levels of chemicals in drinking water to causes low health risks, chronic health impacts are more frequent than acute health problems. Evidences in urban areas showed that chemical contaminants produced adverse human health problems (Hamere & Eyasu, 2017).

Even though, the largest public health treat arises from microbiological contamination, chemical contamination in some circumstances can also be a major health concern. Except huge amount of sudden contamination levels, there are only a few chemicals that can lead to health problems after a single exposure of a drinking water supply. In contrast, there are many chemicals that could occur in drinking water of which some might cause health problems on a large-scale. In general, natural causes such as the presence of arsenic and fluoride can contaminate water naturally or water can be contaminated through human impacts from industries or agricultural practices like that of heavy metals, nitrates, nitrites, lead, uranium, and pesticides (UNICEF/WHO, 2012).

2.7.2.1 Total hardness

The presence of calcium carbonate and magnesium carbonate initiates water hardness. In addition, the presence of bicarbonates which can be avoided through boiling could be the source of hardness. Moreover, magnesium sulfate, calcium sulfate and chlorides which are possibly removed by chemical precipitation with the help of lime and sodium carbonate chemicals could result hardness. The total hardness is the sum of cations concentration of alkaline earth metal that present in water as a result of the occurrence of calcium and magnesium ions in ground water (Jadhav et al, 2015). In general, one of the major sources of hardness in water is that when water bodies are crossing terrains of minerals rich in limestone and/or magnesium.

Hardness could result aesthetic problems, but it is unlikely to result a health risk. Some of the aesthetical problems resulting from hardness could be alkali water taste and the formation of scale or precipitation in pipe systems and fixtures affecting water pressures and interior diameters of piping to decrease. From the utility or service point of view hardness is a crucial water quality parameter. This is because, the community might suffer from hardness impacts of pipe scale deposition in distribution systems, incurring much more money for soap consumption or water boiling materials which consume much fuel and causes taste problems due to crust formation. Therefore, even if there is no guideline value of hardness on the basis of its adverse effects on the health of users, its acceptability may vary from one society to another (Tadesse et al., 2017). According to World Health Organization (2017) and according to National drinking water quality guidelines it is recommended to attain total hardness permissible limit of 300mg/l.

2.7.2.2 Free Chlorine Residue

Disinfection is the most important process in water treatment. Most water supplies are treated with chlorine which is a powerful oxidizing agent and the most effective disinfectant which makes it favorable among other disinfection mechanisms. Disinfection of drinking water supply is done to avoid or disable disease causing microorganisms like that of typhoid, cholera, and others. Chlorine only remains in treated waters of high quality as by nature is a very reactive substance. In addition, it is universally applicable for use due to its cost effectiveness and relative easiness to handle.

In many cases of urban and rural water supply schemes chlorination may be the only disinfection treatment method required as the effects of chlorination are extremely valuable. Usually, water treatment using chlorine in urban water supply systems is performed at reservoir locations leading to longer distance from households and other users. Therefore, it is always necessary to provide continuous as well as sustainable protection throughout the distribution systems along the path traversed by water from the storage to the households especially when we encounter leakage in the distribution system or mixing from other sources. Therefore, the idea behind the chlorination process is that, there should additional chlorine remaining in the system to enhance further protection from recontamination (WHO, 2010). This remaining chlorine in the system is called chlorine residual.

Irrespective of its forms, free chlorine residual might include chlorine, hypochlorite and hypochlorous acid. During disinfection, addition of chlorine is a more efficient method, but it is highly reactive that it vanishes too rapidly. In contrast, the combined chlorine like that of chloramines provides longer protection due to its less reactivity nature. In order to preserve the quality of water throughout the distribution system, residual chlorine level of 0.5 mg/l is sufficient (WHO, 2017). Nevertheless, this amount of chlorine residual is not sufficient sustain the quality of the water when water is stored in the home in a bucket or jerry for 24 hours (CDC, n.d.).

2.7.2.3 Manganese

Manganese could be mainly found in rocks and bearing minerals. In addition, artificial sources include industrial effluents, acid-mine drainage, sewage and landfill leachates. Manganese has quite rigid limits due to its problems of staining. In addition, it produces unpleasant appearance and taste forming deposits within pipes and break off as black particles (EPA, 2001).

According to WHO reports in many surface water and groundwater sources manganese is common to be found naturally specifically in anaerobic or low oxidation conditions. When manganese is deposited in water distribution lines it results in water discoloration, which in turn produces objectionable taste to users. Even though, in the long term it produces accumulation of black deposits in the water systems, manganese concentrations below 0.05–0.1 mg/l are commonly acceptable. Usually, aerobic waters shows higher levels of manganese sourced from industrial pollution on the other hand, fresh water shows levels in the range from 1 to 200 mg/l, although levels as high as 10 mg/l can be detected in acidic groundwater (WHO, 2006).

2.7.2.4 Nitrate

In drinking water quality analysis nitrate is one of the extreme disease causing parameters. In natural waters nitrate is found in relatively low amount. However, most of the nitrate in water is occurred from organic sources such as waste discharges and inorganic sources like that of artificial fertilizers from agriculture. Moreover, another source of nitrate production could be bacterial oxidation and fixing of nitrogen by plants.

Nitrate concentration is a concern in many aspects. Such manifestation includes the "blue baby" syndrome (methaemoglobinaemia) which is caused by the consumption of drinking water with high content of nitrate by infants. In this regard, the nitrate concentration does not have direct influence on the infant`s health but produces favorable substance that possesses reaction with hemoglobin resulting in the disease methaemoglobinaemia (Alley, 2000).

The maximum permissible limit of nitrate for drinking water is 50 mg/l (WHO, 2011). In most countries, water from boreholes often exhibit nitrate levels greater than 50mg/l while as, sources from surface water usually do not exceed 10 mg/l.

2.7.2.5 Iron

Iron is found in insoluble form in soils and rocks forms with significant amounts. Nevertheless, soluble forms of iron could be available due to variety of complex reactions in the geological formation while water passes through the terrain or formation of the ground system. Therefore, it is possible to find considerable amounts of iron from groundwater sources. Consumption of water with significant amount of iron normally does not pose harmful effect on consumers. But, low aesthetic, colored, turbidity or in extreme situations formation of precipitate could be the problems encountered as a result of high iron content water. Besides, water with excessive iron could bring discolored vegetables while cooking and could result stained laundry if it is used for washing purposes. Iron concentration might also result in the change of the taste of water. Generally, iron concentration greater than 0.3 mg/l is irritant and it should be removed (Twort et al., 2000).

2.7.3 Microbial parameters

Drinking water quality should be such that it is free from all pathogenic microorganisms. Moreover, it should be free from bacteria resulting from excremental pollution of water. In this case, the primary indicators are coliform bacteria found in warm-blooded animals feces. Therefore, the microbiological drinking water quality should be controlled. Thus, monitoring and inspection should be done to check the presence of coliform bacteria through specified treatment techniques (WHO, 2008). Mostly, chlorine is used for disinfection as it is readily available and less expensive.

The microbial quality of water is associated with the existence of bacteria indicative of faecal sewage contamination such as total coliforms and faecal coliforms or Escherichia coli. Coliforms are found naturally in the soil and in the gut of humans as well as animals. Thus, if they are detected in water, it means that there occurs possible contamination of water. As bacteria like that of E. coli and certain species of Enterobacter aerogenes are present only in the gut of humans and animals their availability in water dictates possible faecal pollution of water. In summary, the main contaminants for drinking water quality from a health perspective are faecal pathogens, arsenic, and fluoride (WHO/UNICEF, 2008).

There might be several types of bacteria existing in drinking water. Therefore, in order to assess the microbiological water quality it is wise and efficient to establish indicator bacteria. The three most common bacteria indicators used are Escherichia coli, thermo tolerant bacteria, and total coliform. These bacteria are important in the assessment of the level of faecal contamination in drinking water. Therefore, total coliforms and fecal coliforms are the microbial organisms to be assessed in drinking water quality assessment.

Total coliform bacteria are a big group of several types of bacteria. Most of total coliforms are harmless to human health but some of them could be harmful. Total coliforms can be detected in nature in the environment such as vegetation, soil, and also human and animal faeces (Kanangire, 2013).

Faecal coliform are a subgroup of total coliform bacteria which are found from intestines and faeces of human or animals. Faecal coliforms are also known as thermo tolerant bacteria. If faecal coliform is detected in water, it gives a strong signal of faecal contamination of drinking water (Kanangire, 2013). Therefore, according to WHO (2011) thermo tolerant bacteria and Escherichia coli can be used to identify the occurrence of faecal contamination.

Escherichia coli are a like that of faecal coliform they exist in intestines of human and animal. They are the subgroup of faecal coliform bacteria which are harmless in most of the cases; however some of them are detrimental to human health such as E. coli. Therefore, the presence of E. coli in water is the preeminent indicator of faecal contamination of drinking water. E. coli generally survives much longer than the others and it is cheap and easy to detect (Edberg et al, 2000). According (WHO, 2006), Escherichia coli can be used as an excellent indicator of faecal contamination and it gives a conclusive evidence that they must not be present in drinking water.

2.8 Sanitary Assessment

The on-site appraisal of actual and potential contamination hazards and pathways in and around water supply systems by trained people is called sanitary survey. According to WHO (2011), it is possible to accomplish very low degree of contamination in the case of groundwater sources such as protected springs and wells; and protected water connection systems. But, sometimes bacterial contamination of different protected water sources is possible due to a variety of reasons.

The focuses of sanitary assessment are contamination sources for microbiological and chemical hazards from local industries or agricultural activity(UNICEF, 2008). The presence of pit latrines near shallow point sources or stagnant surface waters is the main risk factors of water systems pollution. The routes like that of leaking pipes or cracked well aprons through which contamination may occur, are called pathways. Contamination hazards and pathways can be indirect or intermittent, for instance a broken entry that permits animals into well enclosures or erosion that uncovers buried pipelines.

Sanitary assessment includes those activities: the general sanitation of the sources, the drainage system and reservoir, the physical status of protection box, the situation of the outlet and overflow pipe, pipes, household taps and materials that the users used to fiche water (Seid et al., 2018).

2.9 Guidelines for Water Quality Parameters

Drinking water should be safe as much as possible and all the possible efforts should be made to achieve it (WHO, 2017). Moreover, the domestic purposes such as drinking, food preparation and personal hygiene needs to have safe drinking water.

Drinking water standards and guidelines could possibly vary in regional basis or from country to country and it is not expected to have similar basis of standards due to variety of reasons. But, it is necessary to take in to consideration the existing or planned legislation relating to water, health and the capacity of regulatory body in the process of development and implementation of standards. On the basis of the water quality standards prepared by the WHO guidelines and the Ethiopian national water quality standards, parameters were assessed depending on the respective tested values as given in below in the tables for comparison.

Table 2-1: WHO and Ethiopian physical water quality guidelines

Parameters	WHO guidelines	Ethiopian Guidelines
Temperature (°C)	<15	
Electric Conductivity (µs/cm)	1200	
Total Dissolved Solids (ppm)	<1000	<1000
Turbidity (NTU)	<5	<5

Source:(WHO, 2017); (ESA, 2013)

Table 2-2: WHO and Ethiopian chemical water quality guidelines

Parameters	WHO guidelines	Ethiopian Guidelines
Total hardness, mg/l	300	300
Free chlorine residual, mg/l	0.5	0.5
Manganese mg/l	0.4	0.5
Nitrate mg/l	50	50
Iron mg/l	0.3	0.3
PH	6.5–8.5	6.5–8.5

Source:(WHO, 2017); (ESA, 2013)

Table 2-3: WHO and Ethiopian biological water quality guidelines

Parameters	WHO guidelines	Ethiopian Guidelines
Total coliform Faecal coliform	Must not be detectable in any 100 ml sample	Must not be detectable in any 100 ml sample

Source:(WHO, 2017); (ESA, 2013)

3 MATERIALS AND METHODS

3.1 Description of the Study Area

Kombolcha town is located in the eastern part of Amhara region in South Wollo Administrative Zone at 11°06' north latitude and 39°45' east longitude. It exists at a distance of 23km from Dessie town (zonal capital), 503 km from the regional capital Bahir Dar and 378 km from the Ethiopian capital city Addis Ababa. River Borkena crosses the town emerging from the east and running to the west direction.

The town is situated on Addis Ababa-Dessie- Mekele main asphalt road. It serves as the main junction to connect the regions of Afar and Amhara. Kombolcha town is the business centre and political seat of South Wollo Zone. It is also a home for big industries like the Textile and BGI brewery factories, and is generally found in a good pace of infrastructural and socio economical developments. The total population of Kombolcha town according to 2007 census is 119,545.

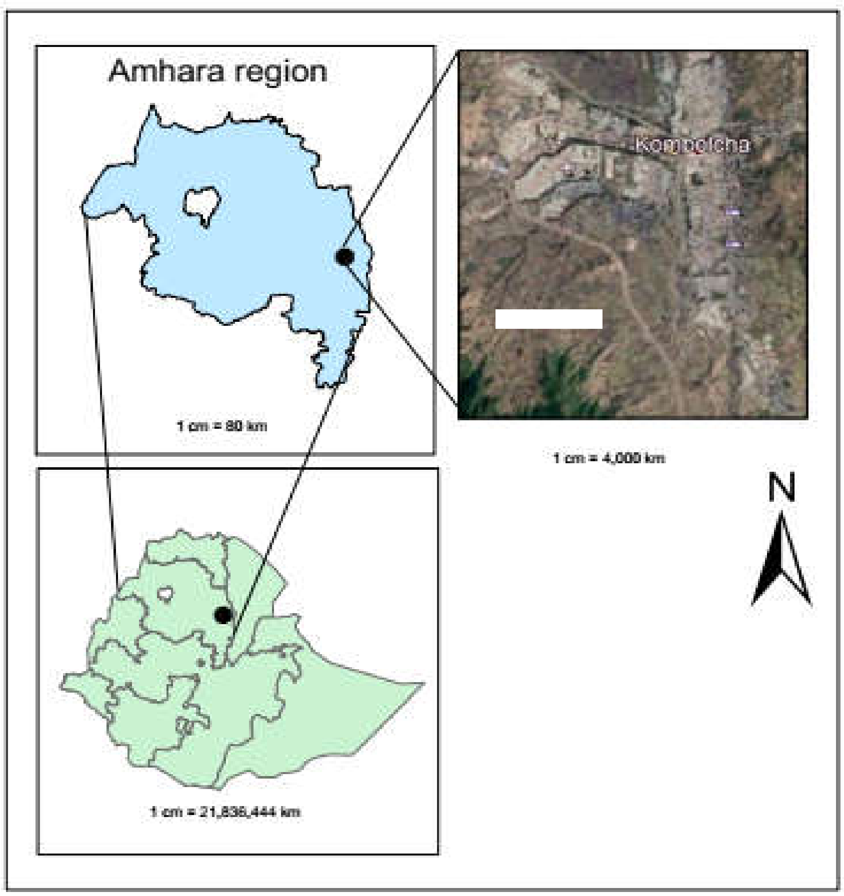

Figure 3-1: Location map of Kombolcha town

3.2 Climate and Topography

The altitude of Kombolcha town varies from 1500-2300m above sea level and the mean annual rainfall in the area is 1248mm and most of which occurs in the main rainy season that lasts from July to September and contribute about 84% of the annual rain fall (Kombolcha Meteorological Branch Directorate, 2015). The main rainfall season prevails from June to mid-September and spring season from September to November. The mean monthly temperature varies between 16.1°c (in December) to 22.1°c (in June) while as monthly mean sunshine hour and relative humidity varies between 5.0 to 8.5 and 40.1% to 64.3% respectively (Kombolcha Meteorological Branch Directorate, 2015) with rainy seasons being humid and have lower sunshine hour.

Kombolcha town, situated along Dessie – Addis Ababa all-weather asphalt road, has highly rugged topography. The eastern and western part of the town is blocked by mountains and the southeast of the town is flat and swampy. River Borkena crosses the centre of town flowing from north to south.

Figure 3-2: Topography of the area

3.3 Socio-Economic Activities

Kombolcha town is one of the dynamic areas of Amhara that is experiencing at high degree of urbanization and fast development. Since its establishment and merging with neighboring small nucleated community centers, Kombolcha town has experienced through a high rate of expansion in terms of area coverage and population growth. Many industries have been developed in the town.

3.4 Existing Water Supply System of the Town

Kombolcha Town got piped water in 1962 for the first time which was provided for limited number of people. Before the piped water supply installation the people of the town used Borkena and Berberi rivers as water sources. Because of population growth and people raised the question of clean water service the city municipality office started to expand and prove the water supply system services which include construction of boreholes, reservoirs, distribution lines.

In the year 1979 Kombolcha water supply and Sewerage office established as office separated from the city municipality. After that the office was able to work expansion projects associated with Ethiopian government, Africa development bank and Germen government.

Kombolcha water supply and Sewerage office have the main task of water supply and sewage collection. The office has a total number of 131 employees under different work decomposition and it has three main branch offices.

3.4.1 Existing Sources and transmission mains

The existing sources location, yield of boreholes, depth of boreholes, and their functionalities are presented in the following table.

