INSTITUTE OF HEALTH SCIENCES

FACULTY OF PUBLIC HEALTH

DEPARTMENT OF ENVIRONMENTAL HEALTH SCIENCES AND TECHNOLOGY

ASSESSMENT OF PHYSICO CHEMICAL AND BACTERIOLOGICAL QUALITY OF DRINKING WATER IN CONVENTIONAL DRINKING WATER TREATMENT PROCESSES AND WATER SUPPLY SYSTEM IN MALLE WOREDA, SOUTH WEST ETHIOPIA

By: KIBRU PHILMON (BSC)

A THESIS SUBMITTED TO DEPARTMENT OF ENVIRONMENTAL HEALTH SCIENCES AND TECHNOLOGY, FACULTY OF PUBLIC HEALTH, INSTITUTE OF HEALTH SCIENCE, JIMMA UNIVERSITY; IN PARTIAL FULFILLMENT FOR THE REQUIREMENT OF MASTERS DEGREE IN ENVIRONMENTAL SCIENCE AND TECHNOLOGY

JANUARY, 2022

JIMMA, ETHIOPIA

ASSESSMENT OF PHYSICO CHEMICAL AND BACTERIOLOGICAL QUALITY OF DRINKING WATER IN CONVENTIONAL DRINKING WATER TREATMENT PROCESSES AND WATER SUPPLY SYSTEM IN MALLE WOREDA, SOUTH WEST ETHIOPIA

BY: KIBRU PHILMON

ADVISORS:

DR. HIGEMENGIST ASTATKIE (ASSISTANT PROFESSOR)

PROFESSOR ALEMAYEHU HDDIS

Approval sheet

As thesis research advisors, we here certify that we have read and evaluated this thesis prepared under our guidance by Kibru Philmon entitled "Assessment of physico chemical and bacteriological quality of drinking water in conventional drinking water treatment processes and water supply system in Malle woreda, south west Ethiopia. Case study for Boshkoro town, Lemogento town and Kella town. We recommended that it could be submitted as fulfilling the thesis requirement.

Advisor's Name	**Signature**	**Date**
______________	______________	______________
______________	______________	______________

As member of the board of examiners of the MSc. thesis open defense examination, we certify that we have read and evaluated the thesis prepared by **Kibru Philmon** and examined the candidate. We recommend that the thesis be accepted as fulfilling the thesis requirement for the degree of Master of Science in Environmental Science and Technology.

______________	______________	______________
Chairperson	Signature	Date
______________	______________	______________
Internal Examiner	Signature	Date
______________	______________	______________
External Examiner	Signature	Date

Department Head Department of Environmental Health Science and Technology appreciates the successful completion of his thesis.

Name ______________________ Signature: __________ Date: ____________

Declaration

I, the undersigned, declare that this thesis on "Assessment of physico chemical and bacteriological quality of drinking water in conventional drinking water treatment processes and water supply system in Malle woreda, south west Ethiopia" is my original thesis work, has not been presented for a degree in this or other university and that all sources of materials used for this have been acknowledged.

Name: _________________ Date_____________ Signature ________________

Abstract

Background: *The contamination of drinking water quality with different contaminants is causing a serious threat to millions of people across the globe. To raise the quality of drinking water, various treatment methods are needed. However, existing water treatment systems and drinking water quality is not investigated in low-income countries including Ethiopia. Continuous examination of water quality analysis in terms of detection of indicator organisms and physico chemical analysis is among the methods of assessing the safe condition of drinking water treatment system.*

Objectives: *To evaluate the performance of Boshkoro, Lemogento and Kella treatement plant and water supply system regarding their ability to produce quality water and control pathogens in Malle woreda, southwest Ethiopia.*

Method*: A cross-sectional study design was employed during the period from August 1 to October 28, 2021, in Boshkoro, Kella and Lemogento towns of Malle woreda, southwest Ethiopia. A total of eleven water sample was collected from four sampling point of three treatment plant of the study area. The collected samples were analyzed for bacteriological quality and physical parameters. Data was analyzed using Statistical Package for Social Sciences (SPSS) software version 23, and Microsoft Excel 2016.*

Result: *The mean results of municipal conventional drinking water treatment analysis and water supply system samples located in the study area showed that pH, turbidity, and electrical conductivity of the water samples were varied between 6.8–8.10, 1-5 NTU, and 198-5340µS/cm, respectively. Sulfate and nitrate concentrations of the water samples also ranged between 2 and 97 mg/l and 0.30 –7.37 mg/l, respectively.Majority of samples were positive for total coliform bacteria with counts ranging from 0 to 85 CFU/100 ml, except for Lemogento and Kella town treatment reservoir after disinfection and main distribution system. Whereas, fecal coliforms were detected in all sampling points ranging from 0 to 90 CFU/100 ml, except, for Lemogento reservoir and distribution and Kella reservoir samples.*

Conclusion*: In general, majority of physicochemical and some of bacteriological quality of the water samples collected from three treatment plant units lies within the maximum permissible limits of WHO guidelines. But, fluoride, conductivity, copper, iron fecal coliforms and total coliforms were not within the recommended limit of WHO guidelines for drinking water.*

Key words: *Bacteriological quality; physicochemical parameters; water quality.*

Acknowledgment

First and foremost I would like to grant my deepest praise to Almighty God for the blessings and guidance. Second, I would like to forward my heartfelt gratitude to my advisors Dr. Higemengist Astatkie who supported and guided me with valuable comments and showed directions during this work. Thirdly, I would also like to offer thanks to Jimma university's environmental science and technology department for giving valuable Ethical consideration documents. I would also like to offer thanks to the south Omo zone and south nations nationalities and peoples regional Water, mineral and energy office who allowed me to use their laboratory and provided me with all the necessary materials for sample analysis in their laboratory.

A special appreciation and thanks go to Mr. Workineh Kerma (vice director of the south Omo zone water minerals and energy memriya) for assigning laboratory technician, Mr Mintobi Chali who helped me in showing directions and avail valuable materials in sampling site andMr. Manaye Degwale (laboratory technician) helped me in sampling collection and analysis and Ms. Yewbdar Tesfaye (regional laboratory technician) helped me with every movement in the laboratory. I would also like to acknowledge south nations' nationalities and people's public health laboratory Jinka branch to use their laboratory for conducting microbial analysis. and Malle woreda Water, Mineral and energy office for giving me the necessary information.

Table of contents

Contents

Abstract II

Acknowledgment III

Table of contents IV

List of Tables VII

List of Figures VIII

Abbreviation and Acronyms IX

CHAPTER ONE 1

INTRODUCTION 1

1.1. Background of the study 1

1.2. Statement of the Problem 3

1.3. Significance of the study 5

CHAPTER TWO 6

LITERATURE REVIEW 6

2.1. Water resource in the world 6

2.2. Water quality and human health 6

2.3. Water quality concerns 7

2.4. Water treatment process 8

2.4.1. Abstraction 8

2.4.2. Preliminary treatment by storage 9

2.4.3. Prefiltration 9

2.4.4. Slow sand filtration 9

2.4.5. Coagulation, flocculation, and sedimentation 9

2.4.6. Aeration 9

2.4.7. Disinfection 10
2.5. Water quality analyses 10
2.6. Water quality parameters 10
2.6.1. Microbiological water quality 10
2.6.2. Physical parameters 11
2.6.3. Chemical parameters 12
2.7. Conceptual frame work 15
CHAPTER THREE 16
OBJECTIVES 16
3.1. General Objective 16
3.2. Specific objectives 16
CHAPTER FOUR 17
METHODS AND MATERIALS 17
4.1. Study Area 17
4.2. Study Design, Period and Sample Size Determination 18
4.3. Sampling methods and procedures 19
4.5. Data analysis 21
4.5.1. Bacteriological analysis 21
4.5. 2. Physicochemical Analysis 21
4.5.3. Statistical analysis 22
4.6. Data quality control 22
4.7. Ethical Issue 22
4.8. Dissemination Plan 22
4.9. Operational definition 23
CHAPTER FIVE 24

RESULT 24
5.1. Physical Quality of water 24
5.2. Chemical parameters of water 25
5.3. Concentration of heavy metals in water 27
5.4. Bacteriological Quality of water 30
5.5. Correlation study 31
CHAPTER SIX 33
DISCUSSION 33
6.1. Physical Quality of drinking water in water treatment process and water supply system. 33
6.2. Chemical Quality of drinking water in treatment process and water supply system. 35
6.3. Heavy metals in water treatment process and water supply system. 38
6.4. Bacteriological Quality of drinking water in treatment process and water supply system. 39
CHAPTER SEVEN 41
CONCLUSION AND RECOMMENDATION 41
7.1. Conclusion 41
7.2. Recommendations 42
REFERANCES 43
ANNEX 51
Annex-1 Raw water quality data for different water sources 51

List of Tables

Table 1: Classification of water-based on the hardness.. 13

Table 2: Mean ± SD of physical parameters of water samples at different *s*ampling points of Boshkoro, Lemogento and Kella treatment systems in Malle woreda, southwest Ethiopia......... 25

Table 3: Mean ± SD of chemical parameters of water samples at different sampling points of Boshkoro, Lemogento and Kella treatment systems in Malle woreda, southwest Ethiopia......... 26

Table 4: The mean and standard deviation of total coliform and fecal coliform counts for water samples collected from Boshkoro, Lemogento and Kella drinking water treatment plant and supply system.. 30

Table 5: Correlation study between physicochemical parameters vs bacteriological load. 32

List of Figures

Figure 1: Conceptual framework 15

Figure 2: Map of the study area 18

Figure 3: The typical treatment process and sample points of Boshkoro and Lemogento town water treatment process, Malle woreda, southwest Ethiopia. 18

Figure 4: Sample collection from the distribution (A); reservoir at disinfection point (B); disinfecting Public tap (C); sample collection from tap (D). 20

Figure 5; Measuring (1) PH and temperature (2) conductivity on site. 20

Figure 6: chromium variation in Boshkoro, Lemogento and Kella town water treatments and supply system. 27

Figure 7: Iron variation in Boshkoro, Lemogento and Kella town water treatments and supply system. 28

Figure 8: Copper variation in Boshkoro, Lemogento and Kella town water treatment and supply system. 29

Figure 9: Manganese variation in Boshkoro, Lemogento and Kella town water treatments and supply system. 30

Abbreviation and Acronyms

AAS	atomic absorption spectrometry
AFD	Action for development
BWTS	Boshkoro water treatment and supply system
CFU	Colony Forming Unit
D	Distribution system
DPD	N, N-diethyl-1,4- phenylenediamine
EC	Electrical Conductivity
EMB	Eosin Methylene Blue
FC	Fecal Coliform
IRC	International risk committee
KWTS	Kella water treatment and supply system
LGWTS	Lemogento water treatment and supply system
NTU	Nephelometric Turbidity Units
PT	Public tap
R	Reservoir after disinfection
S	Source or inlet
SPSS	Statistical Package for Social Science
TC	Total Coliform
UNICEF	United Nations Children's Fund
WHO	World Health Organization
MWWSO	Malle woreda water supply office
AAS	atomic absorption spectrometry

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Accessibility to and availability of fresh, clean water is essential elements of public health (Malhotra *et al.*,2015). However, failure to supply safe water will exert a heavy burden on humanity (Malhotra *et al.*,2015). The fresh water that is needed for a drinking water supply is limited (Behailu et al., 2018). And Nowadays, the agricultural practice and industrial chemical waste disposals due to cross-contamination with sewerage, illegal connections, leakages, and corrosions are being polluting largely the limited water sources (Desye et al., 2021).

Approximately about 844 million people lacked basic drinking water services from the improved sources across the globe (an improved source within 30 minutes' round trip) (UNICEF and WHO, 2017). Due to that, water-related diseases are causing about 30,000 death every day in the world and the situation is much more serious in developing countries (Duressa *et al.*, 2019).

Ethiopia is one of the countries in the world with the worst of all water quality problems and has a 42% water supply in sub-Saharan countries (Sisay et al., 2017). About three-quarter of health problems in children in the country is with microbial contamination of drinking water (Dessie, 2020). In Ethiopia, the drinking water sources are exposed to the forces of different contaminants and pollutants due to a lack of proper management of water sources (Alemu*et al.,* 2015). Even for those people who have access to clean water, the provision does not confidently guarantee the safety of drinking water in terms of its physical, chemical, and bacteriological parameters (Duressa *et al.*, 2019).

Physicochemical parameters including turbidity, pH, temperature, nitrate, phosphate, and others are widely accepted as critical drinking water quality parameters. These parameters either directly affect disinfection efficiencies as well as microbiological quality (Duressa *et al.,* 2019).

Metal contamination in water is one of the most serious environmental concerns in the present world scenario (Sisay et al., 2017, Kilonzo et al., 2019, Pantaleo et al., 2018), wherein metal contamination is a major problem even at low concentration levels it has high toxicity and it may cause serious health hazards if it is present in the excessive amount due to contamination and, the water may need to be treated before use (Salifu et al., 2019).

Safe and potable drinking water needed various treatment methods to raise the quality of water. The treatment processes can be arranged in a treatment sequence of flocculation, sedimentation, filtration, and disinfection for water.

Conventional Water treatment involves removing impurities that are potential to cause harmful in water supply for human consumptions (Teklu, 2018). The Improvement of the quality of water before being used by consumers is depending on the drinking water treatment processes efficiency, which must be safe and meet the standard criteria for public health (Mohsin, 2014).

The water treatment plant can be evaluated by testing the water quality produced by the treatment units that are applied in various conventional treatment plants. Identifying water quality parameters is varying due to water sources used in the water treatment plant (Wakuma & Fita, 2017, Teklu, 2018).

Physicochemical including turbidity, pH, temperature, nitrate, phosphate, and others are taken as important parameters to classify the quality of both raw and treated drinks of water in any water treatment plant (Behailu et al., 2018). Whereas in other studies biological parameters of treated water were included (Berhane & Hailu, 2015;Gara et al., 2017; Guduru et al., 2020). These parameters change widely due to seasonal fluctuation, the type of pollution, ground water extraction, etc. (Abegaz, 2021).

Failures in drinking water systems, treatment processes and distribution networks can often lead to drinking water contamination incidents which result in disease outbreaks. Many studies were carried out in Ethiopia on physicochemical and bacteriological quality of drinking water from various water sources showed that water sources were contaminated with pollution indicators such as fecal and total coliforms (Duresa et al., 2019, Guduru et al., 2020). These indicate that water-quality problems are extensive in the water-delivery systems of the country.

The inhabitants of the Malle woreda use water from different sources such as tap water, springs, and Rivers for different purposes including drinking. It is crucial to identify whether the water obtained from the tap water along its various stages is safe with regard to water quality parameters. This study would, therefore, be initiated to assessment of physico chemical and bacteriological quality of drinking water in conventional drinking water treatment process and water supply system in Malle woreda.

1.2. Statement of the Problem

Clean and safe drinking water is vital for human health and can reduce the load of illnesses, such as diarrheal disease (Shan et al., 2018). However, the contamination of drinking water with different contaminants is causing a serious threat to millions of people across the globe (Teklu, 2018). About 850,000 peoples die every year from lack of access to safe drinking water, sanitation, and hygiene, and from this contaminated drinking water accounted for 72.1%, (UNICEF and WHO, (2017).

Despite the alarming rate of water contaminations and the burden associated with unsafe drinking water supply, very little effort has been set to investigate the efficiency of existing water treatment systems and drinking water quality in low-income countries (Desye et al., 2021).

The majority of the population lives in Africa and Asia are still living without access to the improved water supply (Mekonnen *et al.,* 2019). Due to that, Frequent outbreak of waterborne diseases has been posing major risks to both rural and urban areas of developing countries (Abegaz, 2021). Maintaining high drinking water quality in distribution network in the case of physicochemical and bacteriological parameters is a major challenge for developing countries (Ewelina & Patrycja, 2018).

Ethiopia has suffered access to safe drinking water from improved sources (Reda, 2016). A regular and continuous drinking water quality monitoring activity is not practiced by the main actors in the water supply sector in Ethiopia (Duressa *et al.*, 2019).

The problem of unsafe drinking water may not be limited to untreated drinking water, but may also arise from treated water sources with poor water quality. It is reported that even improved water sources, for instance the water which is delivered from the municipality, do not reliably predict microbial safety of water but they are rather good technologies with a high level of probability to deliver safe and clean drinking-water in Ethiopia (Salifu*et al.,* 2019, Dessie, 2020).

Several studies carried out in Ethiopia on the bacteriological quality of drinking water from different sources showed that the water sources were contaminated with pollution indicators organisms such as fecal and total coliforms (Ameya et al., 2018; Duresa et al., 2019; Eliku, 2015 ; Yasin et al., 2015).

Assessment of qualities of urban water source and tap water distribution systems in Arba-Minch town (Ameya*et al.,* 2018), Adama town (Eliku & Sulaiman, 2015) and Nekemte town (Duressa *et al.,* 2019), showed that the distribution lines are the most likely point of physical, chemical and microbial contamination.

Besides microbial contaminants, pollutions of water resources with heavy metals have received particular concern because of their strong toxicity even at lower concentrations (Reda, 2016). The study was done in south Ethiopia Duressa *et al.,* (2019), reveal that there were considerable variations in the examined samples from different sources concerning their physico chemical characteristics and this indicates that the quality of water substantially differs from location to location.

A limited study was conducted in other places of the country, but for the case of Malle woreda, nothing is done so far. Failures in drinking water systems, treatment processes and distribution networks can often lead to drinking water contamination incidents which result in disease outbreaks. Even if, the quality of the finished drinking water leaving treatment facilities is normally high, it can deteriorates gradually as it transports through the pipes of the distribution system and inside premise plumbing . These indicate that water-quality problems are rampant in water-delivery systems. This needs to know the status of drinking water quality from sources through treatment to public tap in study area.

There is an outbreak of cholera in the study areas of Malle woreda since 2020 and there was a disease in cattle and human that use the water produced from Kella treatement plant. No documented work that reveals the physical, chemical, and bacteriological composition of drinking water around Malle woreda.

The treatment plant of water in study area is far away from the town. Hence, the interconnection between the site of the treatment plant and the distribution system up to public tap may accumulate pathogenic microorganisms by the formation of biofilms. This requires an assessment of municipal water distribution systems of Malle woreda.Therefore the main objective of this study is to fill the gap by assessing physico chemical and bacteriological quality of drinking water in conventional drinking water treatment process and water supply system in Malle woreda, south west Ethiopia.

1.3. Significance of the study

The result of this research benefit the responsible body to a better evaluation and decision making of water distribution and delivery systems and they become known about the status of the quality of the water. They realize that they need to protect water sources from any contaminations.

The result which is generated from this study has also great importance for the community to know the status and to give the care to protect the drinking water. Finally, the finding of the study providing baseline information to the other researchers who want to further research water quality in Malle woreda.

CHAPTER TWO

LITERATURE REVIEW

2.1. Water resource in the world

Water is one of the most crucial and precious natural resources. It is essential in the life of all living organisms from the simp lest plant and microorganisms to the most complex living system known as the human body. Water is a combination of hydrogen and oxygen atoms, with a chemical formula, H2O, and is known to be the most abundant compound (70%) on the earth's surface. It is significant due to its unique chemical and physical properties (Toxicol & Reda, 2016). It is vital to man's existence and without it, there would be no life on earth. The earth holds approximately 1.4 × 109 m^3 of water in the form of oceans, seas, rivers, lakes, ice, etc. But only 3% of the total available water resources are in the form of freshwater found in rivers, lakes, and groundwater. The fresh water that is needed for a clean water supply is limited and the demand far exceeds the available supply due to increasing population and industrialization. A clean water supply is one of the key indicators for development in any country; however, the situation of most African countries is not encouraging because more than 300 million people in Africa live in water-scarce environments (WHO, 2011a).

2.2. Water quality and human health

Understanding the status of drinking water quality and associated health risks is mandatory to make wise decisions on drinking water quality protection and management (Berhane & Hailu, 2015; Gara et al., 2017). Consumption of drinking water that is contaminated with hazardous chemicals or pathogenic microorganisms possess serious health threats or various waterborne diseases (Tamrakar*et al.,* 2017).

Natural quality of water is affected by both chemical and biological contaminants originating from sources like: inadequate collection and disposal of household wastes, industrial wastes, and agrochemicals applied at the catchment level and natural factors. The failure to provide safe drinking water puts public health at risk and drinking of these biological and chemical contaminants can cause both acute and chronic health problems (Massoud*et al.,* 2010). Contaminated water can serve as a vector for disease transmission and cause human health issues unless it is treated and made safe to drink. Consumption of drinking water which is contaminated with hazardous chemicals or pathogenic microorganisms possess serious health threat or various waterborne diseases (Tamrakar*et al.*, 2017).

Drinking water which is contaminated with fecal origins are highly correlated and can cause diseases such as cholera, typhoid, dysentery, legionellosis, enteric fever, schistosomiasis, and many other acute and chronic diseases (Jessoe, 2013, Bain *et al.,* 2014; Szabo & Minamyer, 2014; Li & Wu, 2019). Waterborne diseases have negative impacts and burdens on public health in developing countries where drinking water is of poor quality.

2.3. Water quality concerns

Water quality concerns are the most important element for measuring access to improved water sources. The acceptable quality of drinking water shows the safety of drinking water in terms of its physical, chemical, and bacteriological parameters. The problems related to chemical ingredients of drinking water arise primarily from their ability to cause adverse health effects after extended periods of exposure, of particular concern, are contaminants that have cumulative toxic properties, such as heavy metals and substances that are carcinogenic (Reda, 2016)

WHO estimation implies about 1.1 billion people globally drink unsafe water and the vast majority (88 %) of the diarrheal disease reported across the globe is attributable to unsafe water, sanitation, and hygiene (Yasin et al., 2015a) Furthermore, around 250 million infections each year from water born diseases, which results in 10–20 million deaths world-wide, happend due to water-borne diseases (Yasin et al., 2015a). The extensive spread of diseases such as cholera, dysentery, and salmonellosis are mainly due to the lack of safe drinking water and adequate sanitation that ends up in the death of millions of people in low incoming countries every year (Yasin et al., 2015a).

More than 75 % of the health problems in Ethiopia were due to infectious diseases which are attributed to unsafe and inadequate water supply, unhygienic waste management, and human excreta. Some studies done on bacteriological qualities of drinking water in Akaki-Kalita sub-city of Addis Ababa, Ziway, Bahir Dar and Adama towns showes contamination of the water samples with total coliforms (TTC) and fecal coliforms (Yasin et al., 2015). Besides microbial contaminants, pollutions of water resources with heavy metals have received particular concern because of their strongly toxicity even at lower concentrations(Reda, 2016).