Table 3-1: Existing water supply sources within Kombolcha town

Location of source	design yield	Yield(l/s)	Depth (m)	service year	Remark
Deway -1(BH -1)	10	10	100	1980	functional
Deway -2 (BH -2)	10	10	100	1980	functional
Deway -3(BH -3)	5.5	5.5	100	1980	functional
Deway -4(BH -4)	25	20	110	1996	functional
Deway -5(BH -5)	60	0	140	1999	Not functional
Deway -6(BH -6)	50	21	112	2009	functional
shishaber -7(BH -7)		14.8	112	2009	functional
Shishaber -8	19	19	144		functional
Shishaber -9	30	27			functional
Biraro	50	25	120		functional
Total		**167.1**			

Source: Kombolcha Water Supply office

3.4.2 Existing reservoirs

The total number of reservoirs in Kombolcha town water supply and sewerage office is 11 with a capacity of 4225m^3. The existing reservoirs history and locations are summarized in the table below.

Table 3-2: Existing reservoirs within Kombolcha town

No	Volume(m^3)	Type	Present condition	Name or remark
1	500	concrete	Functional	Aseb Ber
2	500	concrete	Functional	Nejaw Gora
3	500	concrete	Functional	University
4	500	concrete	Functional	University
3	300	concrete	Functional	Meja
4	300	concrete	Functional	Air Port
5	50	sandwich	Functional	Michael 1
6	300	concrete	Functional	Kuti Ager
7	50	Sandwich (booster)	Functional	Sheshabir
8	100	Concrete (booster)	Functional	Biraro
9	1000	concrete	Functional	Michael 2

10	75	sandwich	Functional	Mitikolo 1
11	200	concrete	Functional	Mitikolo 2
Total	**4225m^3**			Excluding boosters

Source: Kombolcha Water Supply office

3.4.3 Existing distribution network

Most of the distribution systems are old and cover few parts of the subsystem, and hence have low efficiency to deliver water to the beneficial communities. The distribution pipes of Kombolcha subsystem covers areas between altitudes ranging from 1500m to 2300 masl and the system is supplied by pumping boreholes directly to distribution system within the subsystem.

Table 3-3 : Existing distribution system

No	Length (m)	Pipe diameter (mm)	Pipe type
1	2681	25	Galvanized iron
2	14284	32	HDPE pipe
3	3422	40	HDPE pipe
4	803	40	Galvanized iron
5	1739	50	Upvc pipe
6	938	50	HDPE pipe
7	10104	50	Galvanized iron
8	27645	63	HDPE pipe
9	1423	65	Galvanized iron
10	4207	80	Upvc pipe
11	6749	80	Galvanized iron
12	346	90	HDPE pipe
13	6958	110	HDPE pipe
14	2518	100	Upvc pipe
15	8917	160	HDPE pipe
16	781	150	Upvc pipe
17	617	200	Ductile iron pipe
18	110	200	Upvc pipe

19	1847	280	HDPE pipe
20	427	250	Ductile iron pipe
21	96	315	HDPE pipe

Source: Kombolcha Water Supply office

3.4.4 Current Status of the system

The current status of Kombolcha town water supply system was evaluated by field observations, discussions with relevant staff and users. As a result, the following gaps were identified.

- Shortage of potable water as the present demand of the community increase however capacity of the existing water supply is below the demand.
- There are areas which are not getting water.
- Water loss in significant amount is the main issues because of leakage.
- There is no design document of existing system.
- The quality of water is not checked frequently because of unavailability of chemicals and instruments to conduct measurements and analysis.
- Limited source capacity.
- Lack of skilled manpower & poor management.

3.5 Research Design

In this research cross-sectional study was used as a research design. To examine different water quality parameters samples were collected from the field and both in-situ as well as laboratory analysis was done as primary data. Data was collected from different sources such as research paper, journal, internet and book as a secondary source of data. Therefore, this research was carried out on the bases of primary and secondary data.

The cross-sectional study design on which based on a one time sampling was performed during the assessment of the physical, chemical and bacteriological characteristics of the drinking water in order to check the water quality at different places and to determine the drinking water quality compliance with the WHO and national drinking water guidelines. Water quality assessments at the water source, reservoirs, distributions and household taps was analyzed. Moreover, sanitary survey checklists were used to assess the sanitary status of water supply facilities.

3.6 Sample Size

The selection of the sampling points was grouped into two major classes or regions which include boreholes, reservoirs and main distribution lines. The other class is consists of households. In the first class, the source of water is groundwater and there are eight functional boreholes in the town all of which were used for sampling. All functional reservoirs (six in number) were selected for sampling. Moreover, all the six main distribution lines were used for this study. Therefore a total of 20 samples were selected.

In the second class, sampling calculation was made to determine the representative household sample numbers as presented below.

In Kombolcha town there are 19,400 household which are connected with the water supply system. The sampling methodology determined by (Cochran, 1977) was used to select households for each source. The sample size determined the expected rate of occurrence as not less than 90% at 95% confidence level as

$$n(i) = \frac{NZ^2PQ}{W^{2(N-1)} + Z^2PQ}$$

Where

n = sample size of Households

N=Total number of household heads

Z=Confidence level (at 95% level z=1.96)

P= proportion 50% (0.5, this maximizes the sample size)

W= error limits of 5% (0.05)

Q=1-P

$$n(i) = \frac{19{,}400 * 1.96^2 * 0.5 * 0.5}{0.05^{2(19{,}400-1)} + 1.96^2 * 0.5 * 0.5}$$

$$n(i) = 377$$

From the above calculation the number of household sample was very high. In addition, most of the households have the same life status. Therefore, use of random sampling technique was adopted to select the sample points needed for the study due to household`s similarity in life status, the sparsely distributed population, financial problems, lack of infrastructure (logistic) and time.

For this study twenty five household were selected. The town was categorized in to five region and each region was consists of five household sampling points.

3.7 Sampling Point Selection and Location

Samples were taken from locations that are representative of the water source, treatment plant, storage facilities, distribution network, points at which water is delivered to the consumer, and points of use. In selecting sampling points, each locality was considered individually. Sampling points were selected based on the criteria that the samples taken are representative of the different sources and points of distributions. The source of drinking water to Kombolcha town comes from boreholes. Therefore, these water sources were chosen. The raw water from these sources was transferred to reservoirs then chlorine addition takes place before the water enters into the main distribution system. In this study main distribution line was included in sampling point. In addition to the above selected components households were chosen as sampling points.

To determine the physical, chemical and bacteriological quality of drinking water a total of 20 samples were used from source, reservoirs and main distribution lines and the figure below shows the location of these sampling points.

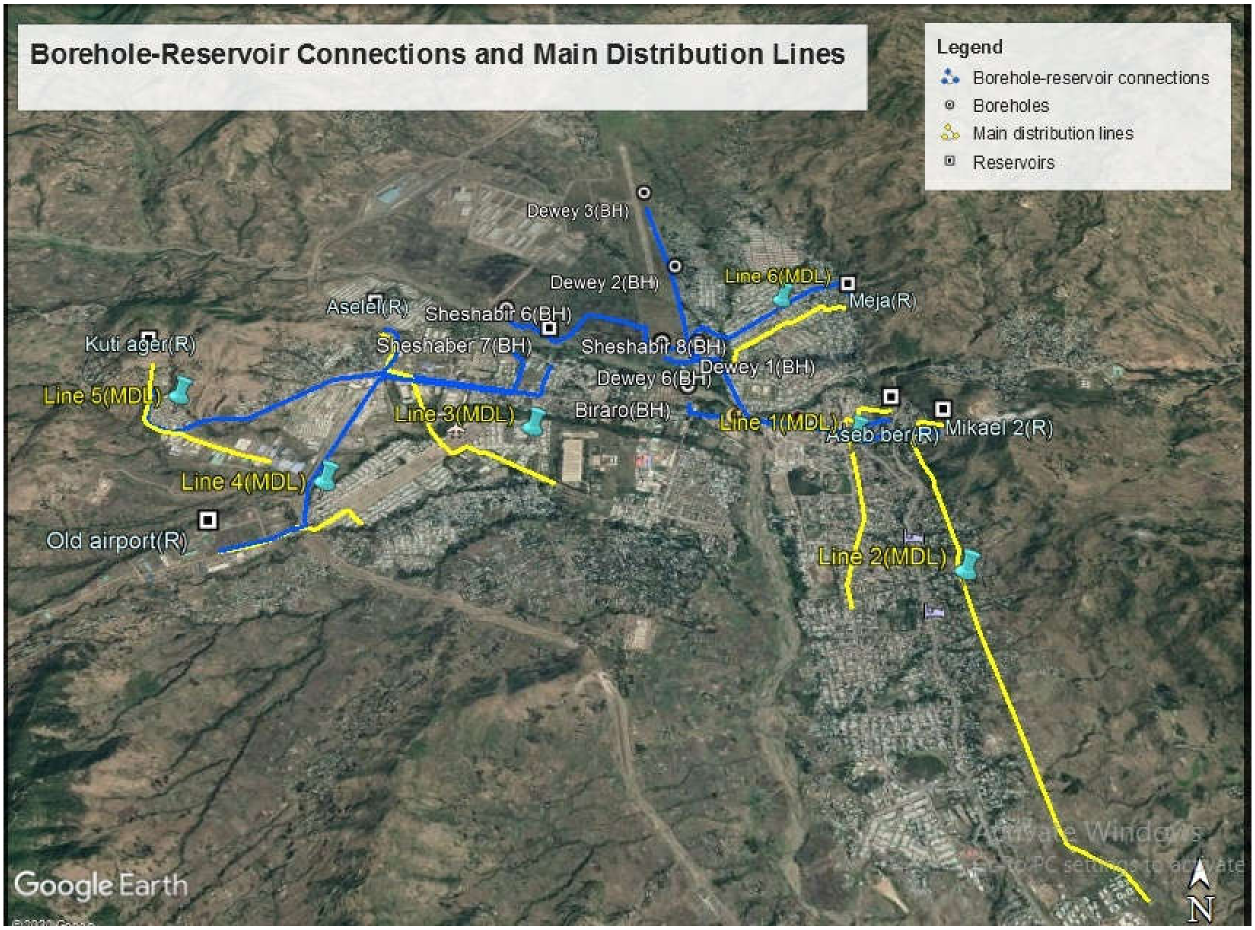

Figure 3-3: Sampling points for boreholes, reservoirs and main distribution lines

Similarly, twenty five household sampling points were selected. The town was categorized in to five region and each region was consists of five household sampling points.

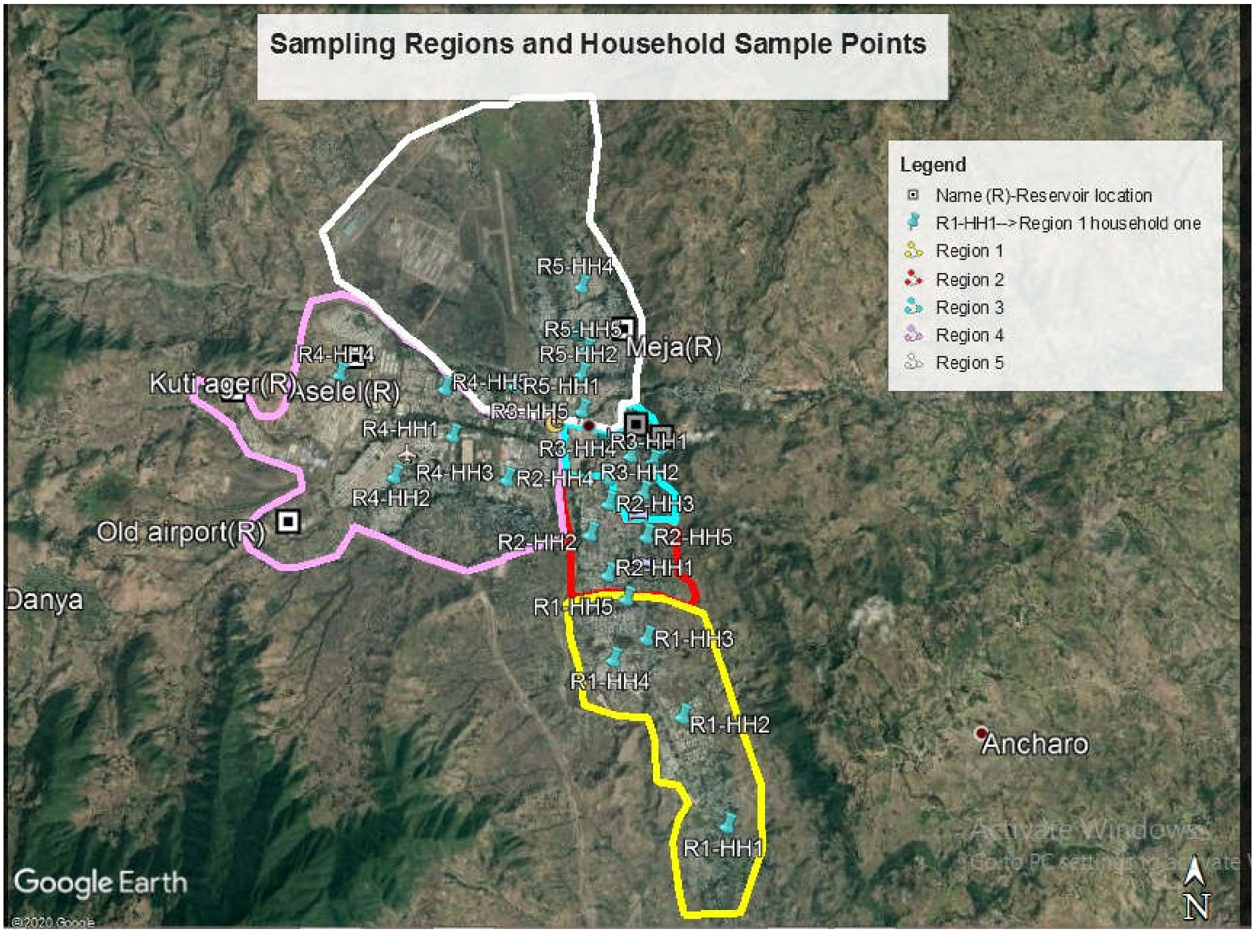

Figure 3-4: Sampling points for households

3.7.1 Sampling Techniques

During this study various methods of data collection are used. Samples were collected during the dry season in order to avoid the effect of dilution from rainfall. On site water quality measurement was conducted beside sample collection for laboratory analysis. Samples were collected at each selected site by using separate bottles for microbial and chemical parameters. To avoid contamination during and after sampling and transportation maximum care has been taken such as the bottles were rinsed three times with running water and then filled to the top. Sampling took place directly at the tap or the faucet of borehole and reservoirs and samples were transported under optimized condition, for the chemical and microbial analysis.

The raw groundwater was collected from the tap that pumps the groundwater directly at the borehole site after letting the water to flow for 10 minutes and sterilizing the tip of the tap by using a lighter. Similarly, reservoir samples were collected directly from the storage inside through the access ladders for those without tap while others were from faucets. The other samples were collected from taps, after sterilization of the tip of the tap by using a lighter and letting the water to flow for about 10 minutes. Acid washed and rinsed 500-ml High-Density Polyethylene (HDPE) bottles were used for sampling of physico-chemical parameters. For microbial analysis sterilized glass containers with a capacity of 250 ml were used. At the site of sampling labelling of each sample was done. Subsequently samples were taken to the laboratory placed in an ice box which contains ice cubes within a maximum of 5 hours of sampling.

3.8 Water Quality Analysis of Samples

Water quality assessment requires Physico-chemical and microbiological analysis as well as adequate selection of quality parameters. Water quality assessment is not only relevant for the analyzed parameters but also to the sampling method, storage during transport and prior to the analysis (WHO, 2011). Physico-chemical and bacteriological tests were carried out based on the standard methods for testing of water quality.

3.8.1 Physical analysis of samples

Analysis of the physicochemical parameters of the water samples such as pH, Temperature, electrical conductivity, total dissolved solids (TDS), Turbidity were conducted onsite because some water quality variables change with time. Onsite determination of water quality was conducted for physical parameters using calibrated digital portable water analyzer kits Wagtech HANNA Instruments (pH meter, EC meter and turbidity meter). For each parameter three measurements were taken onsite and the average was reported. Water samples were collected randomly in properly washed and rinsed appropriate sampling bottles.

Temperature: temperature was measured using thermometer. Measurement was conducted as soon as the sample was collected to avoid errors that could be introduced due to temporal variation. Temperature was measured in °C.

pH: the measurement of pH was done using the Wagtech HANNA pH meter instrument.

Electrical conductivity: Wagtech HANNA EC meter was used to measure the electric conductivity in situ. The electric conductivity values were expressed in μS/cm.

Total dissolved solids: TDS readings were also undertaken using Wagtech HANNA EC meter. The level of total dissolved solids was presented in part per million units.

Turbidity: Wagtech HANNA turbidity meter instrument was used to determine the turbidity level of water samples. Turbidity was measured in Nephelometric Turbidity Units (NTU).

3.8.2 Chemical analysis of samples

The chemical and bacteriological analyses were conducted at Dessie water supply and sewerage service. Chemical water quality parameters (iron, manganese, nitrate, free chlorine residue and total hardness,) were conducted in laboratory. Samples were collected at each site where samples for chemical parameters were taken in bottles and transported to the laboratory.