Drinking water quality monitoring as a regular and continuous activity is an area that is less practiced by the main actors in the water supply sector in Ethiopia (Duressa *et al.*, 2019). Sustainable provision of adequate and safe drinking water to the consumer is crucial for life to address the challenge of urban development (Monica & Khushboo, 2017).However, for most of developing countries maintaining high drinking water quality in distribution network in the case of physicochemical and bacteriological parameters is a major challenge (Simard*etal.*, 2011). Typically, drinking water quality is affected by the quality of raw source water, the treatment in water treatment plants before distributed, the water distribution system and the containers/tanks used for water storage (Li & Wu, 2019).

The quality of drinking water in urban water supplies can be deteriorated because of the inadequacy of treatment plant, contamination of transporting water at different levels of distribution lines and inefficient management of pipe water in distribution system (Eliku & Sulaiman, 2015). The physical, chemical and microbial quality of the drinking water may be degraded in the distribution system as a result of poor environmental conditions and a degraded water supply infrastructure.

2.4. Water treatment process

For small communities, it is generally preferable to protect a groundwater source that requires little treatment than to treat surface water that has been exposed to fecal contamination and is usually of poor quality. The range of treatments available for small-community supplies is necessarily limited by technical and financial considerations; the most appropriate and commonly used treatments are summarized below.

2.4.1. Abstraction

The control measures required at the point of abstraction are determined by the characteristics of the source water and the particular water treatment method adopted. Screens are necessary where large suspended solids are present in the source water; these will require periodic cleaning. Properly constructed intake channels can be used to provide regular lateral intake flows from a surface water source. Sluicegates and valves offer a means of controlling flow but require regular maintenance and adjustment (Kausley et al., 2018).

2.4.2. Preliminary treatment by storage

Preliminary storage in a reservoir helps to serve as a continuous supply of water despite variations in demand and source water availability. It can also provide an economical means of settling out some of the suspended solids (Sorlini & Torretta, 2017).

2.4.3. Prefiltration

In treatment plants where the suspended solids content and turbidity of the source water are periodically high, prefiltration with gravel or other coarse material before sand filtration is an effective means of stopping the rapid blocking of the sand filters. In prefilters, suspended solids, turbidity, and microbiological contamination can be significantly reduced (Kausley et al., 2018). Prefilters require a ripening period, which may be of some months' duration for raw waters with low nutrient levels, before they reach peak operating efficiency.

2.4.4. Slow sand filtration

Slow sand filtration advances the physical, chemical, and microbiological quality of water; it is reliable and inexpensive, and is therefore particularly useful in small-community water supplies. The depth of the sand filter bed is typically in the range of 0.5–1.2m, varying as the sand is skimmed off from time to time to prevent blocking on the upper surface (Health, n.d.).

2.4.5. Coagulation, flocculation, and sedimentation

Fine suspended particles may be removed from water by treating with chemicals that cause the formation of an absorbent, bulky precipitate. These chemicals are called coagulants and react with suspended particles to produce settleable flocs. Most coagulants are salts of iron or Aluminum, e.g., Aluminum sulfate (alum) and ferric chloride. The nature of the floc depends on the characteristics of the raw water, the type of coagulant employed, and the dosing rate. Rapid mixing is essential as soon as the coagulants are added to the water.

2.4.6. Aeration

Aeration can be used in water treatment to reduce tastes and odors (e.g., by oxidation of hydrogen sulfide), lower the levels of volatile organics, and change the concentrations of dissolved gases, although it has little significant effect on those associated with algal growth (Farhaoui & Derraz, 2017).

2.4.7. Disinfection

The microbiological quality of drinking water can be substantially enhanced by protecting the source and by treating the raw water. If the physical and chemical quality of the water is acceptable, disinfection provides the most effective means of falling the number of microorganisms in drinking water. chlorination has been widely applied in treating community water supplies (Kausley et al., 2018).

2.5. Water quality analyses

Before determining the sources of surface or groundwater, it is important to conduct water quality tests through representative samples. These tests ideally should be performed on-site and through samples taken to the laboratory for conclusive analysis (Duressa *et al.,* 2019).

2.6. Water quality parameters

Water quality parameters are classified into three parts such as physical, chemical, and biological characteristics of water in association with the set of standards. These parameters are directly connected to the safety of the drinking water for human use. Water quality parameters deliver important information about the fitness of a water body. These limits are used to find out the quality of water for drinking purposes (Daniel et al., 2015).

2.6.1. Microbiological water quality

Indicator bacteria can be used to assess the microbiological drinking water quality. Total coliform bacteria and thermo tolerant bacteria are the most common indicator bacteria in drinking water. The coliforms are indicative of the general hygienic quality of the water and the potential risk of infectious diseases from water (Iwar, 2018).

2.6.1.1. Total coliform

Are Aerobic or facultative anaerobic, Gram-negative, non-spore-forming, rod-shaped, gas production during lactose fermentation within 48 hours at 35°C (WHO, 2011a). A group of bacteria that are included under coliform bacteria are like Enterobacter, Klebsiella, Aeromonas, etc (Igibah & Tanko, 2019).

The studies conducted in Shambu town drinking water ethiopia showed a total coliform in the range from 4 CFU/100 ml to 151 CFU/100 ml in different sampling points which are significantly different from each other.

The unusual significantly higher number of total coliform in a sample could be associated with the leak of the specific pipeline. The other factor that contributes to increment of total coliform in tap could be associated with the irregular availability of water across the line which gives chance to the stability of microorganisms for reproduction in a specific area.

2.6.1.2. Fecal coliform/fecal streptococci

Fecal coliforms (A subgroup of total coliforms) reside in the intestinal tract of warm-blooded animals (including humans) and can ferment lactose and produce both acid and gas at 44.5°C in 24 hours. These organisms can vary from the total coliform group by their ability to grow at elevated temperatures (Mishra *et al.,* 2019). The studies conducted in Jimma zone showed a fecal coliform in the range of 1-266 CFU/100 ml.

2.6.2. Physical parameters

2.6.2.1. Electrical Conductivity (EC)

Electrical conductivity is an indicator of the taste or salinity of the water can be considered as an alternative indicator of total dissolved solid (TDS). Changes in conductivity with time and high conductivity values can indicate contamination of water (e.g. saline intrusion, sometimes fecal contamination/ pollution or nitrate pollution) (Martínez-Santos *et al.,* 2017; Gwimbi*et al.,* 2019).

2.6.2.2. PH

pH is mostly a result of natural geological conditions at the site and the type of minerals found in the local rock. Water with pH a value greater than 7 indicates alkalinity and tends to affect the taste of the water. Alkaline drinking water may take on a “soda” taste (Damtie et al., 2014).

The pH of the water entering the distribution system must be controlled to minimize the corrosion of water mains in household water systems. Miss adjustment of pH can result in both microbial and chemical contamination of drinking water and can have an antagonistic effect on its odor, taste, and appearance (Dvorak & Schuerman, 2021).

According to Abegaz, (2021), an increase in pH level was observed after treated water left the treatment plant and entered into the distribution system. The pH of the water entering the distribution system must be controlled to minimize the corrosion of water mains and pipes in household water systems (Desye et al., 2021). Failure to control pH can result in both microbial and chemical contamination of drinking water, and can have adverse effect on its odor, taste and appearance.

2.6.2.3. Turbidity

Turbidity of water depends on the quality of solid matter present in the suspended state. The turbidity of the water is related to or affects many indicators of drinking water quality. WHO recommended that the acceptable limit for turbidity in the potable water is 1 NTU and permissible limit is 5 NTU (Dohare*et al.,* 2014). . It is caused by the presence of particulate organic and inorganic matters, such as clay, colloidal particles, silt and microscopic organisms that interfere with the passage of light through the water. Turbidity has no direct health impact but consumption of highly turbid water may create a health risk related to the risk of microbial contamination (Sajitha, 2016).

The studies conducted in Jimma town, Ethiopia (Sisay et al., 2017) shown that up to 12 nephelometric turbidity unit was observed in water samples. whereas, in the other studies in Ethiopia up to 5 nephelometric turbidity unit was observed (Meride & Ayenew, 2016),(Duressa et al., 2019).

According to (WHO, 2011) the turbidity of the water is varied due to the nature of raw surface water, the sampling period, and the runoff conditions.

2.6.3. Chemical parameters

2.6.3.1. Total Hardness

Hardness is caused essentially by calcium and magnesium salts and is communicated regarding identical amounts of calcium carbonate. There is an agreement that groundwater is essentially harder than surface water due to groundwater being wealthy in carbonic corrosive and disintegrated oxygen, as a rule, has a high solvating influence. Hard water incredibly affects the family client tap waters. At the point when the water in family pipes becomes profoundly harder, family lines can get obstructed with scale; hard waters additionally cause incrustations on cooking wares and increment cleanser utilization. The level of hardness of consumable water can be arranged dependent on identical CaCO3 fixation as follows:

Table 1: Classification of water-based on the hardness

S.No	Hardness mg/l as $CaCO_3$	Water class
1	0-60	Soft water
2	60-120	Moderately hard water
3	120-180	Hard water
4	Above 180	Very hard water (terribly hard)

Source; (Alemu et al., 2015)

2.6.3.2. Iron

Iron is the second most abundant metal in the earth's crust. Iron concentration in most of surface water resources is high, due to presence of the iron salts in watersheds and constituent of river-bed (Dvorak &Schuerman, 2021). The presence of iron in distribution networks, accelerates iron bacteria growth, and consequently increases corrosion in network.

In drinking water, the recommended concentration limit of iron is normally less than 0.3 mg/l, but the study conducted in Nekemte town, Ethiopia showed that the concentration of iron in the water 0.67 ± 0.2 mg/l, which is above WHO recommendation (Duressa*et al.,* 2019).whereas less amount of iron were recorded in in Iran (0.11 mg/l) (Al-dulaimi & Younes, 2017).

The concentration of iron may be higher in countries where various iron salts are used as coagulating agents in drinking water treatment plants and where cast iron, steel and galvanized iron pipes are used for water distribution. Aeration of drinking water (having well ventilated dissolved oxygen) can affect the quality of both groundwater and surface water if groundwater table is lower. The dissolution of iron can occur as a result of decrease in water pH and oxidation water.

2.6.3.3. Copper

Copper salts are discharged through industrial wastewaters. Also they are used to control of biological growth in reservoirs and water transport lines. Although copper is an essential micronutrient, but in high concentration causes taste and odor in water and also has physiological effects in human (Maleki et al., 2015).

2.6.3.4. Flouride

Most groundwater samples have low or acceptable concentrations of fluoride (<1.5 mg/L) according to the recommendation of WHO (WHO, 2011). However, some large groundwater provinces have significant concentrations which cause prominent health problems. The presence of large amounts of fluoride is associated with dental and skeletal fluorosis (>1.5 mg/L) and inadequate amounts with dental caries (< 1 mg/L) (Garoma et al., 2019).

The study done in the rift valley areas of Ethiopia shows high concentrations of fluoride, up to 11.6 mg/L was observed in ground water sources. The other study conducted in the Rift Valley area, fluoride concentration was found above 5.0 mg/L in shallow wells and in the rivers (Garoma et al., 2019). Whereas, in Jimma and Metu town water sources, below the recommended WHO guideline values of 1.5 mg/L was observed (Garoma et al., 2019). The studies conducted in other countries shows the fluoride amount in surface water in range value of 0.18–0.65 mg/L was also observe (Iwar, 2018).

2.6.3.5. Nitrate

Nitrate is an oxidizable form of nitrogen and occurs in trace amount in surface water, and is toxic when present in extreme amounts in drinking water. The source of nitrate mostly comes from industrial, agricultural chemicals, and fertilizer applications. The most common source of nitrate concentration is attributed to animals and human waste disposal practices and the use of agricultural fertilizer (Macdonald *et al.*, 2017). The permissible recommended value of nitrate is 50 mg/L as stated by (WHO, 2011). But Mean nitrate concentration up to 95.80 ± 8.45 mg/l were recorded from tap water in Jimma zone, south west Ethiopia (Yasin et al., 2015).

2.6.3.6. Sulfate

Sulfate mainly is derived from the dissolution of salts of sulfuric acid and found in all almost water bodies. Sulfate concentration in natural water ranges from a few to a several 100 mg/liter, but no major negative impact of sulfate on human health is reported. The WHO has established 250 mg/l as the highest desirable limit of sulfate in drinking water (Meride & Ayenew, 2016)

2.6.3.7. Copper

Copper is an indispensable component of many enzyme systems in our body. However, a number of pathogenic characteristics are attributed to this element. It is connection with a form of early childhood liver cirrhosis. EPA has set a goal for copper at a maximum allowable level of 1.3 mg per liter of drinking water.

2.6.3.8. Manganese

Manganese in drinking water at elevated levels can pose neurological effects on health risk (Dvorak & Schuerman, 2021).

2.7. Conceptual frame work

The drinking water quality is determined by the quality of source water, the treatment in water treatment plants before distributed and the water distribution system. Even if improvements in the water quality leaving water treatment facilities, contamination often occurs within the water distribution infrastructure. Subsequently, the water which is ultimately transported may be stored at different storage which may contribute to the contamination of drinking water by different contaminant.

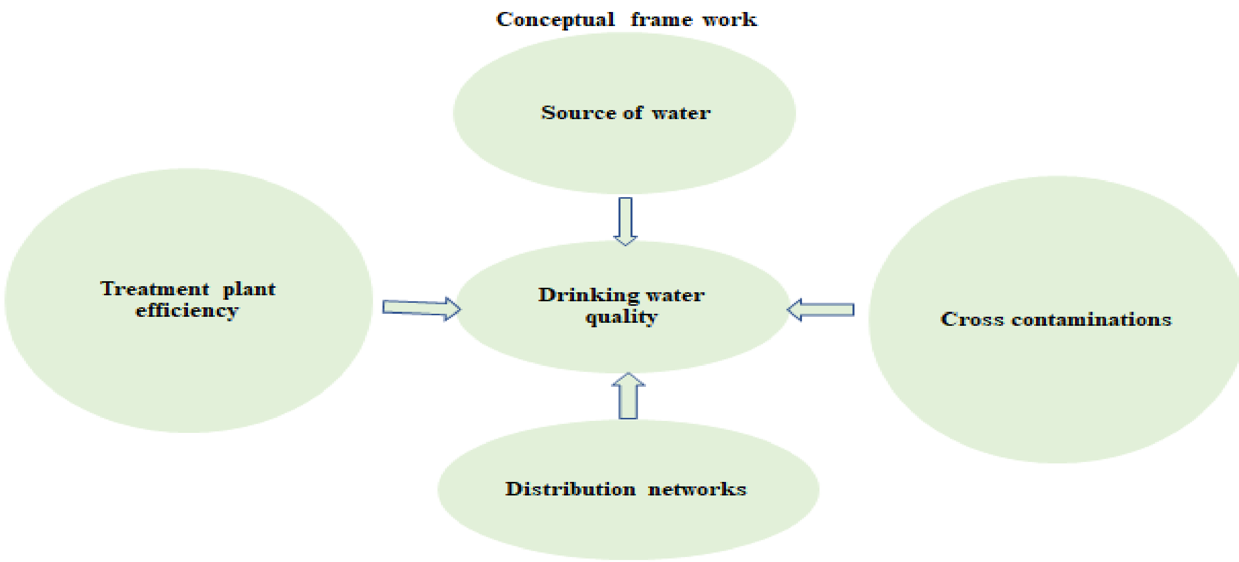

Figure 1: Conceptual framework

CHAPTER THREE

OBJECTIVES

3.1. General Objective

To assess the physico chemical and bacteriological quality of drinking water in conventional drinking water treatment process and water supply system in Malle woreda, southwest Ethiopia.

3.2. Specific objectives

- To assess bacteriological quality of drinking water in Boshkoro, Kella and Lemogento conventional drinking water treatment process and water supply system.
- To assess physico chemical parameters of drinking water in Boshkoro, Kella and Lemogento conventional drinking water treatment process and water supply system.

CHAPTER FOUR

METHODS AND MATERIALS

4.1. Study Area

The study was conducted in three kebeles treatments plants of Malle Woreda, which is found in SNNPRS, South Omo zone and it is 792 km far from Addis Ababa capital city of Ethiopia and covers an area of 1,432 square kilo meters (Teklemariam et al., 2020). The altitude of the Woreda ranges between 600-1500 m above sea level and is astronomical located at 5.08N-6.00N attitudinally and 36.30E-370E longitudinally (Zebire & Gelgelo, 2019). The mean annual temperature of the woreda in degrees Celsius is about 15-35^{o}c (Teklemariam et al., 2020).

Malle woreda has 28 kebles. Before site selection and data collection, a checklist was prepared following the objectives of the study. The Boshkoro treatment plant, Lemogento treatment plant and Kella treatment plant sites were selected purposively because they were the only kebles in Malle woreda in which conventional treatment process were available and they were known to have a reasonable outbreak of cholera in Lemogento and Boshkoro sites and the outbreak of disease on humans and animal that used the water supplied by Kella water treatments and there were no frequent monitoring and evaluation by the owner body and the transportation for laboratory analysis were considered.

World Health Organization guideline WHO (2011) for drinking water quality and the health effect was used as a base for the selection of physicochemical and bacteriological parameters.

Bazo River was the source of raw water for Lemogento and Kella town. Although the final treated water is lifted by high-lift pumps to a distribution reservoir placed in the Lemogento Selam village palace for onward distribution to the Lemo gento town administration. The source of raw water for Boshkoros town drinking water treatemnt was Biyo River.

Boshkoro, Lemogento and Kella town have the same treatment units. The treatment plant has coarse screens and an intake with two low-lift pumps, preliminary treatment by storage, sedimentation, slow sand filtration, and chlorination structures fig 3. The Boshkoro and Lemogento treatment plants are constructed by AFD, while, Kella treatment plant constructed by IRC.

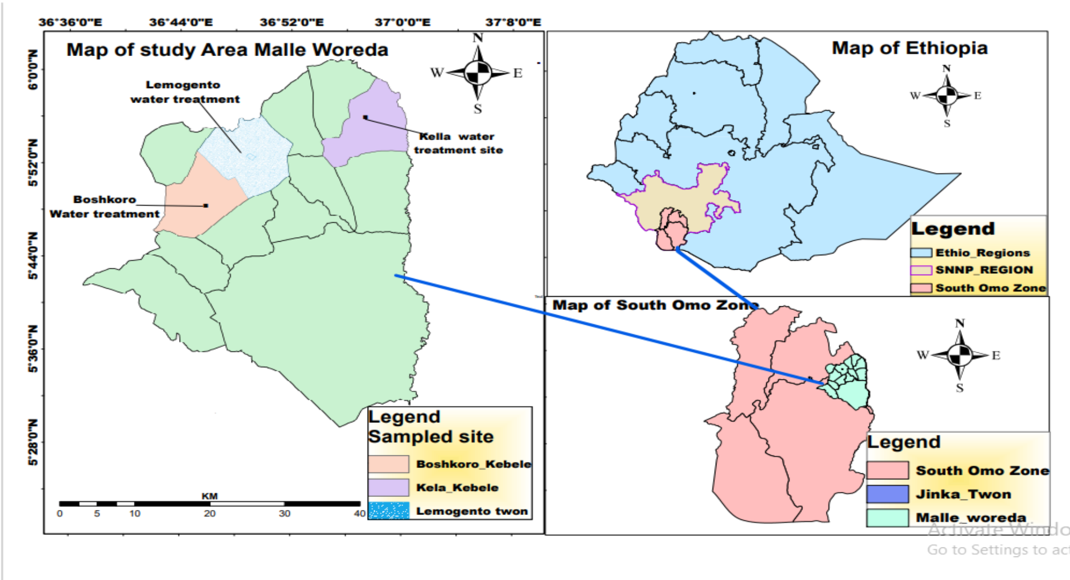

Figure 2: Map of the study area.

4.2. Study Design, Period and Sample Size Determination

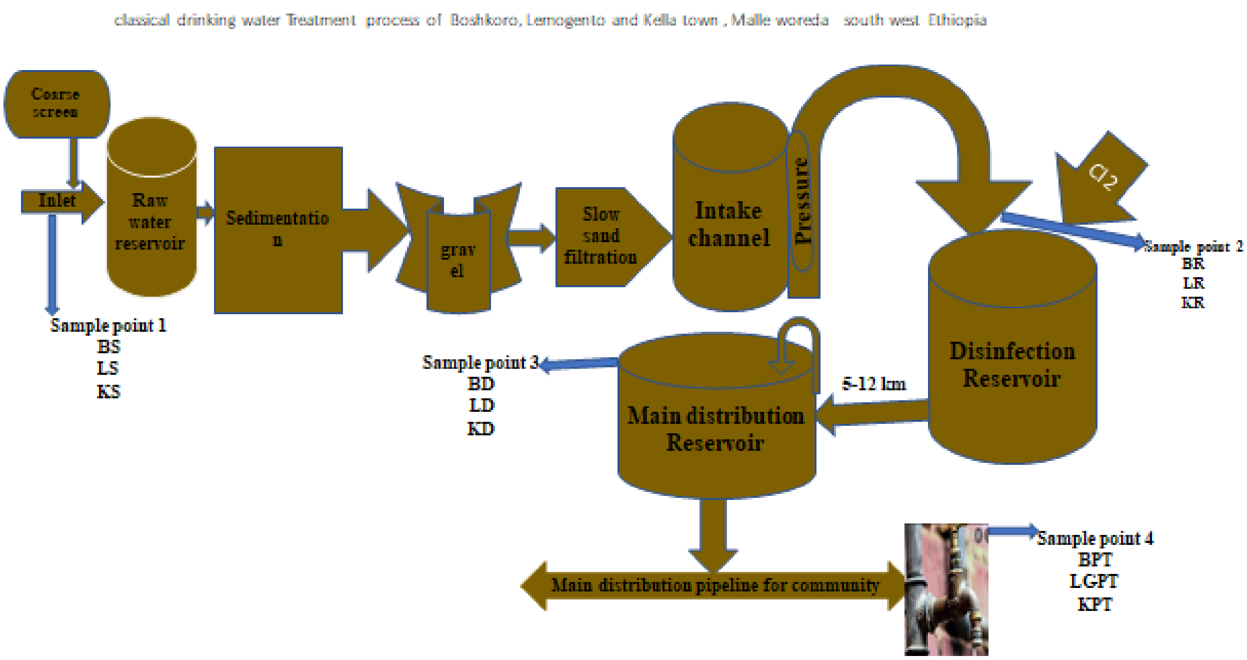

Figure 3: The typical treatment process and sample points of Boshkoro and Lemogento town water treatment process, Malle woreda, southwest Ethiopia.

A laboratory- based cross-sectional study design was conducted to assess the Physco-chemical and bacteriological quality of conventional drinking water treatment processes and water supply system in Malle woreda, from August 1 to October 28, 2021. A total of 12 water samples were collected from the inlet (before undertaking any treatment), disinfection reservoir (treated, after it goes the disinfection unit), distributions, and public tap of Boshkoro, Lemogento and Kella sites. Water samples were collected using WHO-recommended minimum sample numbers for piped drinking water (WHO, 2008, WH O, 2011).