Iron: the presence of iron in the water samples was determined using photometric Palintest method. The Palintest Iron test is performed on the basis of a single reagent with a reducing agent in an acid buffer. The test was carried out by adding a reagent to the water sample under consideration. The reducing agent is used to breakdown forms of iron that have weak complexity, and helps to change the ferric iron form to the ferrous form in the process (https://www.palintest.com). Then, ferrous iron reacts with the reagent to form a pink color. In this regard, the concentration of iron in the sample is proportional to the intensity of the color produced during this test. Therefore, Palintest Photometer was used to measure the pink color concentration.

Manganese: Palintest method was used to determine manganese concentration in water involving two stages. In the first case of this method manganese in lower valence state, through the use of oxidizing agent, was oxidized to form permanganate. In the second case the permanganate formed proceeds further reaction with leucomalachite green resulting in an intense turquoise colored complex (https://www.palintest.com). Here, the total manganese concentration is directly proportional to the color intensity resulted from the experiment. The color concentration of samples was determined by the use of Palintest Photometer.

Nitrate: the nitrate concentration was determined using cadmium reduction method. In this method, nitrate in the sample is reduced almost quantitatively to nitrite when it is run through a column containing cadmium filings loosely coated with metallic copper. The nitrite produced is then allowed to react with thus sulphanilamide in acidic solution resulting in a colored dye solution to be measured spectrophotometrically (Cowan et al., 1978).

Free chlorine residue: free chlorine residue was determined using the Palintest chlorine test by DPD method. In this case, pink color is produced from the reaction of residual chlorine and diethyl-p-phenylene diamine (DPD) in buffered solution (Cowan et al., 1978). The concentration of free chlorine had direct relation with the intensity of the color produced in the experiment. These color intensity was measured using Palintest Photometer.

Total hardness: photometric palintest test method is used to determine the total hardness in water samples. Here, the Palintest test is based on a unique colorimetric method (https://www.palintest.com). The test was carried out simply by adding the appropriate reagents to the water samples. Purple color was produced from the reaction of calcium with hardicol indicator under controlled environment. This color production intensity is directly proportional to the total hardness of the water samples. Therefore, the color intensity was measured by Palintest Photometer.

3.8.3 Microbial analysis of samples

Water samples were collected in pre-sterilized glass bottle and transported in a cold box containing ice freezer packs. Membrane filtration technique was carried out total coliform and fecal coliform counts. To avoid the growth or death of microorganisms in the sample the bacteriological testes were undertaken within 5 hours after collection (WHO, 2006). The filters were examined for 24 hours to assess bacterial growth.

Total coliforms: Samples were collected in a sterile glass bottle. Membrane filtration technique (Cowan et al., 1978) was used to assess the presence of total coliform. Each sample was filtered through a sterile 0.45µ millipores filter. In this case, the filter is placed on a sterile pad saturated with liquid media. Then after, the filter was incubated at 35ºC for 24hours counting the typical coliform colonies which show a pink to dark red color was performed.

Fecal coliforms: in this membrane filtration technique (Cowan et al., 1978), collected samples were filtered through a 0.45µ millipores filter. The filter is cultured on an M-FC saturated pad for 24hours at 44 °C. After culturing the filter, colonies of fecal coliforms showing blue color were counted.

3.9 Sanitary Inspection

At each site sanitary inspection which involved the use of checklist depending on the individual state of the selected sites. Sanitary inspection was conducted during a household interview regarding the covering of water storage vessels, water container volume washing frequency of container.

To assess the sanitary condition of selected water sources and piped tap observation checklist was used. The following items were included in the checklist: the situation of the outlet and overflow pipe the drainage system, the physical status of protection box and the general sanitation of the borehole and reservoirs areas. WHO standard for boreholes with mechanized pump and piped tap evaluation checklist which has a score of the risk out of ten (9-10=very high risk, 6 8=high risk, 3-5= intermediate risk, and 0-3=low risk) was used to categorize them accordingly. The checklists used are appended in Appendix E.

3.10 Data Analysis

The quality of drinking water and the water pollution status were evaluated according to the standards suggested by WHO guidelines (WHO, 2017) in order to analyze the number of samples that did not comply with the guideline values. On the basis of results, Samples were analyzed both onsite and laboratory analysis. The main physical parameters tested on site include pH, temperature, electrical conductivity, total dissolved solids (TDS) and turbidity. On the other hand, chemical water quality parameters analyzed in the laboratory were total hardness, nitrate, free chlorine residue, manganese and iron. Moreover, the presence of microbial parameters of total and feacal coliforms was assessed in the laboratory.

The sampling points assessed were water sources, reservoirs, main distributions and household taps. Water quality data from the onsite and laboratory as well as data gathered from the sanitary inspection checklists from the different sampling points were recorded in a spreadsheet on Microsoft excel for each sampling site.

Finally the water quality data obtained were compared with the WHO and Ethiopian guidelines values. In order to disseminate the results, tabular and graphical representations were used to display the results.

While presenting the results in graphical forms, abbreviation forms were used in order to reduce the space utilized by the sample names for each corresponding sampling points. The abbreviations used and the full forms of sample names are presented in Appendix A.

3.11 Quality Control

For quality control purposes, standard calibration curves have also prepared with each batch analysis of the samples using instruments. Data collection was made by trained data collectors. Both onsite and laboratory analysis were performed by skilled personnel.

3.12 Variables

Dependent variable of this study is water quality. Independent variables include distance of drinking water from the household, water handling practices and water management practices.

4 RESULT AND DISCUSSIONS

4.1 Physical Water Quality

During field survey the following physical parameters were investigated onsite. The physical water quality parameters analyzed onsite were pH, turbidity, temperature, electrical conductivity (EC) and total dissolved solids (TDS).

4.1.1 Temperature

The water temperature of Kombolcha town ranges between 22.5°C and 26.1°C. This showed that the temperature of the water was above the WHO recommended value (<15 °C). Nationally, there is no guideline value for temperature. The high temperature value in the water sample might be due to climatic condition of the area. This high temperature in the water source would speed up the growth rate of mesophilic bacteria and this in turn increase the rates of bacterial decay of disinfection residual chlorine, corrosion rates, taste, odor and color problems.

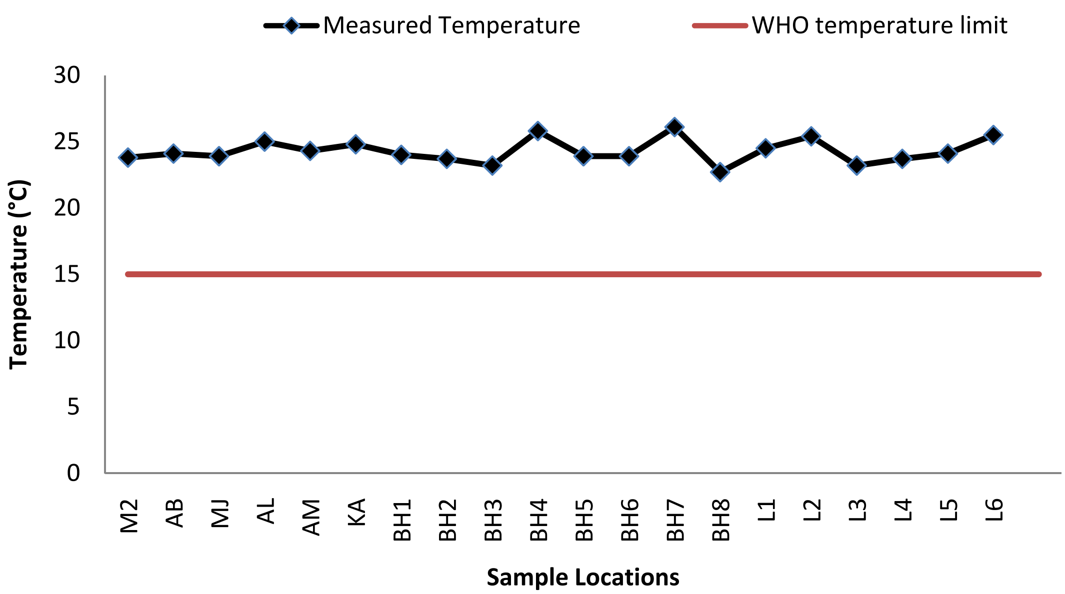

Figure 4-1: Temperature values of boreholes, reservoirs and main distribution lines

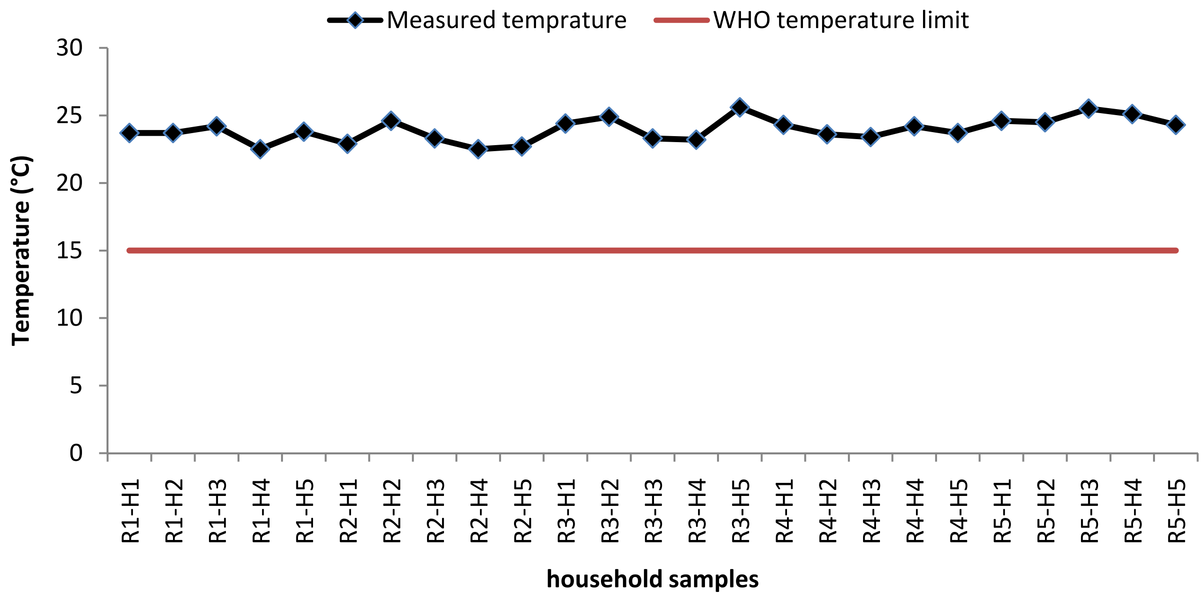

Figure 4-2: Temperature values of household samples

The issue of temperature is not a real health concern here. Similar type of study conducted in Adama town showed that the temperature value in the water samples were also above the WHO permissible limits. The high temperature in Adama was due to the warm climate condition in the area. Adama is found in the rift valley (Temesgen & Hameed, 2015).

4.1.2 Turbidity

The turbidity values found in this study ranges from 0.01-2.4 NTU. This finding showed that the turbidity levels of all water samples were within the permissible limit of both WHO and National guideline of less than 5NTU. Almost all boreholes have turbidity value less than 1NTU which meets minimum recommended value. Often groundwater has very low and zero turbidity. Three samples of reservoirs were unfit for minimum preferable less than 1NTU (which are 1.21NTU, 2.31NTU & 1.44NTU at Mikael 2, Aseb ber and Aselel) respectively. For distribution line all water samples except line 2 have the value less than 1NTU. The slight increment of turbidity observed in region 3 of household samples was due to leakage through pipes.

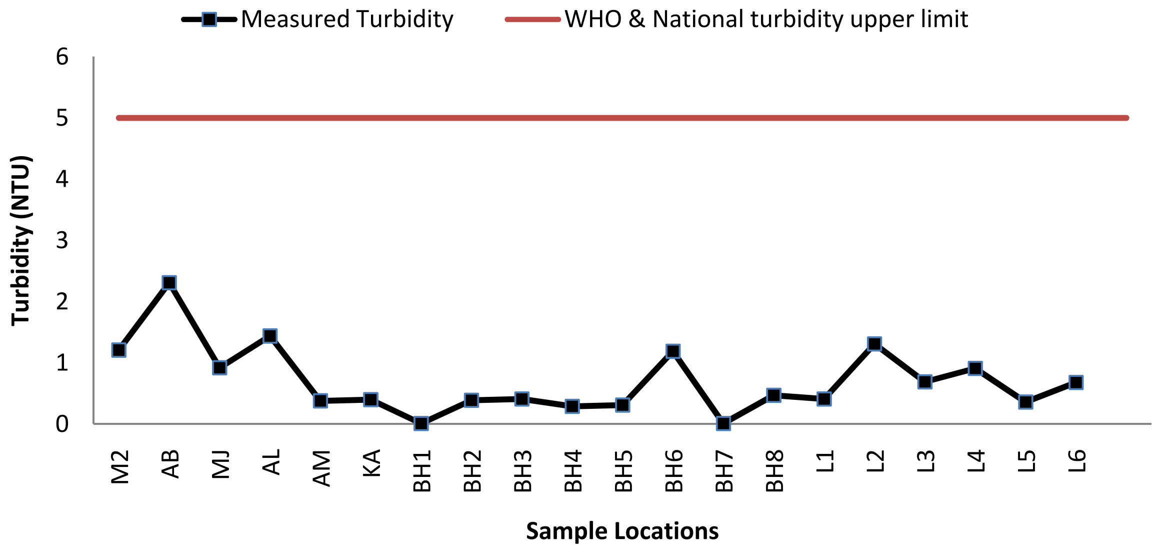

Figure 4-3: The turbidity values of the water in the boreholes, reservoirs and main distribution lines

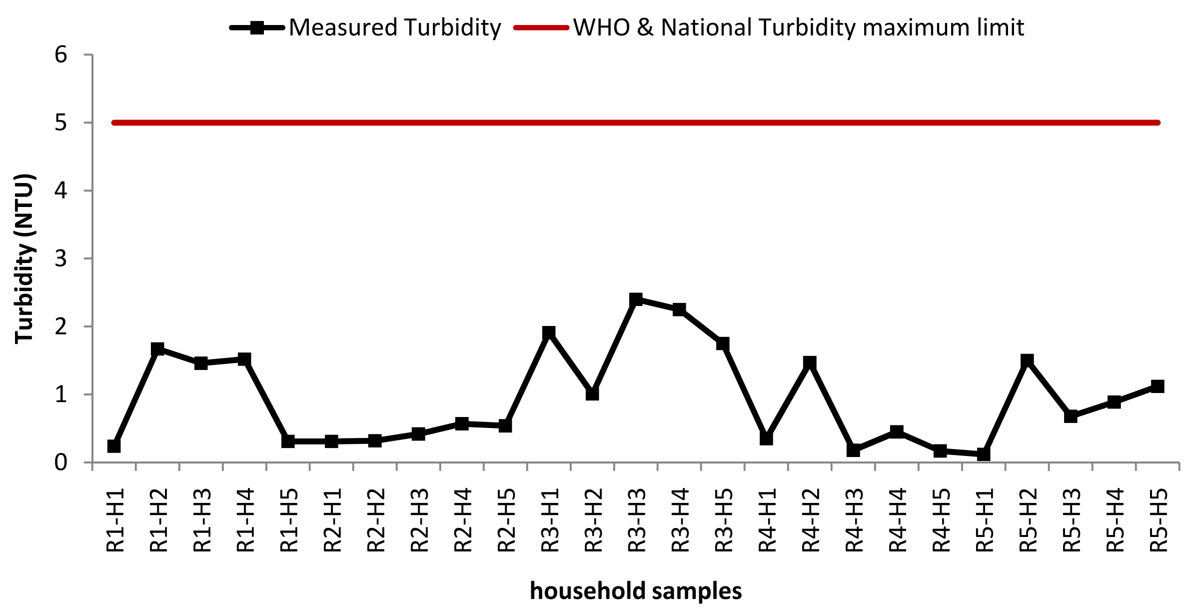

Figure 4-4: The variation of turbidity values in the water samples collected from households

Turbidity is a very critical and widely used water quality physical parameter that can provide the most important data throughout out the water treatment process. According to WHO (2017) maximum allowable permissible turbidity value must be lower than 1NTU for drinking water. The recommended value for water to be disinfected should be less than 5NTU and preferably have a median value of less than 1NTU.

The above finding was consistent with the study reported in Welkite Town (Dessalew & Yonas, 2018).

4.1.3 Electrical conductivity

The EC values recorded during this study were between 447µS/cm and 737µS/cm. The result shows that all the water samples fall within the WHO permissible limit for drinking water. The maximum limit of EC for drinking is 1200 µS/cm. Even though all water samples are within the limit the ionic concentrations of boreholes have distinctly high EC value. This is because of the fact that groundwater has higher ionic concentration than surface waters due to rock-water interactions.

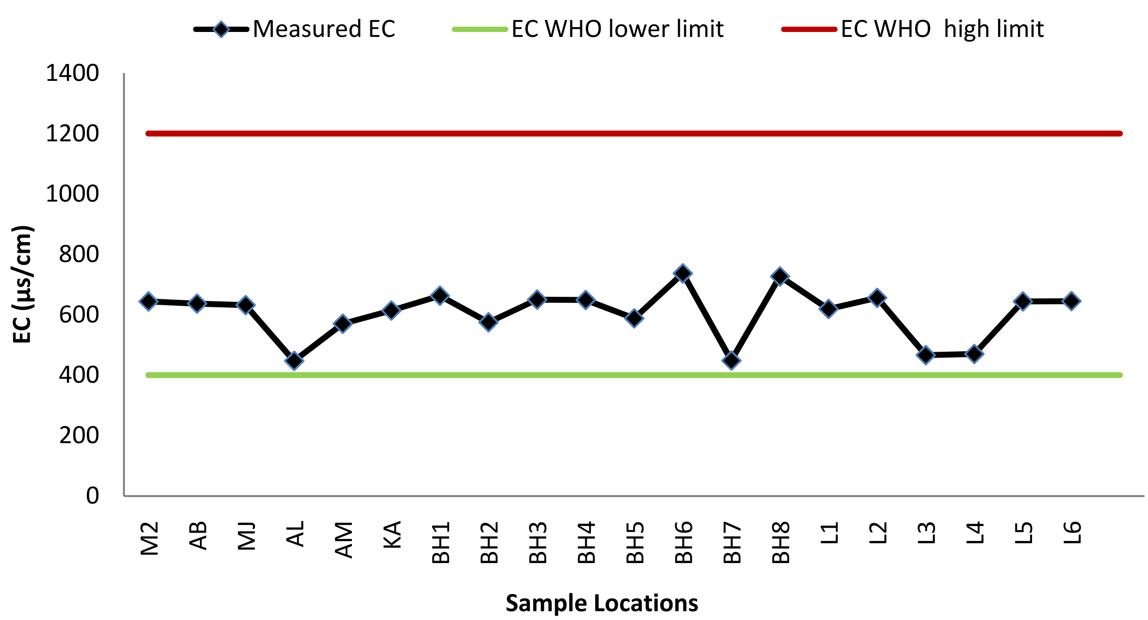

Figure 4-5: Electric conductivity values of boreholes, reservoirs and main distribution lines

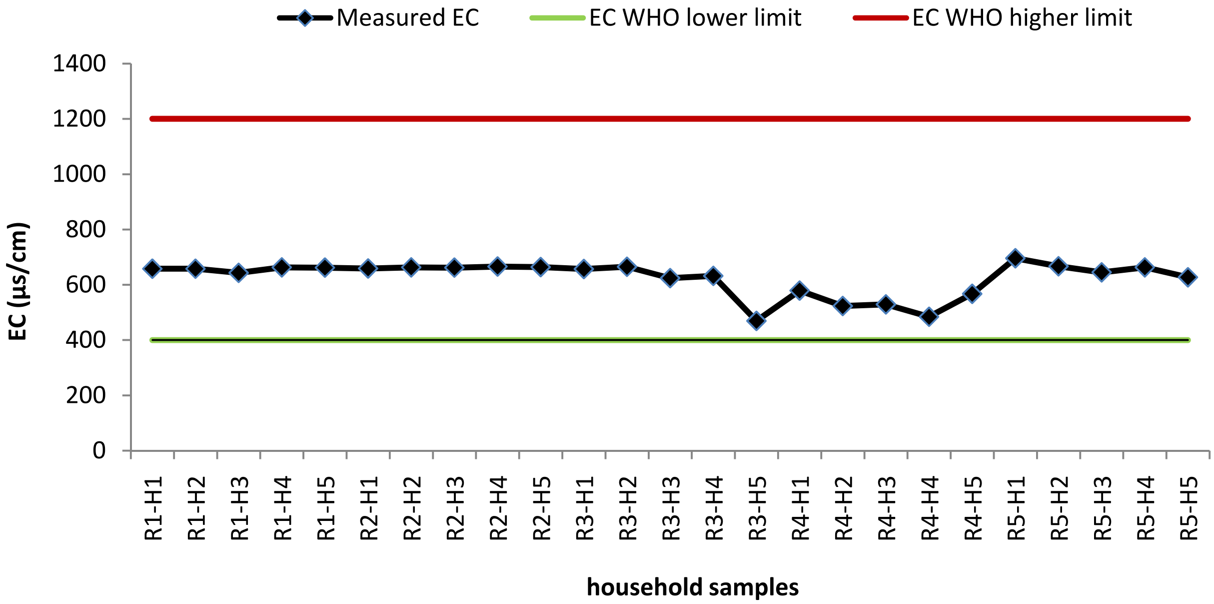

Figure 4-6: Electric conductivity values of household samples

The EC results of other sampling points of reservoir, main distribution line and households show relatively higher EC. Similar taste were reported in the study conducted in Agaro town ground water source was the highest in EC (Tadesse et al., 2017).

4.1.4 Total dissolved solids

The TDS values found in this study ranges from 223 -369 ppm. Depending on these values it is clear that the health risks are not significant as the values of TDS are much less than 1000 ppm, which is the WHO and National standard maximum permissible limit. In similar study, the findings of the research work which was done in WondoGenet showed that the TDS levels of all source water samples were compliant with both WHO and National Guide line (Israel & Awdenegest, 2012).

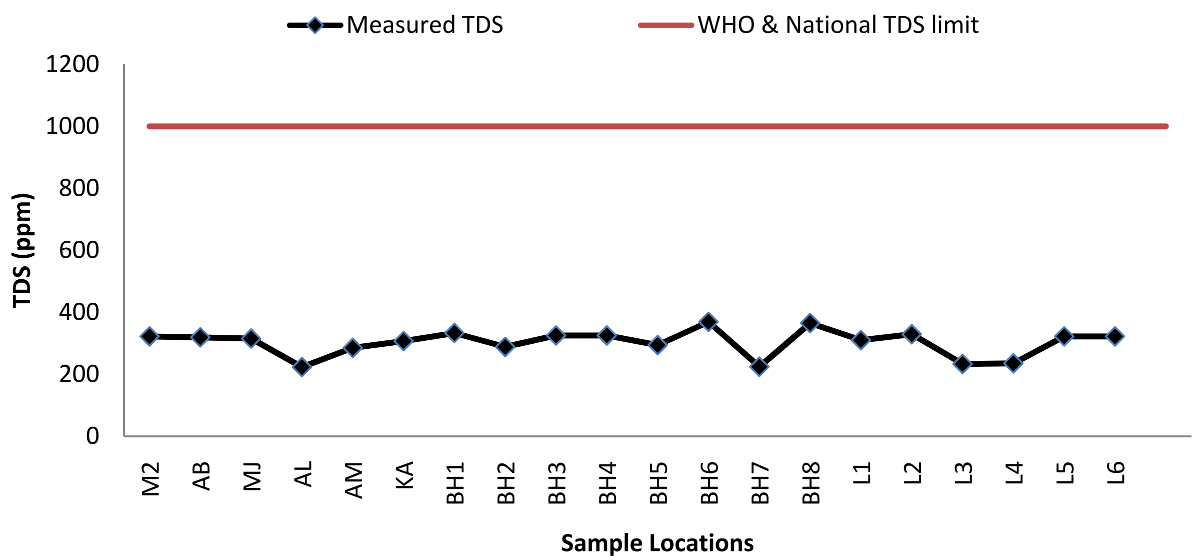

Figure 4-7: TDS values of boreholes, reservoirs and main distribution lines

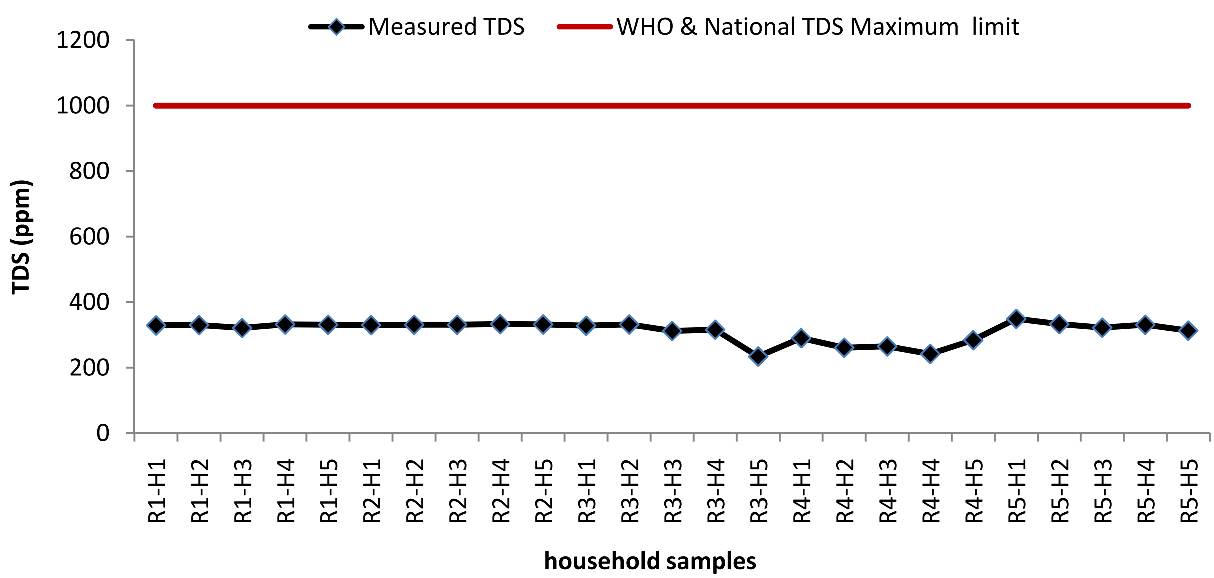

Figure 4-8: TDS values of samples taken from households

4.2 Chemical Water Quality

Chemical water quality parameters analyzed in the laboratory were total hardness, nitrate, free chlorine residue, manganese and iron.

4.2.1 pH

During onsite measurement of pH the values were between 6.5-7.4 which indicates pH value of all tested samples was found to be within the acceptable range of WHO and national guidelines for drinking (6.5-8.5).

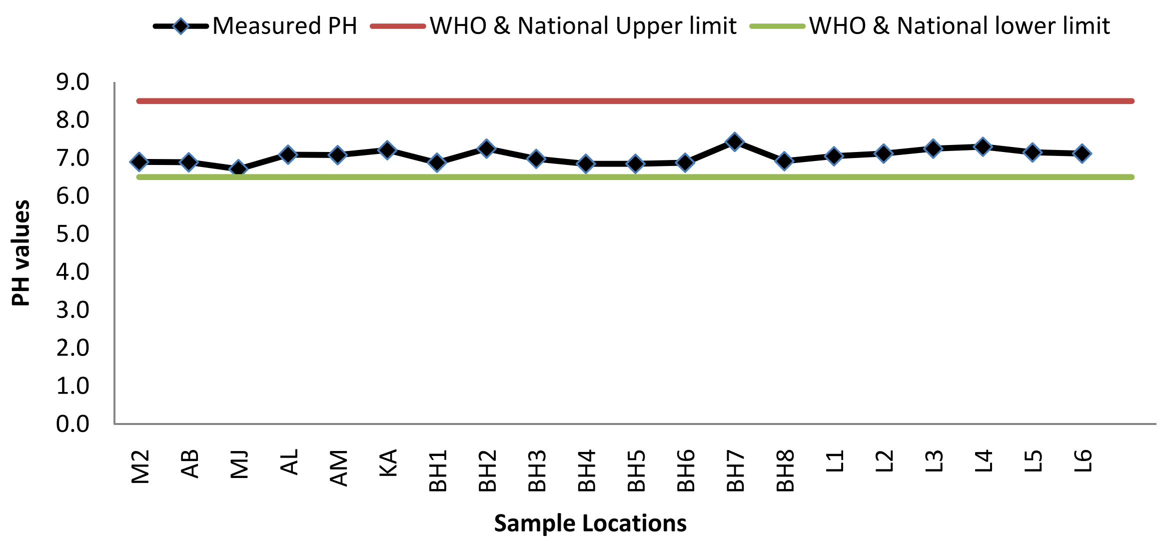

Figure 4-9: pH values of samples taken from boreholes, reservoirs and main distribution lines

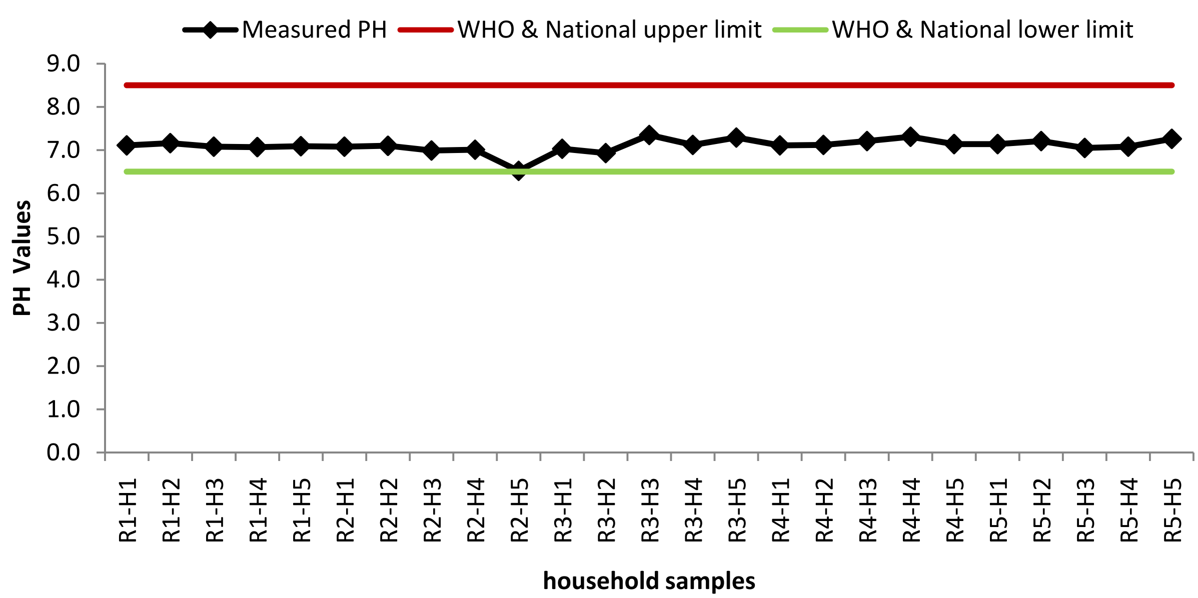

Figure 4-10: pH values of samples taken from households

According to WHO guidelines the pH values more than 8 are not suitable for effective disinfection with chlorine while values less than 6.5 enhance corrosion in water pipes and household plumbing systems. There is no health risks related to consuming slightly acidic or basic water. Study done in Southwest Ethiopia showed similar results (Tadesse et al., 2017).

4.2.2 Total hardness

The total hardness of study area ranges between 295.3 -536 mg/l which is categorized as very hard water. According to WHO and national guide line 300 mg/l is maximum limit for total hardness. The highest value result showed in the connection of borehole Sheshabir 6 to Meja reservoir and to line 6 which have the values of 476, 536 and 531mg/l respectively. Some of the household samples (i.e. samples in region one) have higher hardness values because they receive water from lines which have high value of hardness. Accordingly, the households in region one receives water from line one and two and these two main transmission lines are connected to Mikael 2 and Aseb ber reservoirs which have higher values of total hardness.