4.3. Sampling methods and procedures

World Health Organization guideline for drinking water quality assessment was used to collect and analyze water samples (WHO, 2011).

Grab samples were collected from the inlet of the treatment plant (source)(S), reservoir (disinfection point)(R), distribution(D), and public tap(PT). The samples were collected once from each of the sampling sites.

Water samples were collected aseptically by using 200 milliliter sterilized glass bottles for bacteriological quality analysis and one-liter polyethylene bottles were used for physicochemical analysis. Before sampling had taken, the glass bottles were sterilized by using an autoclaved to avoid any contamination and the polyethylene bottles were rinsed with distilled water.

For chlorinated water (treated water), sample collection was carried out using glass bottles that are autoclaved with 0.1 mL 3% sodium thiosulphate ($Na_2S_2O_3$) to neutralize the chlorine present in the sample (Desye et al., 2021). For the public tap sample collection, the tap was turned on at maximum flow rate, and the water was allowed to flow for 2 minutes and then tap was disinfected for a minute using 70% alcohol and allowed to flow at a medium rate for 2 minutes (Patent al., 2016). Previously sterilized glass and clean polyethylene bottles were open for collecting water samples by holding the bottle steady under the water jet, while the cover cup was held in an up-down position (Pantet al., 2016). Figure 6 shows sampling collection from public tap.

Sample collections at treatment plant units were taken by following to surface water sampling procedure by dipping the sampling bottle to 20 cm of the water body. Sample collection from disinfection reservoir was depicted in figure 5.

The collected water samples from each treatment unite were labeled and kept in a cold box containing ice freezer packs (4ºC) and were transported to the south nation's nationality public health institute for bacteriological analysis and transported to the S/N/N/P/R water mine an and energy office water resource study and management laboratory, Hawassa, Ethiopia, for chemical analysis.

Figure 4: Sample collection from the distribution (A); reservoir at disinfection point (B); disinfecting Public tap (C); sample collection from tap (D).

Figure 5; Measuring (1) PH and temperature (2) conductivity on site.

4.5. Data analysis

4.5.1. Bacteriological analysis

Bacteriological analysis for total coliforms (TC) and fecal coliforms (FC) were determined and enumerated by the Millipore filtration method using the membrane filter technique as outlined in (APHA, 1999) and as per the procedure by (Krishnan *et al.,* 2007). A 100ml sample was placed on the surface of a sterile membrane filter with pore size 0.45µm and 47 mm diameter placed on the funnel unit of the membrane filter support assembly. Then, using a sterile forceps membrane were removed immediately and placed on the adsorbent pad which is filled with Membrane Lauryl Sulphate broth with a rolling motion to avoid entrapment of air in Petri dishes. Finally, for TC and FC, water samples were incubated at 35°C and 44°C for 18-24 hours, respectively, and all yellow colonies were counted as TC and FC with the aid of a magnifying lens (Desalegn e*t al.*, 2013).

4.5. 2. Physicochemical Analysis

For all water samples collected from the Boshkoro, Lemo gento and Kella treatment plants and supply system temperature, pH, EC, turbidity, fluoride, total hardness, chromium, nitrate, sulfate, phosphate, $Fe2^{+}$, $Mn^{2+,}$ and Cu were analyzed three times for each sample.

Onsite measurements were such as; temperature and pH for Lemogento and Kella treatment sites were analyzed by using a waterproof wagtech PH meter. EC was analyzed by using a waterproof wagtech conductivity meter and for a Boshkoro treatment site temperature and pH were analyzed by using standard instrument HQ440d multi-parameter meter electrode. The turbidity of each sample was determined by using (HACH 2000) turbidity meter and the result was put in Nephelometric Turbidity Units (NTU) (Homaida & Goja, 2013).

Nitrate, iron, manganese, fluoride, chromium, sulphate, and phosphate were determined using DR 5000 spectrophotometer. Total hardness was determined by the complexometric titration method using eriochrome black T (EBT) as an indicator and with standardized ethylene diamine tetra acetate (EDTA) solution (Khanet al., 2013;Hassane et al., 2020). The concentration of Cu was determined on the Palintest-Photometer 9300 instrument after zeroing with the experimental blank sample (Hassane et al., 2020).

4.5.3. Statistical analysis

Data were analyzed by Statistical Package for Social Sciences (SPSS) software version 23, Microsoft Excel 2016. The results of triplicate analysis were documented on each day of sampling result. Descriptive measures including mean, median, standard deviation, and the range were used to analyze the laboratory investigation data and the result was analyzed statically with the acceptable standards. The data was presented by using a table and graph. A correlation test was used to determine relationship between physico chemical and bacteriological parameters that shows the value of one parameter in association with a corresponding increase or decrease in the value of the other parameter.

4.6. Data quality control

Calibration of field equipment and cleaning of laboratory glassware were performed just prior to and just after field measurements. A Triplicate analysis was done for physicochemical and bacteriological analysis. For each water sample, code numbers were given and the following information was accompanied; Date of Sampling, Reasons for examination, sampling point from where the water was collected, the exact place from where and which treatment the water samples were taken should also be stated. Calibration and Linearity of Instrumental Responses were done. The calibration curves for each selected heavy metal were settled to ensure the accuracy of the Atomic Absorption Spectrophotometer and to confirm that the results of measurements were true and reliable.

4.7. Ethical Issue

Ethical clearance was first obtained from the research and ethical review board of the Institute of Health Science, Jimma University. Institutional consent was obtained from concerned institutions and bodies after communicating with a formal letter. Permission for dat a collection from Malle woreda was sought from Malle woreda's water and energy office.

4.8. Dissemination Plan

The findings of this study will be submitted to the Jimma University, Institute of Health, Faculty of Public Health, Department of Environmental Health Sciences and Technology. The result will be presented during defense, as partial fulfillment of the requirement of a master’s degree in Environmental Science and Technology. The result of the finding will be published in a reputable journal. Finally, written documents will be submitted to Jimma University, Environmental Health Sciences and Technology and Malle woreda water and energy office that have contributed to alleviating the identified gaps.

4.9. Operational definition

Conventional drinking water treatment: Conventional drinking water treatment consists of a combination of, sedimentation, filtration and disinfection to provide clean and safe drinking water to the public. Physical, chemical, and biological processes and operations to remove solids, organic matter and sometimes nutrients from water. A well protected ground water source, without any treatments for metals (iron, manganese, copper), primary and secondary disinfection with chlorine is most effective.

Water supply system: Is infrastructure for the collection, storage and distribution of water for community.

Distribution of water: is a part of water supply network with components that carry potable water from a centralized treatment plant or wells to consumers.

Filtration: Water passes through a substance, such as sand or a membrane that helps remove unsettled flocs, particles, contaminants and pathogens.

CHAPTER FIVE

RESULT

5.1. Physical Quality of water

To determine whether the unites of water treatment plant removes contaminants and water storage is affecting water quality, a cross-sectional study was conducted between the samples collected from source or inlet(S), reservoir or disinfection(R), distribution(D) and public tap (PT) of Boshkoro, Lemogento and Kella town water treatment, and supply system.

Correlation analysis among physical chemical parameters and the bacteriological load was depicted in the annex part.

The mean pH value for Source, Reservoir after disinfection, Distribution and Public tap of Boshkoro town drinking water treatment and water supply were 7 ± 17, 7 ± 0.73, 7.2 ± 0.17 and 7.17 ± 0.20 respectively. In general, an increase in pH level was observed in all treatments of study areas after treated water left the treatment plant and entered into the distribution system and reached the public tap. The conductivity of the water decreases from source to disinfection unit and increases in distribution.

The mean physical parameters results of municipal conventional drinking water treatment analysis and water supply system from source or inlet to public tap samples located in the targeted area of Boshkoro, Lemogento and Kella towns are summarized in Table 2.

Table 2: Mean ± SD of physical parameters of water samples at different *s*ampling points of Boshkoro, Lemogento and Kella treatment systems in Malle woreda, southwest Ethiopia.

Treatment site	SP	pH ± SD	EC (µS/cm) ± SD	Turbid(NTU) ± SD
Boshkoro town	S	7 ± 173	322 ± 9.54	2.67 ± 0.57
	R	7 ± 0.73	334 ± 30.3	1.67 ± 0.57
	D	7.2 ± 0.17	326 ± 4.58	1.3 ± 0.57
	PT	7.17 ± 0.20	337 ± 5	1.3 ± 0.58
Lemogento town	S	7.53 ± 0.15	206.67 ±9.60	1.7 ± 0.56
	R	7.27 ± 0.18	202.13 ± 1.02	1.00 ± 0.00
	D	7.43 ± 0.3	201.67 ± 0.58	1.00 ± 0.00
	PT	7.27 ± 0.15	204.33 ± 3.51	1.00 ± 0.00
Kella town	S	8.3 ± 0.100	5014.33 ± 7.76	3.50 ± 1.50
	R	7.9 ± 0.40	4849.67 ± 5 .3	1.3 ± 0.5
	D	8.1 ± 0.23	5008.00 ± 0.40	1.67 ± 0.58
	PT	7.4 ± 0.30	5005.67 ± 7.23	2.0 ± 1.00

Note. SP: Sampling point; S: sampling from source; R: sampling after disinfection Reservoir; D: sampling from distribution; PT: sampling from public tap; SD: standard deviation;

5.2. Chemical parameters of water

Water samples collected from inlet or source, reservoirs at disinfection point, distribution and public tap were analyzed for chemical parameters. The mean and SD of chemical parameters for all treatment units from which samples had taken were depicted in table 3 below.

Table 3: Mean ± SD of chemical parameters of water samples at different sampling points of Boshkoro, Lemogento and Kella treatment systems in Malle woreda, southwest Ethiopia.

Treatement site	SP	Total Hardness [mg/L as $CaCO_3$]	[Cl_2][mg/L]	Fluoride [mg/L]	Nitrate [mg/L]	Sulfate [mg/L]	Phosphate [mg/L]
Boshkoro town	S	144.66 ± 0.57	0.17 ± 0.22	0.40 ± 0.01	6.70 ± 0.40	11.58 ± 1.62	0.63 ± 0.15
	R	144.00 ± 1.00	0.24 ± 1.00	0.38 ± 0.01	2.67 ± 0.58	5.00 ± 2.64	0.40 ± 0.10
	D	143.67 ± 0.58	0.33 ± 0.11	0.37 ± 0.01	2.33 ± 0.58	3.67 ± 0.58	0.36 ± 0.08
	PT	140.00 ± 1.00	0.30 ± 1.00	0.35 ± 0.02	1.33 ± 0.58	4.00 ± 2.00	0.22 ± 0.10
Lemogento town	S	87 ± 2	0.16 ± 0.11	0.28 ± 0.13	0.91 ± 0.08	6.20 ± 0.85	0.34 ± 0.11
	R	85.67 ± 2.51	0.30 ± 0.10	0.27 ± 0.16	0.62 ± 0.10	5.36 ± 0.18	0.26 ± 0.06
	D	83.00 ± 2.00	0.23 ± 0.05	0.27 ± 0.05	0.55 ± 0.15	5.23 ± 0.69	0.22 ± 0.02
	PT	81.7 ± 2.89	0.21 ± 0.10	0.20 ± 0.00	0.53 ± 0.20	4.83 ± 1.04	0.07 ± 0.12
Kella town	S	1783.00 ± 115.05	0.20 ± 0.10	1.64 ± 0.06	4.74 ± 0.10	92.40 ± 4.61	0.98 ± 0.06
	R	1778.33 ± 3.51	0.50 ± 1.00	1.64 ± 0.11	4.57 ± 0.18	94.50 ± 3.96	0.96 ± 0.01
	D	1777.33 ± 12.22	0.30 ± 0.15	1.64 ±0.03	4.51 ± 0.03	90.00 ± 0.00	0.94 ± 0.01
	PT	1776.33 ± 1.15	0.46 ± 0.57	1.62 ± 0.04	4.49 ± 0.28	86.00 ± 2.64	0.92 ± 0.02
WHO	-	300	5	1.5	50	250	-

Note. Sampling point (SP), Source point (S), Disinfection point (R), Main distribution (D), public Tap water (PT), Total chlorine [Cl_2], World Health Organization drinking water permissible standard (WHO limit).