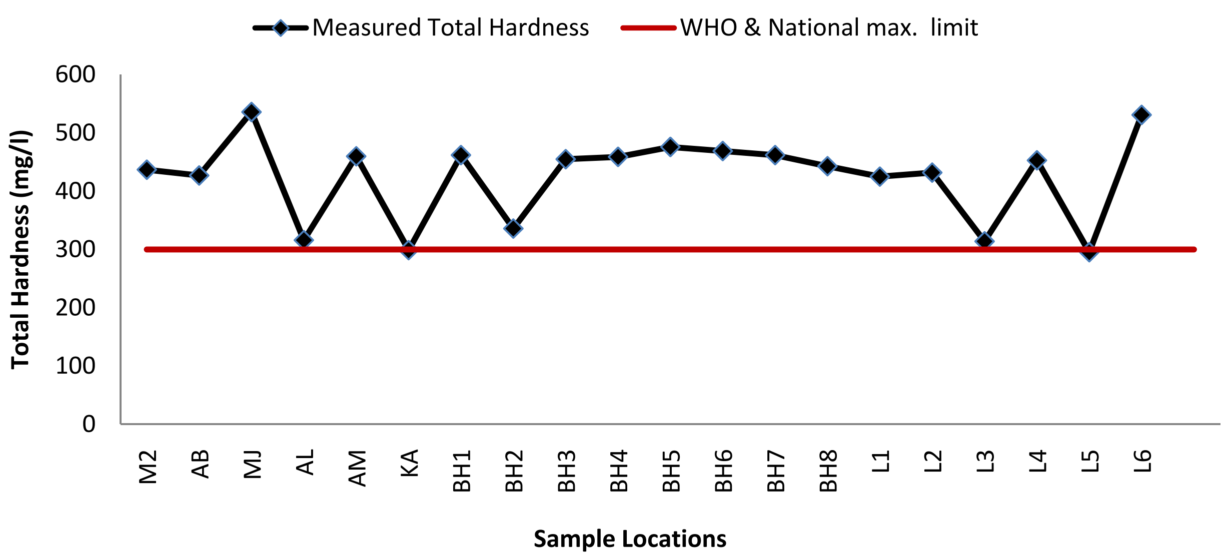

Figure 4-11: Total hardness values of boreholes, reservoirs and main distribution lines

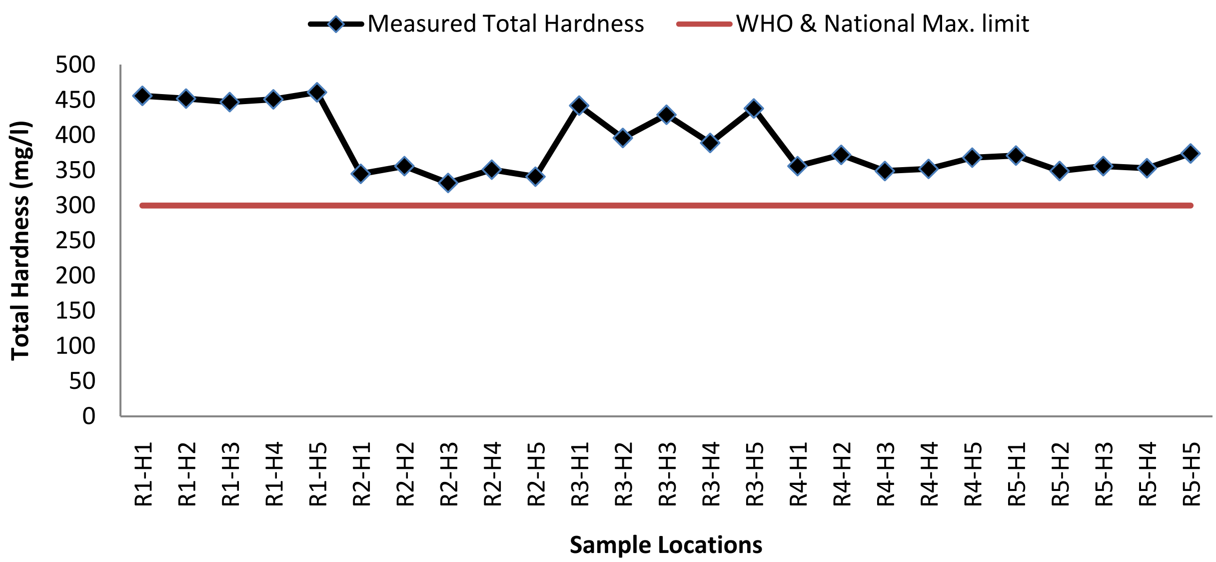

Figure 4-12: The variation of total hardness values among household samples

As the sources of Kombolcha town water supply is ground water it is expected that it may have high concentration of calcium and magnesium ions due to abundance of calcium and magnesium in groundwater because of the dissolving of limestone and also can be released when water reacts with gypsum. Hard water causes no health problems (UNICEF, 2008). However it is a problem due to interference with soaps and detergents and leaves a white crusty scale around faucets and utensils. Therefore, total hardness should be removed by different mechanisms. In the contrary, similar study conducted in Gimbi town showed that the degrees of hardness of sampling points were categorized as soft and moderately soft water (Gurmessa, 2015).

4.2.3 Free chlorine residual

Based on the laboratory results free chlorine residual ranges between 0.01 and 0.94. The World Health Organization guidance level for drinking water supply recommends a minimum free Chlorine residual of 0.2mg/l at household levels and minimum residual chlorine 0.5mg/l on the other sampling points. The national guideline also requires minimum residual chlorine of 0.5mg/l. When residual chlorine levels drop below recommendations, several water quality problems can occur. In Kombolcha town water supply system as the source is ground water the disinfection method is addition of chlorine in reservoir within three days of interval. However, this result shows that the study area was experiencing high loss of chlorine in the system.

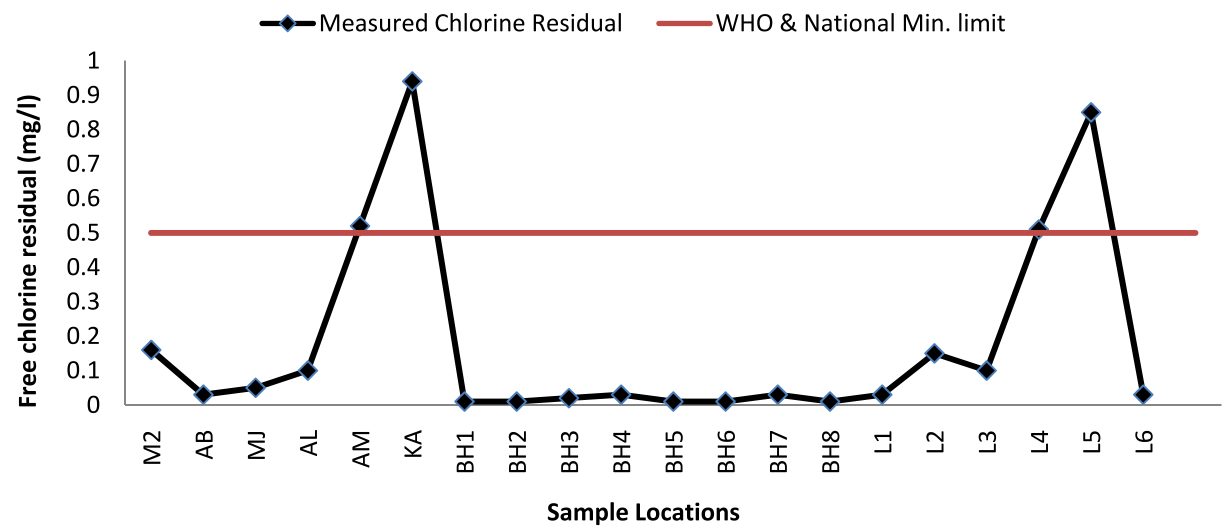

Figure 4-13: Chlorine residual values of samples collected from boreholes, reservoirs and main distribution lines

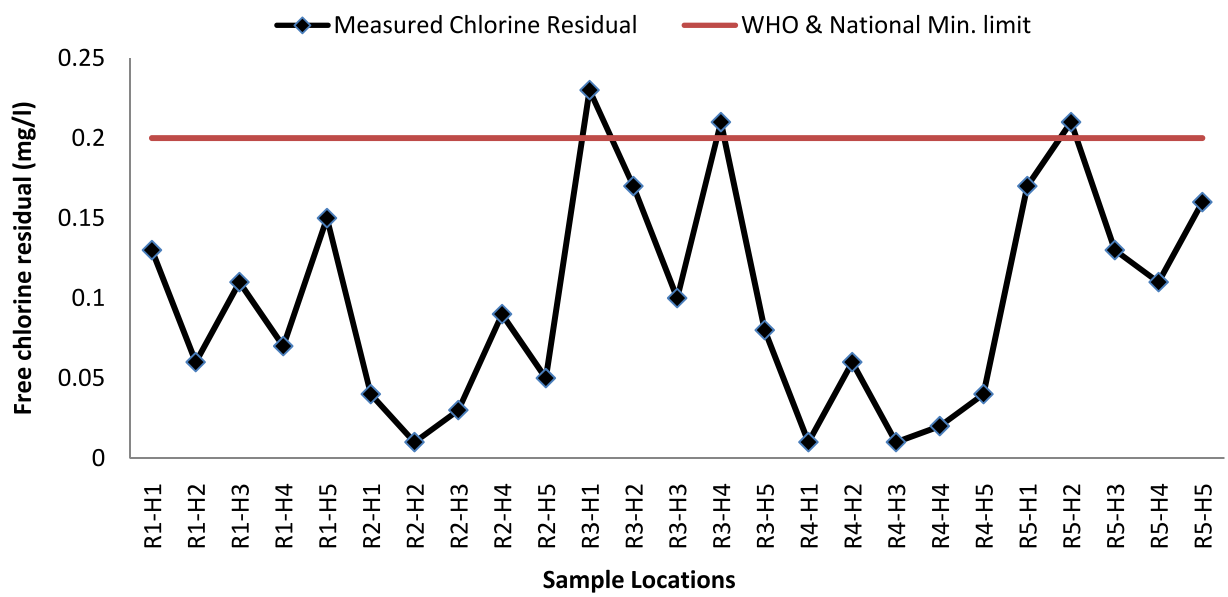

Figure 4-14: Chlorine residual values for samples collected from households

Free chlorine residual measured in this study showed a decreasing trend as we go far from reservoirs where chlorine addition takes place. But a high value of free chlorine residue on two sample from reservoirs of Ayer marefya (Jelma) and kuti ager was observed. This was later found that it was due to the addition of chlorine by the KWSSSO laboratory experts before samples were taken for this study. Some of the reasons for decreasing of free chlorine residue throughout the distribution system could be result of pipe breaks or construction intrusion since they are usually followed by line disinfection which consumes the free chlorine residual and decreases it. The other reason is the decay of chlorine residual within the system as it is added in three day interval. Decay might be naturally as a result of reaction of chlorine with materials in or on the pipe wall that can be due to the pipe material itself or the presence of biofilm, or sediment at the pipe itself depending on the physical characteristics of pipes within the distribution system (age, construction material, diameters, encrustation, etc.). Almost all household water from piped sources had low residual chlorine and it may be the reason for total coliform contamination. In contrast, according to similar study done in Jimma and Metu the value of residual chlorine was found within the recommended limits (Tadesse et al., 2017).

4.2.4 Manganese

The values of manganese for the study area range between 0.001-0.034mg/l. According to WHO guidelines the maximum permissible limit of manganese concentration in drinking water quality should not exceed 0.4mg/l. Ethiopian national guide lines set the maximum limit of 0.5mg/l. The result showed that the values are within maximum permissible limit. Similarly, in a study in WondoGenet area showed that manganese values were within the limit (Israel & Awdenegest, 2012).

Table 4-1: Manganese values of samples collected from boreholes, reservoirs and main distribution lines

S. No.	Type	Name	Manganese (mg/l)	WHO limit	National limit
1	Reservoirs	Mikael 2	0.002	0.4 mg/l	0.5 mg/l
2		Aseb ber	0.014		
3		Meja	0.013		
4		Aselel	0.003		
5		Ayer marefya (Jelma)	0.016		
6		kuti ager	0.015		
7	Boreholes	Dewey 1	0.031		
8		Dewey 2	0.027		
9		Dewey 3	0.033		
10		Dewey 6	0.022		
11		Sheshabir 6	0.024		
12		Sheshabir 7	0.031		
13		Sheshabir 8	0.034		
14		Biraro	0.002		
15	Main distribution Lines	Line 1	0.010		
16		Line 2	0.002		
17		Line 3	0.003		
18		Line 4	0.013		
19		Line 5	0.013		
20		Line 6	0.011		

Table 4-2: Manganese values of samples collected from households

S. No.	Type	Name	Manganese (mg/l)	WHO limit	National limit
1	Households	R1-HH1	0.017	0.4 mg/l	0.5 mg/l
2		R1-HH2	0.013		
3		R1-HH3	0.012		
4		R1-HH4	0.018		
5		R1-HH5	0.017		
6		R2-HH1	0.004		
7		R2-HH2	0.002		
8		R2-HH3	0.002		
9		R2-HH4	0.001		
10		R2-HH5	0.007		
11		R3-HH1	0.015		
12		R3-HH2	0.008		
13		R3-HH3	0.023		
14		R3-HH4	0.014		
15		R3-HH5	0.016		
16		R4-HH1	0.016		
17		R4-HH2	0.021		
18		R4-HH3	0.011		
19		R4-HH4	0.020		
20		R4-HH5	0.015		
21		R5-HH1	0.022		
22		R5-HH2	0.018		
23		R5-HH3	0.017		
24		R5-HH4	0.021		
25		R5-HH5	0.014		

4.2.5 Iron

The laboratory results of the study area ranges between 0-0.07 mg/l. WHO and national guidelines for drinking water quality recommended that the iron levels should be kept below 0.3 mg/l. It clearly indicates the values were within the permissible limit value. However, similar study conducted in Nekemte showed that iron values of the water did not meet the standards (Gonfa et al., 2019).

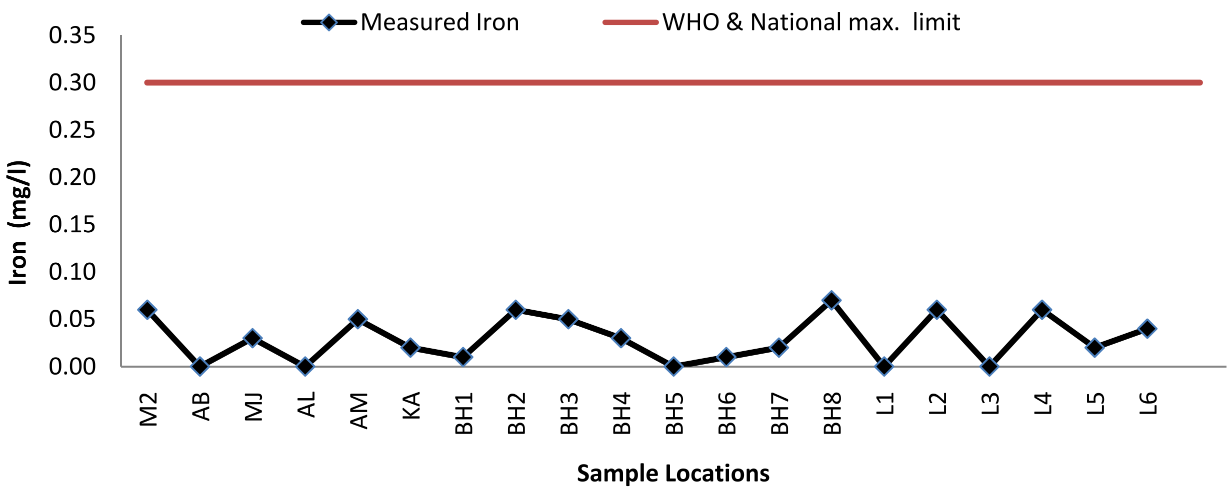

Figure 4-15: Iron values of samples collected from boreholes, reservoirs and main distribution lines

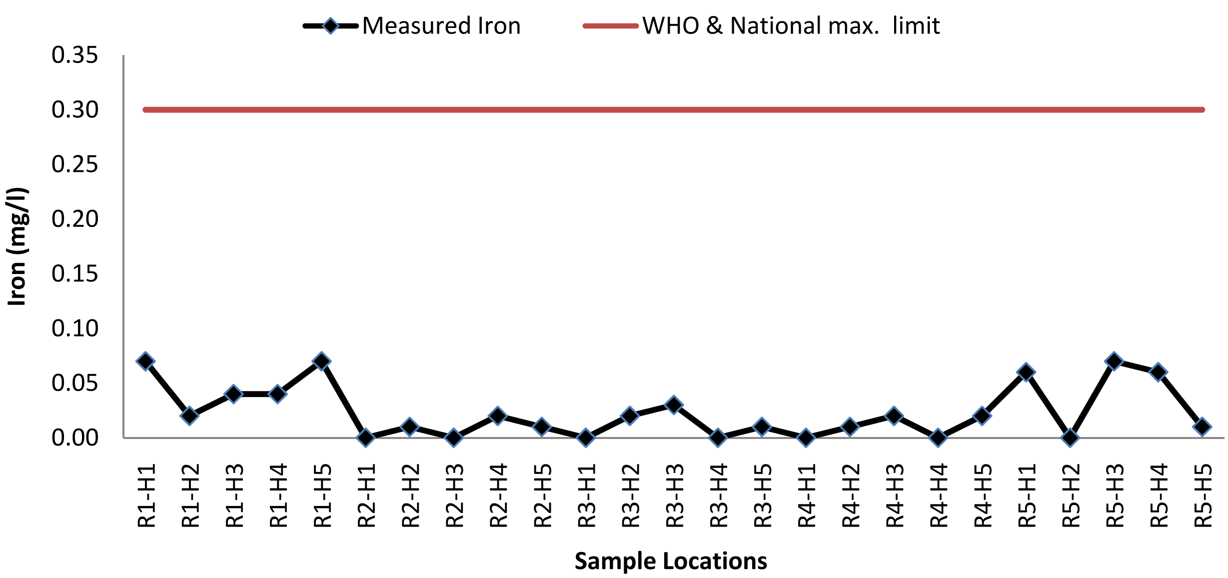

Figure 4-16: The variation of Iron values for household samples

4.2.6 Nitrate

In this study the values for nitrate varies in a wide range between 2.9 and 43.6 mg/l. Maximum value for nitrate is 50 mg/l as set by both WHO and Ethiopian standard for drinking water specifications. The highest is in the borehole Dewey 3 and the lowest in region 3 household 5.

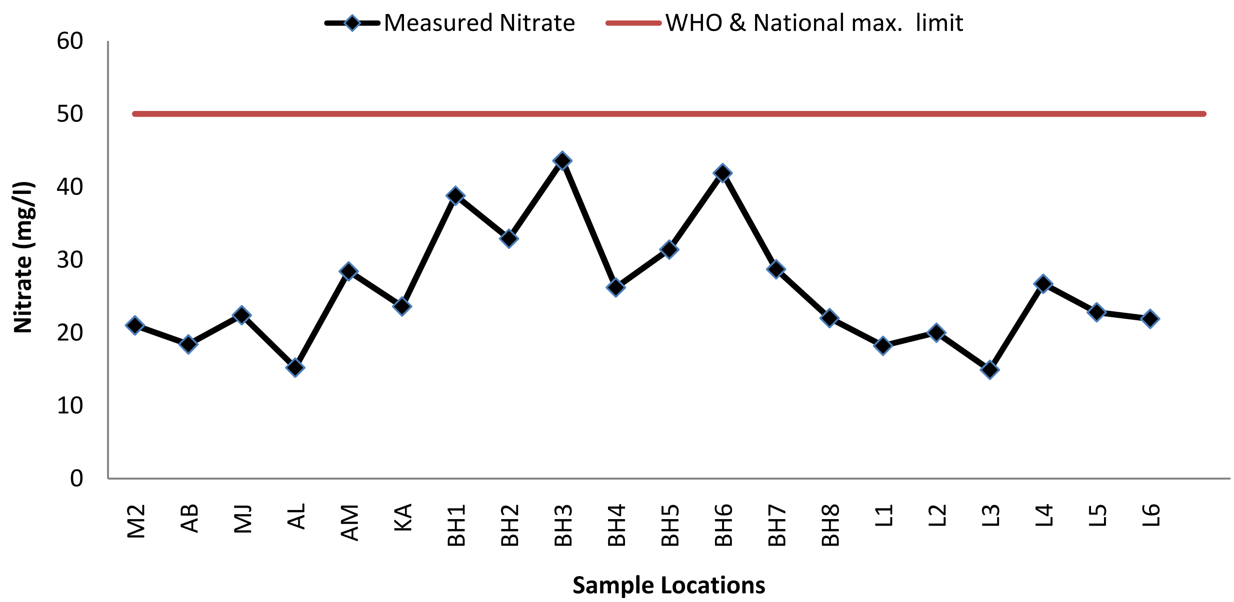

Figure 4-17: Nitrate values of boreholes, reservoirs and main distribution lines

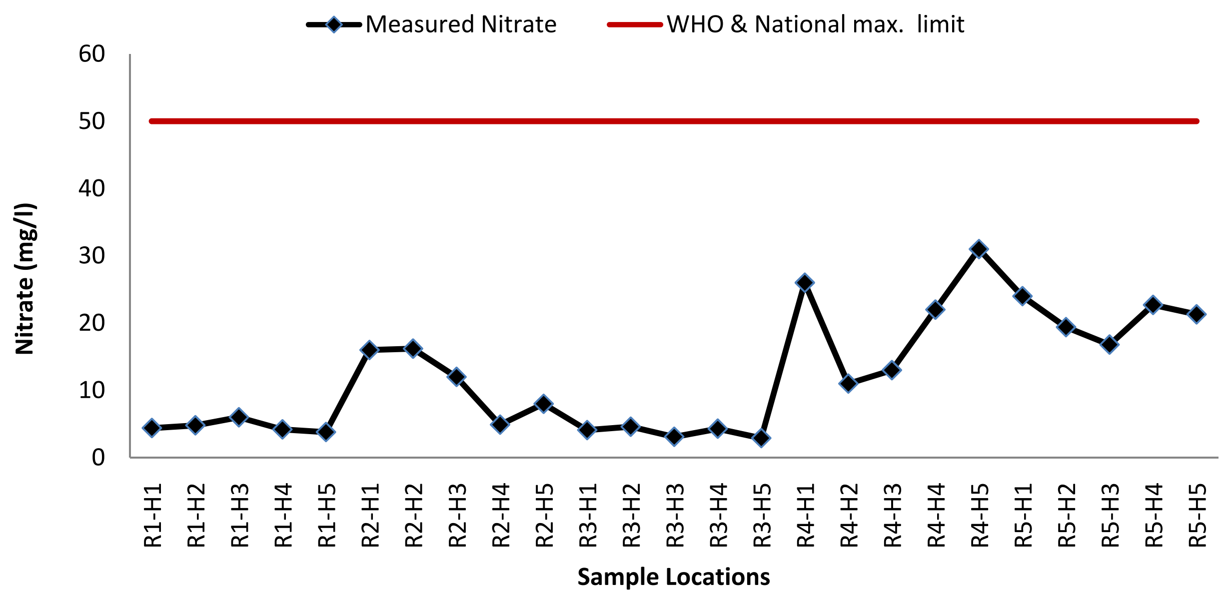

Figure 4-18: Nitrate values of household samples

The result clearly indicates that the nitrate values in the boreholes had higher value. Boreholes are sited in agriculture land due to the infiltration of fertilizer used for agriculture might be the reason for higher value of nitrate. The results show in both cases the values of nitrate concentration is below the values of WHO and Ethiopia guideline recommended values.

Similarly, in Adama town the nitrate values were within the permissible limit of both WHO and Ethiopian standard (Temesgen & Hameed, 2015).

4.3 Microbial Water Quality

For fecal coliform the test result shows zero value in which there is no feacal coliform contamination from water at source to a point of use. But total coliform test results shows that boreholes Dewey 2 and Dewey 3 contained 1CFU/100ml of total coliform and Sheshabir 6 and Biraro boreholes contained 2CFU/100ml and 4CFU/100ml of total coliform respectively. For microbial parameters guidelines WHO (2017) and National (2013) for drinking water recommend zero total coliforms and faecal Coli CFU /100 ml of water at source and point of use. Total coliform presence at source level could be the result of poor construction well with a cracked apron. The absence of total coliform on the water samples of reservoirs sites is an indication for the presence of enough residual chlorine in the reservoir.

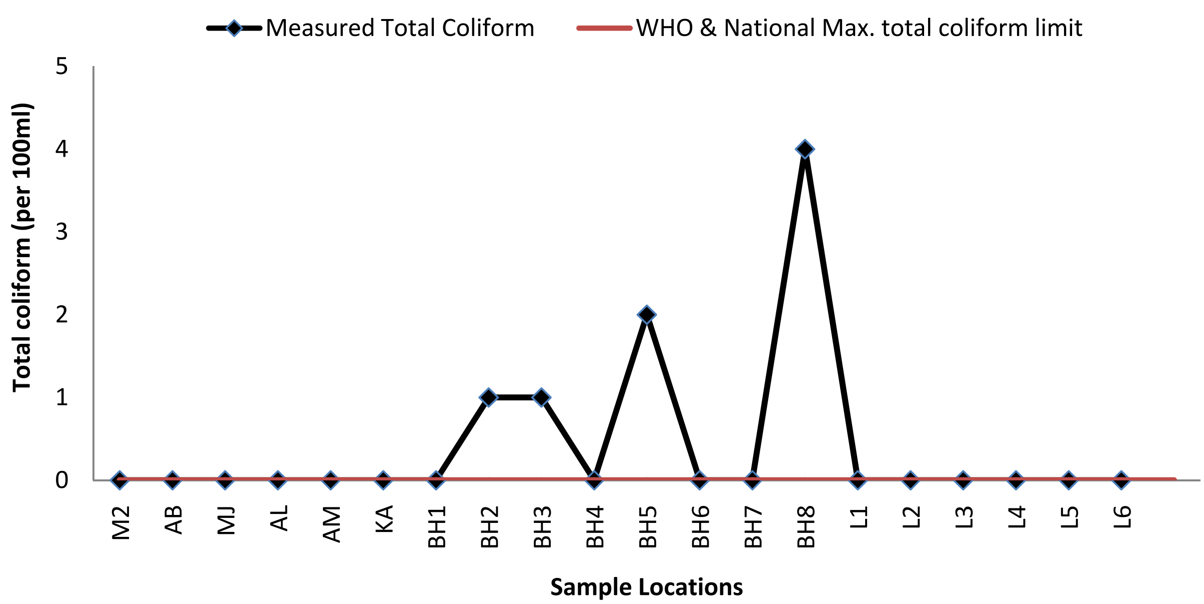

Figure 4-19: Total coliform values of boreholes, reservoirs and main distribution lines

The test result for household samples indicated that five households contained 1CFU/100ml of total coliform. The reason for this has been the leakage from old pipelines which pave the way for intrusion of contaminants and also there was no or very low residual chlorine at household level. According to similar study in Jimma town, the result of FC indicates that there was no contamination however the values for TC were above the standard limit (Tadesse et al., 2017).

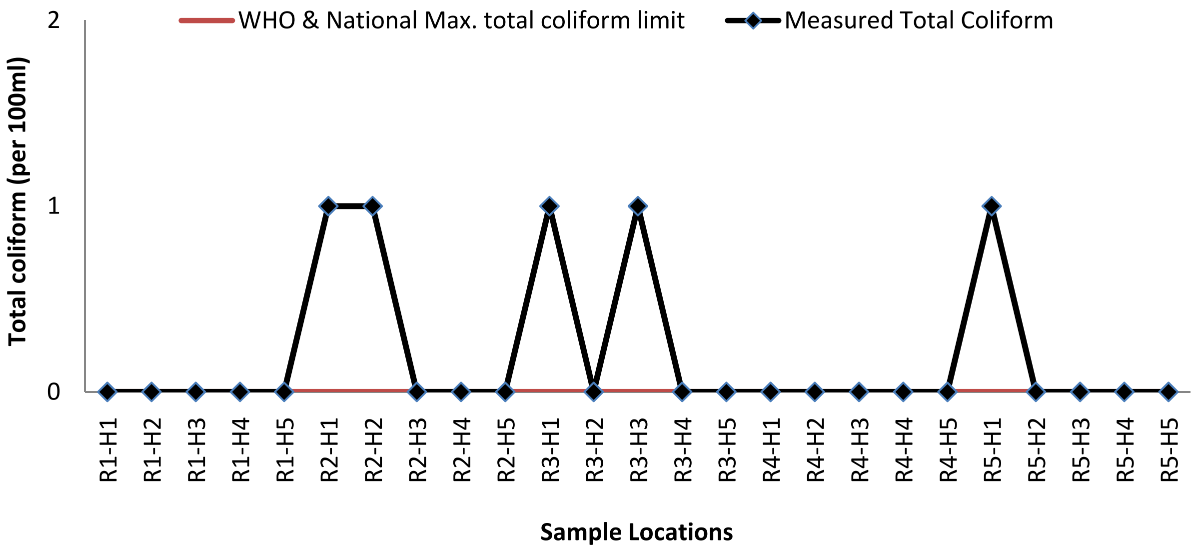

Figure 4-20: Total coliform values for samples taken from households

4.4 Sanitary Status of Drinking Water Facilities

A sanitary risk score was computed as qualitative risk category (low, medium, high and very high risks) for each water sources, reservoirs, households by putting the number of positive factors as a range (0 – 2, 3 – 5, 6 – 8 and 9 – 10) of the total number of factors being assessed.

4.4.1 Sanitary status of boreholes

According to the observation during the data collection, the sanitary assessment of the borehole area was assessed. The boreholes are constructed around same area. An observation check-list was prepared to evaluate the sanitary conditions of selected water sources in the study area. WHO prepared a standard borehole evaluation checklist which has a score of the risk out of ten (9-10=very high risk, 6-8=high risk, 3-5= intermediate risk, and 0-2=low risk). Accordingly, the study revealed that; Dewey 6, Sheshabir 8, Dewey 1, Dewey 2 and Sheshabir 6 were found to have low risk. Dewey 3 and Sheshabir 7 have scored medium level risk value. However, Biraro borehole has high sanitary risk level due to the presence of source of pollution within 50m distance, faulty drainage in the pump house, presence of nearest latrine within 100 m distance, and unsewered latrine near the borehole site.

Generally the most significant defects observed were inadequate protection, lack of fencing, and poor drainage system, presence of nearest latrine within 100 m distance and unsewered latrine near the borehole site. Depending on the results found from sanitary inspection at boreholes the presence of total coliform indicators can be correlated with the sanitary risks such as lack of sanitation in water source area, inadequate water source maintenance and poor quality of construction.

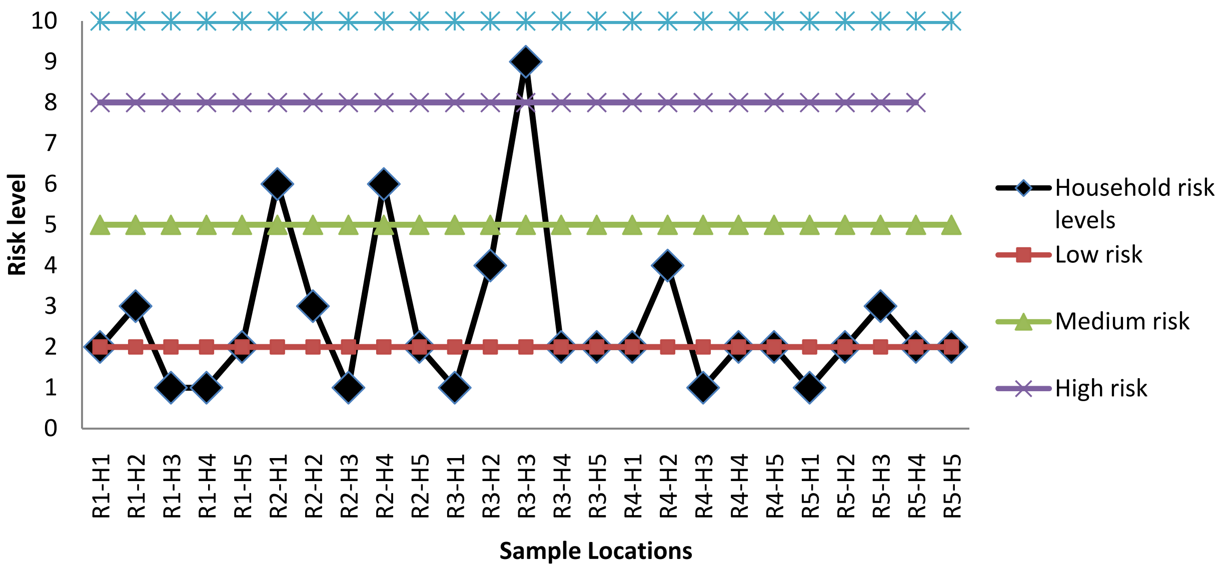

Figure 4-21: Risk assessment score classes at sources

4.4.2 Sanitary status of household piped water

The sanitary conditions of household taps were evaluated. Observation check-list was prepared in order to check the selected household taps during sanitary assessment. WHO prepared a standard evaluation checklist for piped tap which has a score of the risk out of ten (9-10=very high risk, 6-8=high risk, 3-5= intermediate risk, and 0-2=low risk). Out of the total twenty five households 17 households have low risk level. This finding showed that five households scored medium risk level as the results of leakage in the pipe, eroded tap and service discontinuity. However R2HH1and R2HH4 has high risk level. Moreover, R3HH3 was identified as very high risk level. Sample points with medium and high risk level were due to the leakage at tap stands, collection of surface water around taps, presence of erosion at tap stand, discontinuity of water service and pipe breaks. The association between the water quality and sanitary inspection results at households suggested that there is interconnection between pipe leakage, loss of free residual chlorine and total coliform contamination at households.

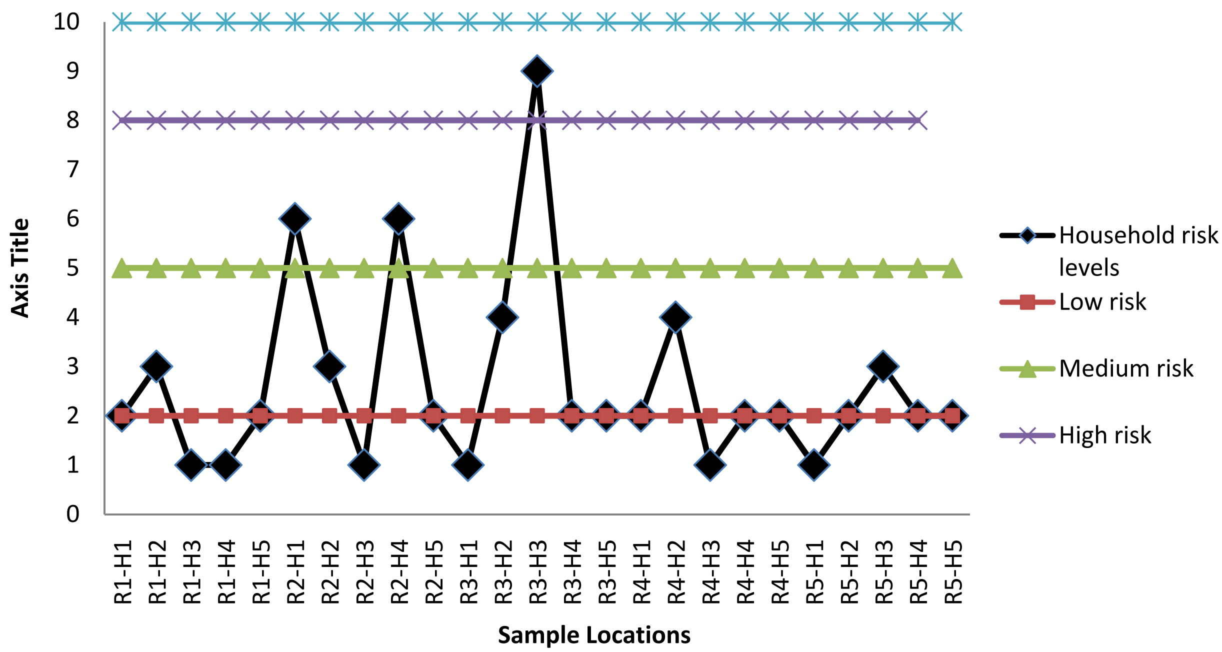

Figure 4-22: Risk assessment score classes at households

4.4.3 Water handling practices

The storage container type and washing frequency among the households has been assessed for the selected twenty five households. The type of container materials used in the households includes Jerrycan, Plastic bucket and plastic bottles. According to the observation 84% of the total household stored drinking water in separate container. However, the inspection showed that the containers were not properly placed above floor level. On the other hand, all the containers of households had cover either its own or modified cover. It was observed that 72% of the containers had narrow mouth opening as a result the water is taken by pouring which reduces the risk of contamination by avoiding contact. The remaining households which used other utensils material to draw water from the containers keep the utensils in hygienic manner.