5.3. Concentration of heavy metals in water

The level of heavy metals (micronutrients) in drinking water is of significant concern. The metals analyzed include chromium, iron, copper and manganese, viewed against the standards as prescribed by the WHO guidelines for drinking water which were depicted in figure 6, figure 7 figure 8 and 9.

Chromium concentrations in public tap of Boshkoro, Lemogento and Kella treatment site water sample was 0.01± 0.01, 0.002± 0.18 and 0.002 ± 0.01 respectively fig 6.

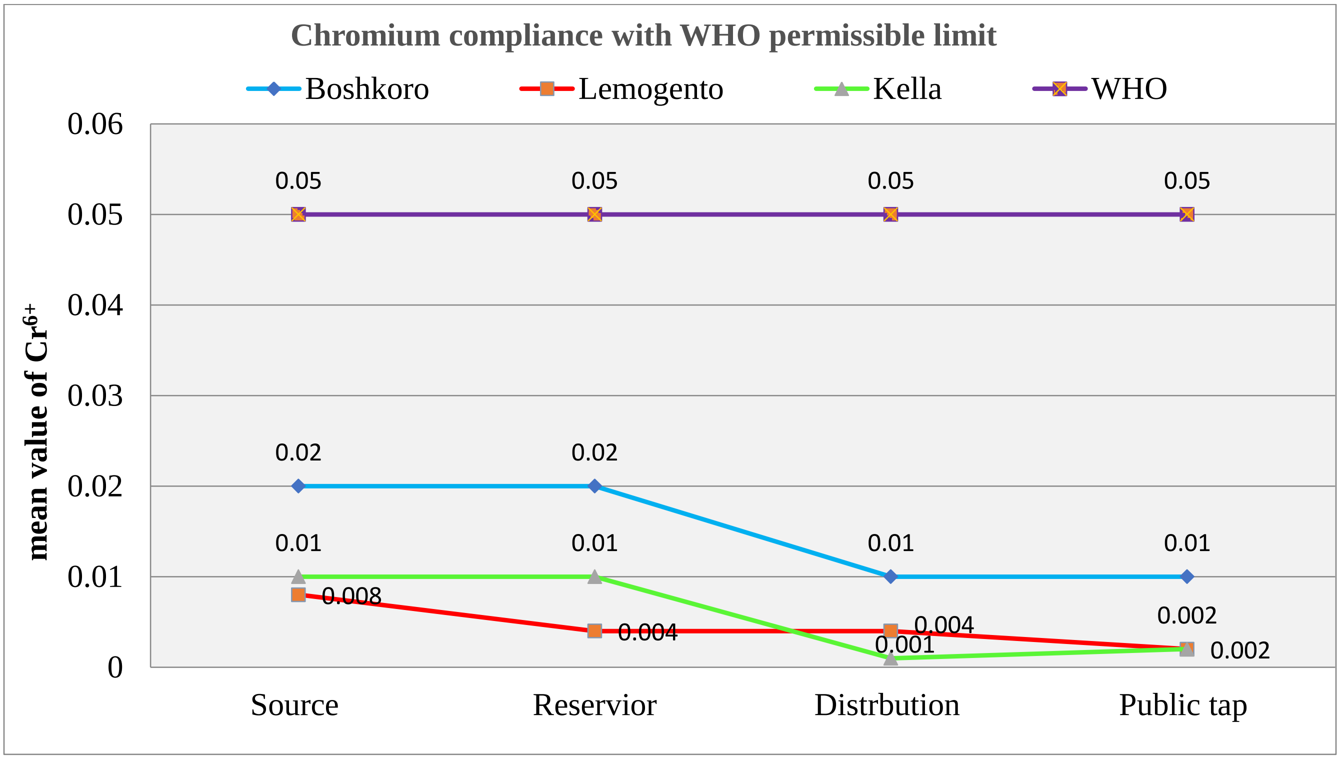

Figure 6: chromium variation in Boshkoro, Lemogento and Kella town water treatments and supply system.

Iron is an essential element in the human body. But, consuming a high concentration of iron was suffering liver diseases. The mean result for iron from which samples had taken from source or inlet(S), reservoir after disinfection(R), at distribution (D) and public tap (PT) of Boshkoro, Lemogento and Kella towns water treatments and supply system were depicted in figure 7.

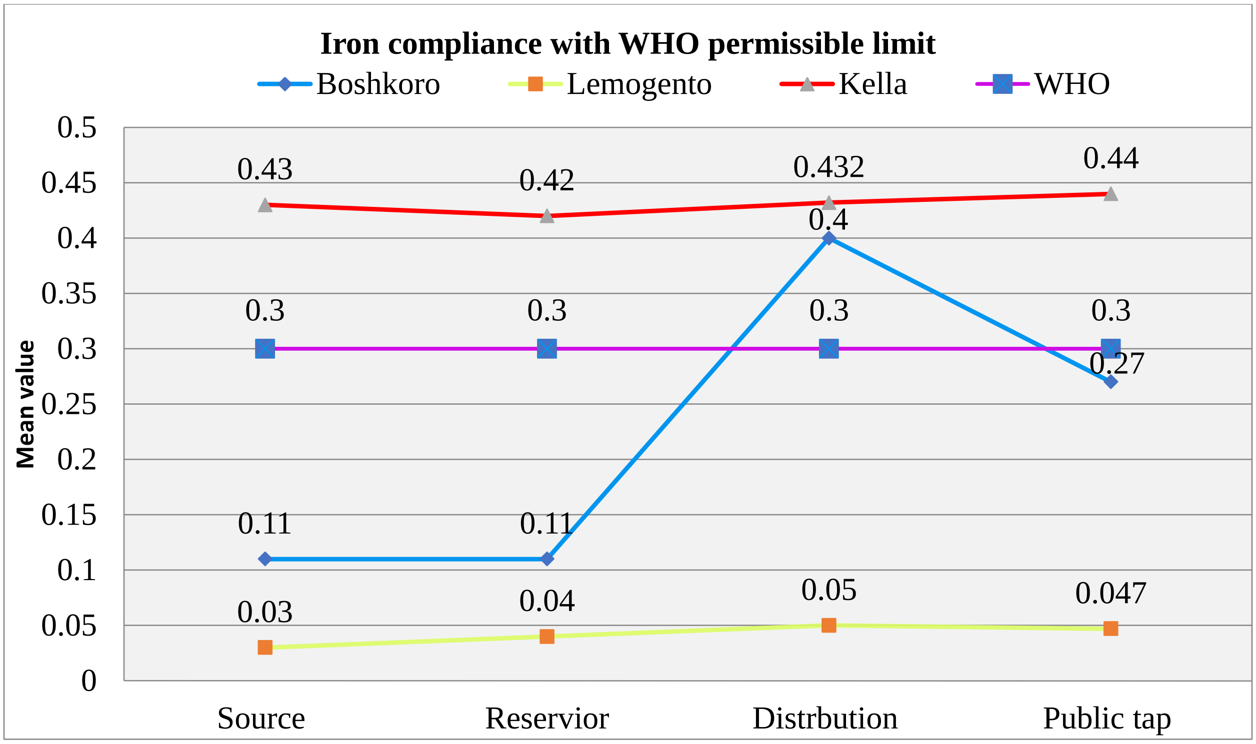

Figure 7: Iron variation in Boshkoro, Lemogento and Kella town water treatments and supply system.

The mean of copper for all treatment units from which samples had taken S, R, D and PT of the study area was depicted in figure 8.

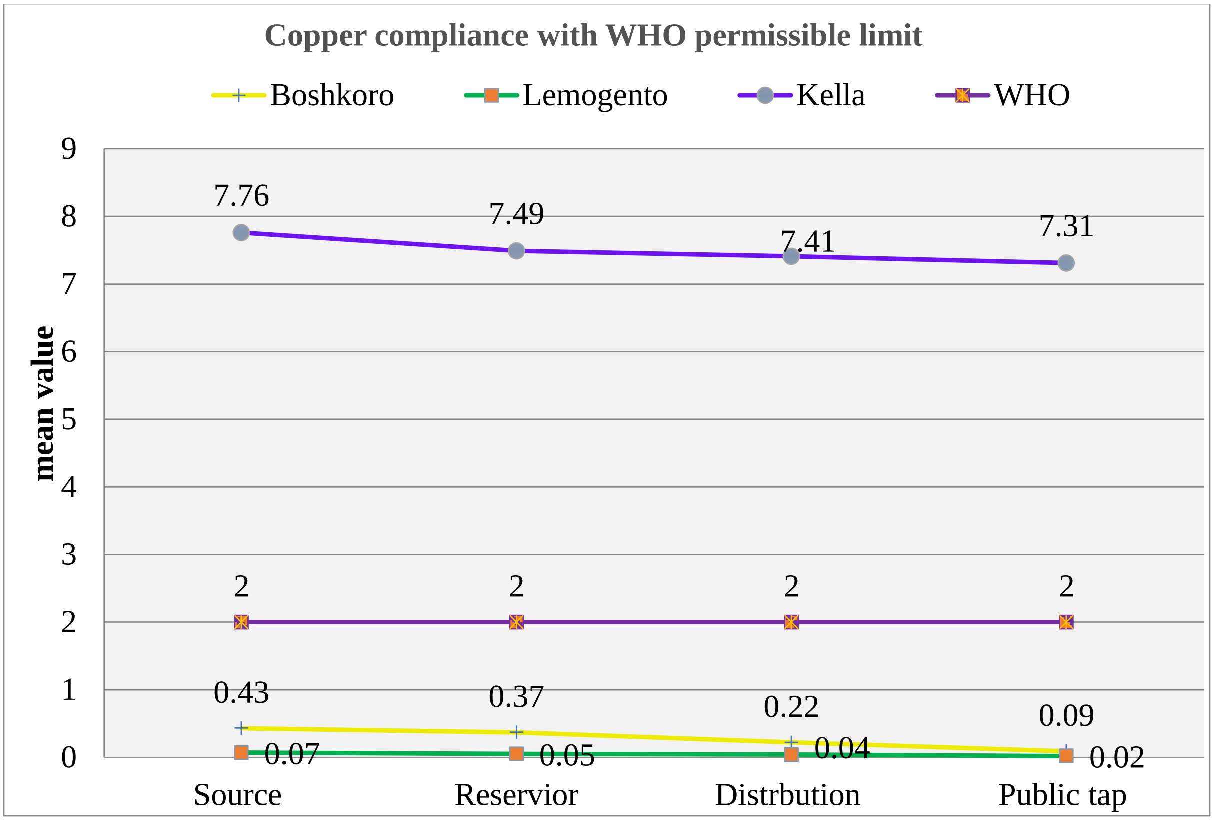

Figure 8: Copper variation in Boshkoro, Lemogento and Kella town water treatment and supply system.