Table 4-3: Water handling practices related to storage and usage by households

No.	Household (n=25)		Risk frequency in (%)	Risk frequency in (%)
1	Is drinking water kept in a separate container?		21	84
2	Is drinking water container kept above floor level and away from contamination		7	28
3	Do water containers have a narrow mouth/opening?		18	72
4	Do containers have a lid/cover?		25	100
5	How is water taken from the container? (Poured, cup ,other utensil)	poured	18	72
		cup	5	20
		other utensils	2	8
6	Is the utensil used to draw water from the container clean?		22	88
7	Is the utensil used to draw water the container kept away from surfaces and stored in a hygienic manner?		19	76
8	How often the container is cleaned? Every day, Every week, Every Month, Rarely ,Never	every day	5	20
		every week	15	60
		every month	3	12
		rarely	2	8
		never	0	0
9	Is the inside of the drinking water container clean?		20	80
10	Is the outside of drinking water container clean?		16	64

The storage container washing frequency among the households has been assessed and it was found that only 5 (20%) households wash containers every day before refilling while others used to wash every week, every month and rarely are 15(60%) , 3 (12%) and 2 (8%) respectively. It clearly indicates that the containers were not washed frequently which might lead to contamination of drinking water.

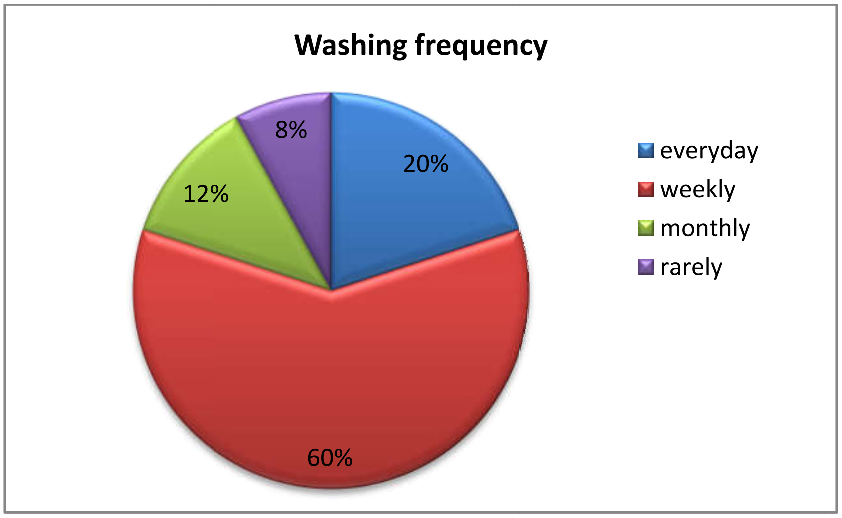

Figure 4-23: Washing frequency of containers at households

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main physical parameters tested on site include pH, temperature, electrical conductivity, total dissolved solids (TDS) and turbidity. Except temperature the measured parameters are within the permissible limit of the WHO and national guidelines. The result from chemical parameter tests showed that the values for iron, manganese and nitrate samples were within the permissible limit of the WHO and national guidelines. But, the total hardness was above the guidelines limit value of 300mg/l. The result for chlorine residual indicates that only seven samples were according to the guideline minimum requirement, while others were below the permissible limit which might be the result of low amount and less frequency of chlorine addition.

The permissible limits of WHO and national guidelines with regard to microbiological results of fecal coliform were met for all selected samples. However, total coliform for certain samples were found to be above zero which might be caused by pollution from nearby unsewered latrines, inadequate treatment and possible regrowth or biofilm formation in the distribution system and less chlorine residue in the system.

Generally, the analysis of the Physico-chemical parameters indicated the water is safe with no significant effect on the health of the users. Nevertheless, the results of bacteriological analyses have shown that some of the sample points are at risk. In this regard, further research that involves a wide-scale, intensive and regular data collection, and analysis is necessary to arrive at precise and ultimate conclusions to evaluate the degree of risk associated with the presence of total coliforms

5.2 Recommendations

To improve the current water quality problems of Kombolcha Town water supply system, this research helped to put following appropriate recommendations in order to maintain the existing quality of water. The most important ones are the following:

- Town municipality office must implement urban drainage system and sewer line in order to protect boreholes and reservoirs.
- Kombolcha Water Supply and Sewerage Service office should establish regular monitoring and inspection of boreholes, reservoirs and the whole distribution system in terms assuring good water quality management
- The office should establish laboratory and instruments to conduct measurements and analysis.
- The present work was done on few Physico-chemical and biological parameters only based on one time sampling. The temporal variations are not addressed well therefore, sampling and monitoring at different times is essential and analysis of additional water quality parameters should be undertaken.
- Fencing of borehole and reservoir sites should be done as the fences are too old and damaged.
- As much as possible the oldest galvanized pipe iron should be replaced by either PVC pipes or HDPE pipes.
- Leakage points through distribution line must be identified and fixed as it may introduce pollutants to the treated water.
- Proper disinfection ways must be practiced to avoid total coliform presence.
- Further research on the presence of thermo-tolerant bacteria should be done as the area experiences high temperature.
- To maintain the necessary residual chlorine in the distribution system, sufficient chlorination has to be practiced and specific identification of source of chlorine decay should be known. Thus further study could be done in this respect.

6 REFERENCES

ADF. (2005). *Ethiopia rural water supply and sanitation programme appraisal report*. TUNIS, TUNISIA. Retrieved from https://www.afdb.org/

Alhassan, H., & Kwakwa, P. (2014). When water is scarce: The perception of water quality and effects on the vulnerable. *Journal of Water, Sanitation and Hygiene for Development*, *4*, 43. https://doi.org/10.2166/washdev.2013.140

Alley, E. R. (2000). *Water Quality Control Handbook* (Second edi). New York, USA: McGraw-Hill. Retrieved from https://books.google.com.et/books?id=6SNSAAAAMAAJ

CDC. (n.d.). *Chlorine Residual Testing Fact Sheet, CDC SWS Project*. Retrieved from https://www.cdc.gov/safewater/chlorine-residual-testing.html

Cochran, W. G. (1977). *Sampling techniques* (Third edit). New York, USA: Wiley. Retrieved from https://www.wiley.com/en-et/Sampling+Techniques,+3rd+Edition-p-9780471162407

Cowan, P., Porcella, D., Adams, V., & Gardner, L. (1978). *Water Quality Analysis Laboratory Procedures Syllabus*. *Reports*. Retrieved from https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1519&context=water_rep

CSA. (2011). Ethiopia demographic and health survey preliminary report, Addis Ababa, Ethiopia.

CSA. (2017). *Drinking Water Quality in Ethiopia. Results from the 2016 Ethiopia Socioeconomic Survey*. Retrieved from https://washdata.org/sites/default/files/documents/reports/2018-07/Drinking-water-quality-ethiopia-ESS-2016.pdf

Dessalew, B., & Yonas, S. (2018). Evaluation of bacteriological and physicochemical quality of water supply systems in Welkite Town , Southwest-Ethiopia. *International Journal of Water Resources and Environmental Engineering*, *10*(2), 17–23. https://doi.org/10.5897/IJWREE2017.0761

Edberg, S., Rice, E., Karlin, R., & Allen, M. (2000). Escherichia coli: the best biological drinking water indicator for public health protection. *Journal of Applied Microbiology*, *88*, 106S-116S. https://doi.org/10.1111/j.1365-2672.2000.tb05338.x

EPA. (2001). *Parameters of water quality Interpretation and Standards*. *Environmental Protection agency*. Wexford, Ireland. https://doi.org/10.1017/CBO9781107415324.004

ESA. (2013). Compulsory Ethiopian Standard. Drinking Water Specifications,CES 58. Addis ababa, Ethiopia: Ethiopian Standards Agency. Retrieved from https://www.humanitarianresponse.info/sites/www.humanitarianresponse.info/files/documents/files/drinking_water_specifications.pdf

Fewtrell, L., Prüss-Ustün, A., Bos, R., & Bartram, J. (2007). *Water, Sanitation and Hygiene: Quantifying the Health Impact at National and Local Levels in Countries with Incomplete Water Supply and Sanitation Coverage* (Environmen). Geneva, Switzerland: World Health Organization.

Garoma, B., Kenesa, G., & Jida, M. (2018). Drinking Water Quality Test of Shambu Town (Ethiopia) from Source to Household Taps Using Some Physico-chemical and Biological Parameters. *Journal of Ecology and Environmental Sciences*, *6*(4).

Gonfa, D., Fassil, A., & Mulissa, J. (2019). Assessment of Bacteriological and Physicochemical Quality of Drinking Water from Source to Household Tap Connection in Nekemte, Oromia, Ethiopia. *Journal of Environmental and Public Health*, *2019*, 1–7. https://doi.org/10.1155/2019/2129792

Guptaa, D. P., Sunita, & Saharan, J. P. (2009). Physiochemical Analysis of Ground Water of Selected

Area of Kaithal City (Haryana) India. *Researcher*, *1*(2), 2–6. Retrieved from http://www.sciencepub.net

Gurmessa, O. E. (2015). *Investigation of drinking water quality from source to point of distribution: the case of gimbi town, in Oromia regional state of Ethiopia*. Addis Ababa University, Ethiopia, Addis ababa, Ethiopia. Retrieved from http://localhost/xmlui/handle/123456789/10727

Hamere, Y., & Eyasu, E. (2017). Contamination of Rivers and Water Reservoirs in and Around Addis Ababa City and Actions to Combat It. *Environment Pollution and Climate Change*, *01*(02), 1–12. https://doi.org/10.4172/2753-458X.1000116

Hoko, Z. (2008). An Assessment of Quality of Water from Boreholes in Bindura District, Zimbabwe. *Physics and Chemistry of the Earth*, *33*(8–13), 824–828. https://doi.org/https://doi.org/10.1016/j.pce.2008.06.024

Howard, G., Ince, M. E., Schmoll, O., & Smith, M. (2012). *Rapid asssessment of drinking-water quality: a handbook for implementation*. Geneva, Switzerland: World Health Organization. Retrieved from http://www.bvsde.ops-oms.org/bvsacg/e/foro4/19 marzo/Way/Rapid.pdf%5Cnhttps://dspace.lboro.ac.uk/dspace-jspui/handle/2134/12381

Israel, H. D., & Awdenegest, M. (2012). Assessing water quality of rural water supply schemes as a measure of service delivery sustainability: A case study of WondoGenet district, Southern Ethiopia. *African Journal of Environmental Science and Technology*, *6*(5), 229–236. https://doi.org/10.5897/AJEST12.010

Jadhav, S. D., Sawant, R. S., Patil, R. S., & Godghate, A. G. (2015). Drinking water quality analysis of some villages from Gadhinglaj Tahsil , Maharashtra. *Biolife*, *3*(3), 608–613. https://doi.org/10.17812/blj.2015.336

Kanangire, O. (2013). *Laboratory validation of low-cost methods for the measurement of E.coli and total coliforms*. IHE-Delft, The Netherlands.

Khelif, S., & Abderrahmane, B. (2018). Multivariate statistical characterization of groundwater quality in Fesdis, East of Algeria. *Journal of Water and Land Development*, *37*, 65–74. https://doi.org/10.2478/jwld-2018-0026

Kombolcha Meteorological Branch Directorate. (2015). *Meteorological information and climate records of Kombolcha administration city*. Kombolcha, Ethiopia.

MoFED. (2014). *Growth and transformation plan annual progress report for F.Y. 2012 / 13, Addis Ababa, Ethiopia*. Addis ababa, Ethiopia. Retrieved from http://www.aigaforum.com/

MoH. (2005). *National hygiene and sanitation strategy:To Enable 100 % Adoption of Improved Hygiene and Sanitation*. Retrieved from http://documents.worldbank.org/

Mohammed, M., Safari, S., Asghar, F., & Jamal, F. (2013). Assessment of drinking water quality and its impact on residents health in Bahawalpur city. *International Journal of Humanities and Social Science*, *3*(15).

MoWRD. (2006). Universal access program for water supply and sanitation services 2006–2012, international calendar 1999–2005 Ethiopian calendar Part I– Rural. *Ministry of Water Resources Development*.

Nakade, D. (2013). Assessment of Bacteriological Quality of Water in Kolhapur City of Maharashtra, India. *International Research Journal of Environment Sciences*, *2*(2), 63–65. Retrieved from www.isca.in

NHMRC. (2011). *Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.* (Vol. 1). Canberra, Australia.

https://doi.org/1864965118

Qing, G., Jinsong, D., Ke, W., Yi, L., Jun, L., Muye, G., & Ligang, M. (2014). Identification and Assessment of Potential Water Quality Impact Factors for Drinking-Water Reservoirs. *International Journal of Environmental Research and Public Health ISSN*, *11*, 6069–6084. https://doi.org/10.3390/ijerph110606069

Sabrina, S., Daniela, P., Joseph, M. S., & Martin, B. N. (2013). Assessment of Physical-Chemical Drinking Water Quality in the Logone Valley (Chad-Cameroon). *Sustainability*, *5*, 3060–3076. https://doi.org/10.3390/su5073060

Seid, T., Werku, L., Hailu, E., & Kebede, F. (2018). Factor affecting water quality from source to home in Tehuledere woreda, Northeast Ethiopia. *Ethiopian Journal of Health Science*, *13*(2), 94–106.

Shamsur, R., Muhammad, A., Md, A. I., Sayema, Tf., & Mohammod, L. (2017). Assessment of Drinking Water Quality and Hygienic Conditions of the People Living around the Dingaputha Haor Area of Netrokona District, Bangladesh. *Research & Reviews: Journal of Ecology and Environmental Sciences*, *5*.

Tadesse, S., Abebe, B., & Esayas, A. (2017). Assessment of Drinking Water Quality and Treatment Plant Efficiency in Southwest Ethiopia. *Journal of Environmental Science and Pollution Research*, *3*(3), 208–212. Retrieved from http://www.jacsdirectory.com/jespr

Temesgen, E., & Hameed, S. (2015). Assessment of physico-chemical and bacteriological quality of drinking water at sources and household in Adama Town, Oromia Regional State, Ethiopia. *African Journal of Environmental Science and Technology*, *9*(5), 413–419. https://doi.org/10.5897/AJEST2014.1827

Twort, A. C. (Alan C., Ratnayaka, D. D., & Brandt, M. J. (2000). *Water Supply* (Fifth edit, Vol. 5th editio). TOKYO: Butterworth-Heinemann. https://doi.org/https://doi.org/10.1016/B978-0-340-72018-9.X5000-0

UNICEF/WHO. (2012). Progress on drinking water and sanitation: 2012 update. WHO/UNICEF Joint Monitoring Program for water supply and sanitation. UNICEF, New York.

UNICEF. (2008). *Promotion of Household water treatment and Safe Storage in UNICEF Wash Programmes*. New York, USA. Retrieved from https://www.unicef.org/wash/files/Scaling_up_HWTS_Jan_25th_with_comments.pdf

Werner, C., Panesar, A., Rüd, S. B., & Olt, C. U. (2009). Ecological sanitation: Principles, technologies and project examples for sustainable wastewater and excreta management. *Desalination*, *248*(1–3), 392–401. https://doi.org/10.1016/j.desal.2008.05.080

WHO/UNICEF. (2008). *Progress on Drinking Water and Sanitation*. Geneva, Switzerland. Retrieved from http://www.wssinfo.org/fileadmin/user_upload/resources/1251794333-JMP_08_en.pdf

WHO/UNICEF. (2014). *Progress on Drinking Water and Sanitation 2014 update*. Geneva, Switzerland. Retrieved from www.wssinfo.org

WHO/UNICEF. (2015). *Progress on Sanitation and Drinking Water : 2015 Update and MDG Assessment*. Geneva, Switzerland. Retrieved from https://books.google.com.et/books/about/Progress_on_Sanitation_and_Drinking_Wate.html?id=KFA0DgAAQBAJ&printsec=frontcover&source=kp_read_button&redir_esc=y#v=onepage&q&f=false

WHO. (2006). *Guidelines for drinking - water Quality First Addendum to Third Edition.* (Vol. Volume 1 R). Geneva, Switzerland.