Manganese is a most abundant trace element in the earth crust which is usually occurring together with iron and it is widely distributed in sedimentary rocks, soil and water. The mean result for manganese from S, R, D, and PT of Boshkoro, Lemogento, and Kella treatment and water supply system were shown in figure 9.

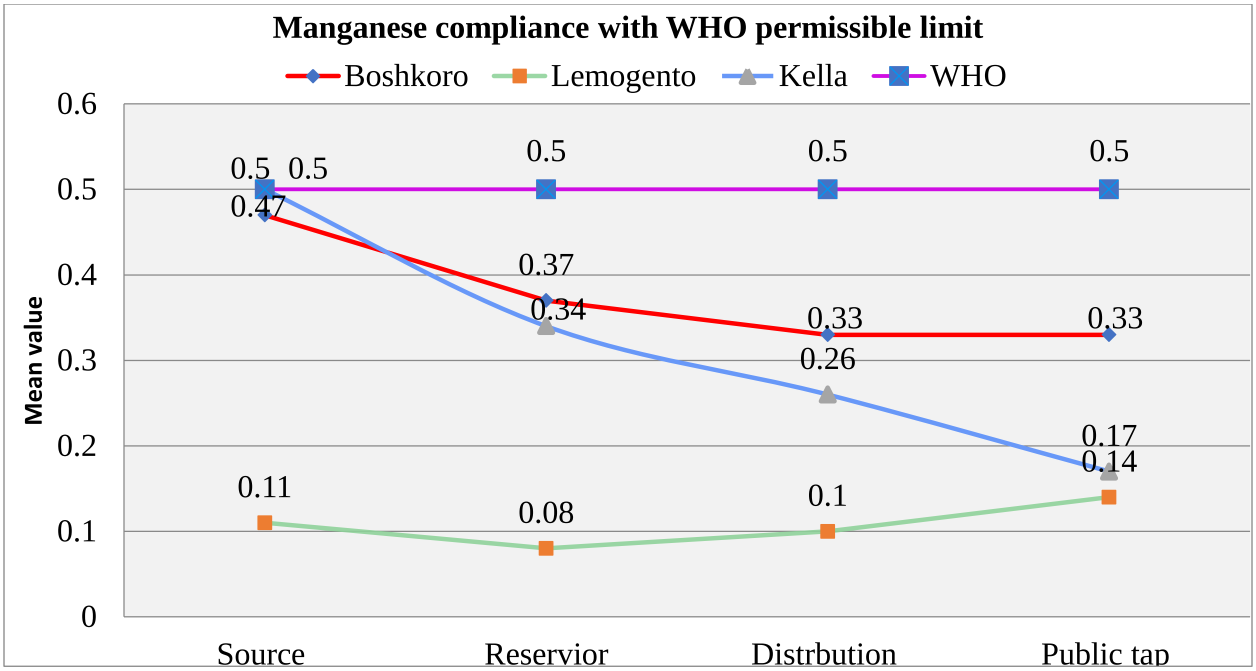

Figure 9: Manganese variation in Boshkoro, Lemogento and Kella town water treatments and supply system.

5.4. Bacteriological Quality of water

The mean and standard deviation of total coliform and fecal coliform counts for water samples collected from the inlet or source, disinfection point or R, distribution and public tap of Boshkoro and Kella drinking water treatment and water supply were depicted in table 5.

Table 4: The mean and standard deviation of total coliform and fecal coliform counts for water samples collected from Boshkoro, Lemogento and Kella drinking water treatment plant and supply system.

Treatment site	SP	TC(CFU)			FC(CFU)			WHO
		Minimum	Maximum	Mean±SD	Minimum	Maximum	Mean±SD	
Boshkoro town	S	10	14	11.66 ± 2.08	17	22	19.00 ± 2.64	0
	R	2	5	3.00 ± 1.00	4	10	8.00 ± 3.46	
	D	1	3	1.67 ± 1.53	3	4	3.67 ± .58	

	PT	1	2	1.33 ± 0 .58	2	4	3.00 ± 1.00	
Lemogento town	S	6	14	10.00 ± 4.00	7	11	8.67 ± 2.08	0
	R	0	0	0 ± 0	0	0	0 ± 0	
	D	0	0	0 ± 0	0	0	0 ± 0	
	PT	46	85	69.0 ± 20.42	30	90	56.67 ± 0.55	
Kella town	S	10	16	12.67 ± 3.05	5	8	6.67 ± 1.53	0
	R	0	2	1.00 ± 1.00	0	1	0.33 ± 0.58	
	D	0	3	1.33 ± 1.53	1	3	2.00 ±1.00	
	PT	1	2	1.67 ± 0.56	2	4	3.00 ± 1.00	

Note. SP: sampling point; S: sampling from source; R: sampling after disinfection Reservoir; D: sampling from distribution; PT: sampling from public tap SD: standard deviation; FC: fecal coliform; TC: total coliform; CFU: colony-forming unit.

5.5. Correlation study

The correlation coefficient has the value between +1 and -1 and it is characterized as strong, when it is in the range of ± 0.7 to ±1.0, moderate in the range of ±0.5 to ±0.7 and weak when in the range of ±0.0 to ±0.5. Correlation is the mutual relationship between two variables that shows the value of one parameter in association with a corresponding increase or decrease in the value of the other parameter. In order to trace the relationship among the various physicochemical parameters correlation coefficient (r) matrix among was calculated and the values of the correlation coefficients were given in the Table 6.

Table 5: Correlation study between physicochemical parameters vs bacteriological load.

Correlations							
		pH meter	Electrical conductivity	Turbidity	Total chlorine	Total colonies count in 100ml of sample	Fecal colonies count in 100ml of sample
pH meter	Pearson Correlation	1					
Electrical conductivity	Pearson Correlation	.722**	1				
Turbidity	Pearson Correlation	.205	-.057	1			
Total chlorine	Pearson Correlation	.231	.012	-.003	1		
Total colonies count in 100ml of sample	Pearson Correlation	-.113	-.201	.059	-.210	1	
Fecal colonies count in 100ml of sample	Pearson Correlation	-.241	-.266	.000	-.276	.895**	1
**. Correlation is significant at the 0.01 level (2-tailed).							

The pH meter showed significant positive correlation with EC and turbidity, and negative correlation with total coliform and fecal coliforms. From this parameters pH vs EC showed a significant strong positive correlation of (r= 0.722) pH vs turbidity showed weak correlation, (r=0.205). The pH vs TC and pH vs FC showed negative correlation (r= -0.113, r= -0.241) respectively table 5.

The EC showed significant negative correlation with turbidity, Tc and Fc (r= -0.057, 0.0201 and0.266) respectively (table 5).Turbidity showed positive correlation with pH, FC and TC and negative correlation with EC Total chlorine showed a significant negative correlation with both FC and T (r= -.210 And -.276) respectively (table 5).

CHAPTER SIX

DISCUSSION

6.1. Physical Quality of drinking water in water treatment process and water supply system.

pH

pH is an important parameter in evaluating the acid-base equilibrium of drinking water. From the above Table 2, the mean pH values at sampling locations were within the maximum limit set by national, WHO and EPA limits. However, the mean pH values between the source inlet, disinfection point, distribution and tap were determined to be significant ($p<0.05$) among each other.

In general, an increase in pH level was observed after treated water left the treatment plant and entered into the distribution system and reached the public tap in all treatment systems which is consistent with the study by (Abegaz, 2021) who reported that the pH in drinking water increased as a result of corrosion taking place in distribution systems. Accordingly, the reason for this significant increase in pH level in between the treatment plant and the public tap water may be attributed to the corrosion of pipeline materials used in the distribution systems (Desye et al., 2021).

The pH of water samples was within the narrow range of 7–8.3. It remained within the recommended standard limits of 6.5–8.5 (WHO, 2011). The pH values of water obtained in this study are compliance with the results of previous studies, i.e., the average pH records of various cities water sources, pH 7.6 at Akaki Kality, subcity of Addis Ababa Yasin et al., 2015);; pH 8.3 at Nekemte town (Duressa *et al.*, 2019); and pH of 7.8 at Adama (Eliku & Sulaiman, 2015). The variation could be due to geological conditions of the water sources. (Duressa *et al.*, 2019).

Electrical conductivity

Pure water is not a good conductor of electric current rather than a good insulator. An increase in ions concentration enhances the electrical conductivity of water (Abegaz, 2021). Generally, electrical conductivity of the water is determined by the amount of dissolved solids. According to WHO standards, electrical conductivity value should not exceed 400 μS/cm. As shown in table 2 of the current investigation indicated that the mean of EC value was ranged from 201.67 to 5014.3µS/cm.

In general the conductivity of the water decreases from source to disinfection unit and it increased from disinfection to distribution system water table 2. The increments of EC were attributed to the addition of chlorine-based chemicals for disinfection purpose (Duressa et al., 2019). These chemicals became dissolved solids in the water and thereby increased the EC of the water (Sisay et al., 2017) the higher the dissolved solids in the water, the higher its Electrical conductivity (Subedi *et al.* 2017) and it increased from disinfection to distribution water.

The highest EC was observed in Kella source water (5014.3µS/cm). This study was much more higher than a study conducted in Jimma zone, Ethiopia (366.93 µS/cm) (Sisay et al., 2017). The variation might be due to the local geological conditions, soil types, and agricultural activities of the study area. EC of water analyzed in Kella towns treatment units were found above the WHO drinking water permissible limit of (1000 µS/cm) (WHO, 2011) and EC of all water samples collected from Boshkoro and Lemogento town treatement units was found below the WHO drinking water permissible limits of 1000 µS/cm (WHO, 2011).

Turbidity

Turbidity is a very crucial water quality parameter that is used to determine the safety and acceptability of the drinking water to the consumer. In general the finding of turbidity was consistent with previous studies conducted in Ethiopia (Meride & Ayenew, 2016),(Duressa et al., 2019). However, it was lower than the study reported at Jimma town, Ethiopia (Sisay et al., 2017). The variation might be due to the nature of raw water, the sampling period, and the local runoff conditions (WHO, 2011) (Duressa et al., 2019). For effective disinfection in a drinking water treatment plant, turbidity of 0.5 NTU is recommended. However, according to the WHO, up to 5 NTU is considered acceptable for drinking water treatment (WHO, 2011). However, the turbidity value of tap water for all samples in this study is lower than the WHO recommended value of 5.00 NTU.

6.2. Chemical Quality of drinking water in treatment process and water supply system.

Total hardness

The total hardness of the water samples from a source point, disinfection point, main distribution, and tap water of the Kella treatment plant was 1783 ± 115.05 mg/L 1778.33 ± 3.51, 1777.33 ± 12.22 mg/L, and 1780 ± 0 mg/L, respectively as shown in table 4. The finding of total hardness in tap water (1780mg/L) was much higher than that of a study conducted in Jimma town, Ethiopia (Sisay et al., 2017). This might be due to the source of water and natural geological conditions (WHO, 2011). The total hardness value in pubic tap water source in this study was above the permissible limit of WHO (300 mg/L) (WHO, 2011). The degree of hardness of drinking water is important for aesthetic acceptability by consumers, for economic and operational consideration (WHO, 2011).