WHO. (2008). *Guidelines for drinking-water quality. Incorporating the first and second addenda*. *WHO Press, Geneva* (Third edit, Vol. 1). Geneva, Switzerland: World Health Organization.

https://doi.org/10.1016/S1462-0758(00)00006-6

WHO. (2010). *Water for health, WHO Guidelines for Drinking-water Quality*. Geneva, Switzerland. Retrieved from https://www.who.int/

WHO. (2011). *Guidelines for Drinking-water Quality Fourth Edition* (Fourth edi). Geneva, Switzerland: World Health Organization. Retrieved from http://www.who.int

WHO. (2017). *Guidelines for Drinking-water Quality. Incorporating the first addendum* (Fourth edi). Geneva, Switzerland: World Health Organization.

Yibeltal, B. (2011). *The Value of Improved Water Supply Service in Motta Town, East Gojjam, Ethiopia: Application of Contingent Valuation Method (CVM)*. Addis Ababa University, Addis Ababa, Ethiopia. Retrieved from http://localhost/xmlui/handle/123456789/15015

7 LIST OF APPENDICES

Appendix A Kombolcha Town Sample Locations

Table- A-1: Sample Locations

No.	Name	Abbreviations used	Location	Coordinates and Elevations			Sample types
				X	Y	elevation (m.a.s.l)	
1	Dewey 1	BH1	Dewey	11° 05' 35"	39° 43' 49"	1830.9	Boreholes
2	Dewey 2	BH2	Dewey	11° 06' 06"	39° 43' 44"	1842.1	
3	Dewey 3	BH3	Dewey	11° 06' 39"	39° 43' 36"	1857.8	
4	Dewey 6	BH4	Dewey	11° 05' 36"	39° 43' 40"	1823.5	
5	Sheshabir 6	BH5	Sheshabir	11° 05' 40"	39° 43' 01"	1839.9	
6	Sheshabir 7	BH6	Sheshabir	11° 05' 33"	39° 43' 12"	1818.6	
7	Sheshabir 8	BH7	Sheshabir	11° 05' 38"	39° 43' 44"	1833	
8	Biraro	BH8	Sheshabir	11° 05' 20"	39° 43' 46"	1814.5	
9	Mikael 2	M2	Bati outlet	11° 05' 6"	39° 44' 45"	1981.5	
10	Aseb ber	AB	Piassa	11° 05' 12"	39° 44' 33"	1900.3	Reservoirs
11	Meja	MJ	Berbere Wenz	11° 05' 54"	39° 44' 28"	1894.6	
12	Aselel	AL	Aselel	11° 05' 42"	39° 42' 28"	1935.4	
13	Old Ayer marefya (jelma)	AM	Kuteba	11° 04' 29"	39° 42' 02"	1942.5	
14	kuti ager	KA	Dessie Outlet	11° 05' 26"	39° 41' 35"	2026.2	
15	Line 1	L1	From Aseb ber res.	11° 05' 08"	39° 44' 23"	1813.9	
16	Line 2	L2	From Mikael res.	11° 04' 20"	39° 44' 36"	1848.1	Main Distribution Lines
17	Line 3	L3	From Aselel res.	11° 04' 55"	39° 43' 14"	1847.7	
18	Line 4	L4	From Ayer menged(old) res.	11° 04' 01"	39° 11' 23"	1860.5	
19	Line 5	L5	From Kuti ager	11° 05' 05"	39° 41' 46"	1968.1	
20	Line 6	L6	From Mija	11° 04' 43"	39° 23' 11"	18.36.2	
21	R1-H1	R1-H1	Region 1	11° 03' 44"	39° 44' 43"	1834.6	
22	R1-H2	R1-H2		11° 03' 33"	39° 44' 36"	1837.4	Households
23	R1-H3	R1-H3		11° 03' 34"	39° 44' 32"	1833.5	
24	R1-H4	R1-H4		11° 03' 36"	39° 44' 27"	1825.4	
25	R1-H5	R1-H5		11° 03' 51"	39° 44' 27"	1816.1	
26	R2-H1	R2-H1	Region 2	11° 03' 56"	39° 44' 20"	1815.1	
27	R2-H2	R2-H2		11° 04' 19"	39° 44' 08"	1809.3	

28	R2-H3	R2-H3		11° 04' 33"	39° 44' 20"	1821.1	
29	R2-H4	R2-H4		11° 04' 35"	39° 44' 29"	1820.6	
30	R2-H5	R2-H5		11 04' 11"	39° 44' 56"	1816.4	
31	R3-H1	R3-H1	Region 3	11° 04' 58"	39° 44' 31"	1852	
32	R3-H2	R3-H2		11° 04' 35"	39° 44' 22"	1829.8	
33	R3-H3	R3-H3		11° 05' 32"	39° 44' 12"	1835.4	
34	R3-H4	R3-H4		11° 05' 59"	39° 44' 44"	1833.1	
35	R3-H5	R3-H5		11° 05' 25"	39° 44' 11"	1833.4	
36	R4-H1	R4-H1	Region 4	11° 05' 02"	39° 43' 10"	1852.5	
37	R4-H2	R4-H2		11° 04' 50"	39° 43' 25"	1838.1	
38	R4-H3	R4-H3		11° 04' 50"	39° 43' 28"	1834.2	
39	R4-H4	R4-H4		11° 05' 27"	39° 42' 46"	1863.9	
40	R4-H5	R4-H5		11° 05' 23"	39° 43' 06"	1850.5	
41	R5-H1	R5-H1	Region 5	11° 05' 23"	39° 43' 38"	1839.6	
42	R5-H2	R5-H2		11° 05' 28"	39° 44' 07"	1834.6	
43	R5-H3	R5-H3		11° 05' 46"	39° 44' 05"	1833.7	
44	R5-H4	R5-H4		11° 05' 58"	39° 44' 41"	1832.9	
45	R5-H5	R5-H5		11° 05' 39"	39° 44' 09"	1834.29	

Note: The town was classified in to five regions comparable in areas for the sake of simplicity during data collection.

Example key: R1H1= Region one household 1
Region 1=From Kedida to the main bridge near Medihanialem church
Region 2=From the main bridge to Sport center
Region 3=From sport center up to the new bus station
Region 4=Sheshabir and kuteba
Region 4=Beriberie wenz area

Appendix B Kombolcha Town Physical Parameters Test Result

Table- B-1: Kombolcha town boreholes physical parameters test result

S.No.	Name	Parameters (units)				
		T(°C)	PH	EC(μs/cm)	TDS(ppm)	TUR(NTU)
1	Dewey 1	24	6.88	663	333	0.01
2	Dewey 2	23.7	7.25	575	288	0.39
3	Dewey 3	23.2	6.98	650	325	0.41
4	Dewey 6	25.8	6.85	649	325	0.29
5	Sheshabir 6	23.9	6.85	588	294	0.31
6	Sheshabir 7	23.9	6.88	737	369	1.19
7	Sheshabir 8	26.1	7.43	448	224	0.01
8	Biraro	22.7	6.92	727	365	0.47

Table- B-2: Kombolcha town reservoirs physical parameters test result

S.No.	Name	parameters (units)				
		T(°C)	PH	EC(μs/cm)	TDS(ppm)	TUR(NTU)
1	Mikael 2	23.8	6.9	644	322	1.21
2	Aseb ber	24.1	6.9	637	319	2.31
3	Meja	23.9	6.7	632	315	0.92
4	Aselel	25	7.1	447	223	1.44
5	Ayer marefya (Jelma)	24.3	7.1	570	285	0.38
6	kuti ager	24.8	7.2	614	307	0.40

Table- B-3: Kombolcha town main distribution lines physical parameters test result

S.NO	Name	Parameters (units)				
		T(°C)	PH	EC(μs/cm)	TDS(ppm)	TUR(NTU)
1	Line 1	24.5	7.05	619	310	0.41
2	Line 2	25.4	7.12	656	329	1.31
3	Line 3	23.2	7.25	466	233	0.69
4	Line 4	23.7	7.3	470	235	0.91
5	Line 5	24.1	7.15	644	322	0.36
6	Line 6	25.5	7.12	645	322	0.68

Table- B-4: Kombolcha town household's physical parameters test result

S.No.	Name	Parameters (units)				
		T(°C)	PH	EC(μs/cm)	TDS(ppm)	TUR(NTU)
1	R1-HH1	23.7	7.1	658	329	0.24
2	R1-HH2	23.7	7.2	658	330	1.67
3	R1-HH3	24.2	7.1	643	321	1.46
4	R1-HH4	22.5	7.1	663	332	1.52
5	R1-HH5	23.8	7.1	662	331	0.31
6	R2-HH1	22.9	7.1	659	330	0.31
7	R2-HH2	24.6	7.1	663	331	0.32
8	R2-HH3	23.3	7.0	662	331	0.42
9	R2-HH4	22.5	7.0	666	333	0.57
10	R2-HH5	22.7	6.5	664	332	0.54
11	R3-HH1	24.4	7.0	657	328	1.91
12	R3-HH2	24.9	6.9	665	332	1.01
13	R3-HH3	23.3	7.4	624	312	2.40
14	R3-HH4	23.2	7.1	632	316	2.25
15	R3-HH5	25.6	7.3	469	234	1.75
16	R4-HH1	24.3	7.1	579	290	0.35
17	R4-HH2	23.6	7.1	523	261	1.47
18	R4-HH3	23.4	7.2	529	265	0.18
19	R4-HH4	24.2	7.3	484	242	0.45
20	R4-HH5	23.7	7.1	567	284	0.17
21	R5-HH1	24.6	7.1	696	349	0.12
22	R5-HH2	24.5	7.2	667	333	1.50
23	R5-HH3	25.5	7.1	645	322	0.68
24	R5-HH4	25.1	7.1	663	331	0.89
25	R5-HH5	24.3	7.3	627	313	1.12

Appendix C Kombolcha Town Chemical Parameters Test Result

Table- C-1: Kombolcha town boreholes chemical parameters test result

S.No.	Name	Parameters (units)				
		Total hardness, mg/l	Free chlorine residual, mg/l	Manganese mg/l	Nitrate mg/l	Iron mg/l
1	Dewey 1	462	0.01	0.031	38.8	0.01
2	Dewey 2	336	0.01	0.027	32.9	0.06
3	Dewey 3	455	0.02	0.033	43.6	0.05
4	Dewey 6	459	0.03	0.022	26.2	0.03
5	Sheshabir 6	476	0.01	0.024	31.4	0
6	Sheshabir 7	469	0.01	0.031	41.9	0.01
7	Sheshabir 8	462	0.03	0.034	28.7	0.02
8	Biraro	443	0.01	0.002	22	0.07

Table- C-2: Kombolcha town reservoirs chemical parameters test result

S.No.	Name	Parameters (units)				
		Total hardness, mg/l	Free chlorine residual, mg/l	Manganese, mg/l	Nitrate, mg/l	Iron mg/l
1	Mikael 2	437	0.16	0.002	21	0.06
2	Aseb ber	427	0.03	0.014	18.4	0.00
3	Meja	536	0.05	0.013	22.4	0.03
4	Aselel	316	0.1	0.003	15.2	0.00
5	Ayer marefya (jelma)	460	0.52	0.016	28.42	0.05
6	kuti ager	298.8	0.94	0.015	23.6	0.02

Table- C-3: Kombolcha town main distribution lines chemical parameters test result

S.No.	Name	Parameters (units)				
		Total hardness, mg/l	Free chlorine residual, mg/l	Manganese mg/l	Nitrate mg/l	Iron mg/l
1	Line 1	425	0.03	0.01	18.2	0
2	Line 2	432	0.15	0.002	20	0.06
3	Line 3	314	0.1	0.003	14.9	0
4	Line 4	453	0.51	0.013	26.7	0.06
5	Line 5	295.3	0.85	0.013	22.8	0.02
6	Line 6	531	0.03	0.011	21.9	0.04

Table- C-4: Kombolcha town household's chemical parameters test result

S.NO	Name	Parameters (units)				
		Total hardness, mg/l	Free chlorine residual, mg/l	Manganese mg/l	Nitrate mg/l	Iron mg/l
1	R1-HH1	456	0.13	0.017	4.4	0.07
2	R1-HH2	452	0.06	0.013	4.8	0.02
3	R1-HH3	447	0.11	0.012	6	0.04
4	R1-HH4	451	0.07	0.018	4.2	0.04
5	R1-HH5	461	0.15	0.017	3.8	0.07
6	R2-HH1	345	0.04	0.004	16	0.00
7	R2-HH2	356	0.01	0.002	16.2	0.01
8	R2-HH3	332	0.03	0.002	12	0.00
9	R2-HH4	351	0.09	0.001	4.9	0.02
10	R2-HH5	341	0.05	0.007	8	0.01
11	R3-HH1	442	0.23	0.015	4.1	0.00
12	R3-HH2	396	0.17	0.008	4.6	0.02
13	R3-HH3	429	0.1	0.023	3.1	0.03
14	R3-HH4	389	0.21	0.014	4.3	0.00
15	R3-HH5	438	0.08	0.016	2.9	0.01
16	R4-HH1	356	0.01	0.016	26	0.00
17	R4-HH2	372	0.06	0.021	11	0.01
18	R4-HH3	349	0.01	0.011	13	0.02
19	R4-HH4	352	0.02	0.02	22	0.00
20	R4-HH5	368	0.04	0.015	31	0.02
21	R5-HH1	371	0.17	0.022	24	0.06
22	R5-HH2	349	0.21	0.018	19.4	0.00
23	R5-HH3	356	0.13	0.017	16.8	0.07
24	R5-HH4	353	0.11	0.021	22.7	0.06
25	R5-HH5	374	0.16	0.014	21.3	0.01

Appendix D Kombolcha Town Sanitary Assessment Result

Table- D-1: Kombolcha town boreholes sanitary assessment result

S.NO	Name	Risk value	Risk level
1	Dewey 1	2	Low
2	Dewey 2	2	Low
3	Dewey 3	3	Low
4	Dewey 6	1	Low
5	SHESHABIR 6	2	Low
6	SHESHABIR 7	3	Medium
7	SHESHABIR 8	1	Medium
8	BIRARO	6	High

Table- D-2: Kombolcha town household sanitary assessment result

S.NO	Name	Risk value	Risk level
1	R1-HH1	low	2
2	R1-HH2	medium	3
3	R1-HH3	low	1
4	R1-HH4	low	1
5	R1-HH5	low	2
6	R2-HH1	high	6
7	R2-HH2	medium	3
8	R2-HH3	low	1
9	R2-HH4	high	6
10	R2-HH5	low	2
11	R3-HH1	low	1
12	R3-HH2	medium	4
13	R3-HH3	very high	9
14	R3-HH4	low	2
15	R3-HH5	low	2
16	R4-HH1	low	2
17	R4-HH2	medium	4
18	R4-HH3	low	1
19	R4-HH4	low	2
20	R4-HH5	low	2
21	R5-HH1	low	1
22	R5-HH2	low	2
23	R5-HH3	medium	3
24	R5-HH4	low	2
25	R5-HH5	low	2

Appendix E Sanitary Inspection Forms

I. Type of Facility PIPED WATER

1. General Information : Zone:
: Area
2. Code Number
3. Date of Visit
4. Water samples taken? …….. Sample Nos. ………

II. Specific Diagnostic Information for Assessment

(Please indicate at which sample sites the risk was identified) Risk Sample No

1. Do any tap stands leak? Y/N………….
2. Does surface water collect around any tap stand? Y/N………….
3. Is the area uphill of any tap stand eroded? Y/N………….
4. Are pipes exposed close to any tap stand? Y/N………….
5. Is human excreta on the ground within 10m of any tap stand? Y/N………….
6. Is there a sewer within 30m of any tap stand? Y/N………….
7. Has there been discontinuity in the last 10 days at any tap stand? Y/N………….
8. Are there signs of leaks in the mains pipes in the Parish? Y/N………….
9. Do the community report any pipe breaks in the last week? Y/N………….
10. Is the main pipe exposed anywhere in the Parish? Y/N ………….

Total Score of Risks ..../10

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-2 = Low

III Results and Recommendations:

The following important points of risk were noted: (list nos. 1-10)

Signature of Health Inspector/Assistant: Comments:

I. **Type of Facility** DEEP BOREHOLE WITH MECHANISED PUMPING

1. General Information : Supply zone
   : Location:
2. Code Number
3. Date of Visit
4. Water sample taken? …….. Sample No. ……… FC/100ml ………..

II. **Specific Diagnostic Information for Risk Assessment**

1. . Is there a latrine or sewer within 100m of pump house? Y/N………….
2. Is the nearest latrine unsewered? Y/N………….
3. Is there any source of other pollution within 50m? Y/N………….
4. Is there an uncapped well within 100m? Y/N………….
5. Is the drainage around pump house faulty? Y/N………….
6. Is the fencing damaged allowing animal entry? Y/N………….
7. Is the floor of the pump house permeable to water? Y/N………….
8. Does water forms pools in the pump house? Y/N………….
9. Is the well seal insanitary? Y/N………….

Total Score of Risks …./9

Risk score: 7-9 = High; 3-6 = Medium; 0-2 = Low

III. **Type of Facility** Household Water Quality Inspection

1. General Information : Supply zone
   : Location:
2. Code Number
3. Date of Visit
4. Water sample taken? …….. Sample No. ……… FC/100ml ………..