Total chlorine

Chlorine is added to water for killing disease causing bacteria to prevent the spread of waterborne disease. Chlorine is added during water treatment process to kill bacteria from untreated and treated water (Wakuma & Fita, 2017). The total chlorines of the water samples from source point, reservoir after disinfection point, distribution, and public tap water were ranged from 0.16-2 mg/L. The higher level of total chlorine was detected in Kella disinfection reservoir and the lowest chlorine was detected in Lemogento source point. The total chlorine content of water samples in tap water of Boshkoro, Lemogento and Kella town were (0.21, 0.30 and 0.46) mg/L respectively table 4. The result this study was higher than (0.21 mg/L) at Nekemte Oromia, Ethiopia (Duressa et al., 2019). In general, the finding of total chlorine in tap water was higher than the source water and lower than the disinfection reservoir and distribution system. The possible justification for increments level of total chlorine at the tap, disinfection reservoir and distribution system water source could be the addition of chlorine in disinfection reservoir.

Fluoride

The fluoride amounts in water samples from inlet or source, reservoir or disinfection point, main distribution, and tap water of Boshkoro and Lemogento water treatment units and water supply system were 0.40 ± 0.01, 0.38 ± 0.01, 0.37 ± 0.01 and 0.35 ± 0.02 and 0.28 ± 0.13, 0.27 ± 0.16, 0.27 ± 0.05 and 0.20 ± 0.00mg/L, respectively, as shown in Table 4.

The result of fluoride amount in studies was reliable than the range value 0.18–0.65 mg/L of study found in East Azerbaijan, Iran (Iwar, 2018), and higher than 0.15 mg/L in Jimma town, southwest Ethiopia (Sisay et al., 2017). The variation may be due to the source of raw water and the treatment capability of the treatment plant (WHO, 2011),(Sisay et al., 2017). The amount of fluoride in tap water sources of Boshkoro and Lemogento water treatment units and supply system was found below the allowable limit of WHO guideline values (1.5 mg/L) (WHO, 2011b). while, The fluoride amounts in water samples from a source point, reservoir, main distribution, and tap water of Kella water treatement units and water supply system were 1.64 ± 0.06 mg/L, 1.64 ± 0.11 mg/L, 1.64 ±0.03 mg/L, and 1.62 ± 0.04 mg/L respectively as shown in table 4 that was found above the permissible limit of WHO guideline values (1.5 mg/L) (WHO, 2011).Therefore, urgent measures should be taken by the water authority before the community exposed to high risk of dental fluorosis.

The finding of fluoride amount in this water treatment and water supply system was higher than the range value 0.18–0.65 mg/L found in East Azerbaijan, Iran (Iwar, 2018) and 0.15 mg/L in Jimma town, Ethiopia (Sisay et al., 2017). The variation might be due to the source of raw water and the treatment capability of the treatment plant (WHO, 2011). In some of the groundwater sources in India, Africa, and the rest of the world, an excess amount of fluoride (up to 100 m/L) has also been reported (Ijumulana et al., 2021).

Nitrate

Nitrate is one of the diseases causing parameters of water quality particularly blue baby syndrome in infants. The WHO permits the maximum permissible limit of nitrate is 5 mg/l in drinking water. The minimum and maximum measured nitrate concentration of the water samples from a source point, reservoir, main distribution, and public tap waters of Boshkoro, Lemogento and Kella drinking water treatment process and water supply system was 0.53mg/L in Lemogento tap and 6.70 mg/L in Boshkoro source water (Table 4).

The results of this finding are consistent to the average values of 0.3–7.0 mg/l from Ziway town (Gonfa et al. 2019). and less than the result of nitrate content reported from Bahr Dar (9–30.1 mg/l) (Meride & Ayenew, 2016).

The lowest finding of nitrate in Boshkoro source water was consistent with previous studies conducted in Ethiopia (Meride & Ayenew, 2016). But, the nitrate level of the tap water sources (0.53 mg/L) measured in Lemogento public tap is lower than 0.89 mg/L in Jimma town, Ethiopia (Sisay et al., 2017) and 3.6 mg/L in Nekemte Oromia, Ethiopia (Duressa et al., 2019). The variation might be due to, the local runoff, the source of untreated water and sewage conditions (WHO, 2011).

The nitrate content in sources was significantly higher than the rest sampling points in all treatment plants. This might be due to the leaching of nitrate containing organic wastes and from of fertilizers use in the nearby agricultural fields. But, the nitrate level in the tap water supply system was less than the permissible limit of WHO for drinking water quality 5 mg/l.

Sulfate

Sulfate is derived from the dissolution of salts of sulfuric acid and is abundantly found in almost all water bodies. The WHO has established 250 mg/l as the highest permisable limit value of sulfate in drinking water (Meride & Ayenew, 2016). In the study area, the concentration of sulfate ranges from 3 to 92 mg/l table 4 in all treatment plant and supply systems. The results shows that the concentration of sulfate in the study area was lower than the standard limit value and may not be harmful to human health.

Phosphate

The phosphate concentration of the measured water samples from the inlet point, reservoir after disinfection points, distribution point, and tap waters of Boshkoro, Lemogento and Kella towns drinking water treatment plant and supply system was 0.63± 0.15, 0.40 ± 0.10, 0.36 ± 0.08 and 0.22 ± 0.10, 0.34 ± 0.11, 0.26 ± 0.06, 0.22 ±0.02, and 0.07 ± 0.12, 0.98 ± 0.06, 0.96 ± 0.01, 0.94 ± 0.01 and 0.92 ± 0.02 respectively as depicted in Table 4. The amount of phosphate in a source at inlet was significantly higher than the rest sampling points. But, there was no statistically significant difference ($p < 0.05$) in public tap water and distribution.

6.3. Heavy metals in water treatment process and water supply system.

Water treatment process in Malle woreda is by conventional method. This means that treatment process during; sedimentation, filtration and chlorination remove particular and colloidal matters (weather organic or mineral). Because metallic ions were entered to treatment plant in soluble form, treatment process cannot remove completely them. Conventional water treatment processes can only reduce relatively metallic salts using trapped salts during flocculation and then during sedimentation and filtration process (Garoma et al., 2019). Also chlorination can oxidizes some metallic salts; and can reduce relatively some of oxidized metal solutions. The variations of chromium iron, manganese and copper in the treatment plant and after the water treatment processes are presented in Fig 6 to 9.

Chromium

Ingestion of 1–5 g of "chromate" results in severe acute effects such as gastrointestinal disorders, hemorrhagic diathesis, and convulsions. Chromium concentration in the in public tap of Boshkoro, Lemogento and Kella treatment site water sample was 0.01± 0.01, 0.002± 0.18 and 0.002 ± 0.01 respectively fig. 6 which is within the WHO recommended limits of 0.05 mg/L (WHO, 2011).

Iron

The result of iron in figure 7 shows that the concentrations of iron measured in Boshkoro and Lemogento treatment and water supply system of public tap water sources were generally found within the national and WHO guideline value of 0.3 mg/l. The present study is similar with regard to WHO recommendation with a study conducted in Iran (0.11 mg/l) (Al-dulaimi & Younes, 2017). But, it is far from a study conducted in Nekemte town that showed that the concentration of iron in the water 0.67 ± 0.2 mg/l, which is above the present study and WHO recommendation (Duressa*et al.,* 2019).

The concentration iron in the Kella water treatment process and water supply source in figure 7 was beyond the WHO recommended limits of 0.3 mg/L (WHO, 2011). The reason for high iron content in Kella water sources would be the infiltration of ground water with iron content. People consuming water sources with high concentration of iron were suffering liver diseases, while, people those exposed to less concentration would be highly vulnerable to anemia as cited in (Duressa*et al.,* 2019).

In general, the mean iron concentrations measured in the water sample collected from three treatment plant and water supply system was significant ($p<0.05$). Accordingly, a study conducted Dvorak & Schuerman, (2021), showed that the concentration of iron in the distribution network can be affected by the corrosion of materials used in the water supply distribution system.

Copper

Copper is an essential trace element for the human body and is an indispensable component of many enzyme systems. However, a number of pathogenic characteristics are attributed to this element. It is connection with a form of early childhood liver cirrhosis. Copper concentration value measured in public tap of Boshkoro and Lemogento water treatment was 0.09 ± 0.02 and 0.02 ± 0 .01 respectively (figure 8) which is within allowable limit. However, the mean copper values determined in the public tap of Kella town treatment system (7.31 ± 0.20) in figure 8 is above the permissible limit. EPA has set a goal for copper at a maximum allowable level of 1.3 mg per liter of drinking water.

Manganese

Manganese concentration value measured in the public tap of Boshkoro, Lemogento and Kella town drinking water treatment were 0.33 ± 0.06, 0.14 ± 0.03 and 0.17 ± 0.05 respectively (figure 9). The mean manganese concentrations measured in the reservoir and source water were significantly higher than the tap and distributions water samples. The reason for a significant increase in source water may be attributed to the type of rock. Manganese in drinking water at elevated levels, however, can pose neurological effects on health risk (Dvorak & Schuerman, 2021). However, the mean result of manganese in public tap of all treatment sample were within WHO recommended limits.

6.4. Bacteriological Quality of drinking water in treatment process and water supply system.

Total coliform bacteria and fecal coliforms bacteria are the most common indicator bacteria in drinking water. If large numbers of coliforms are found in water, there is a high probability that other pathogenic bacteria or organisms exist (Ogbiye et al., 2018).

The total coliform group has been selected as the primary indicator bacteria for the presence of disease causing organisms in drinking water (Teklu, 2018). It is the main indicator of the fitness of water for consumption. The WHO guidelines require the absence of total coliform in public drinking water distributions (WHO, 2011).However, the highest Total Coliform count was recorded from public tap water at Lemogento town water supply water with 85 CFU/100 ml, followed by 16 CFU/100 ml at source water point of Kella town water treatment (Table 5).

The lowest TC count was found at sampling point from reservoir at disinfection and distribution system of Kella and Lemogento treatment site which was 0 CFU/100 ml. This finding was in agreement with the studies conducted in Nekemte town (Duressa et al., 2019). But, was lower than the studies conducted in Addis Ababa City (Yasin et al.,2015).

On the other hand, The highest FC count of 90 CFU/ 100 ml was recorded from public tap of Lemogento water supply, whereas, no fecal coliform was detected from disinfection reservoir and distribution system of Lemogento town water treatment.(Table 5).

Generally, Total and fecal coliforms in disinfection reservoir and distribution system were lower than that recorded for the source water and public tap. Significant reduction was observed for total and fecal coliform which might be attributed to the treatment process. And the increment of TC and FC in public tap may be the fact that the treatment plant or the disinfection point of water treatment plant is far away from the city. Hence, the interconnection between the site of the treatment plant and the distribution system up to public tap may accumulate pathogenic microorganisms by the formation of biofilms (Nzung, 2019). In all cases, both Total and Fecal coliform counts in public tap were above the recommended levels set by WHO standards (0 CFU/100 ml) (WHO, 2011).

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7.1. Conclusion

Based on the result of the study all of the studied physicochemical parameters of the Boshkoro and Lemogento treatment plant and water supply system were found to be within WHO drinking water standards. However, In Kella drinking water treatment plant, majority of the investigated physicochemical parameters (electrical conductivity, total hardness, Fluoride,) were found to be not within the permissible limits of WHO guidelines guideline values for drinking water quality.

For the presence of heavy metals in drinking water guidelines have been set at different levels. Among the four heavy metals analyzed (Cr^{6+}, Fe, Mn, and Cu), all are in the permissible limits range of reference in both Boshkoro and Lemogento treatment plant and water supply system. However, iron and copper was not within the permissible limits of WHO guidelines in Kella town drinking water treatment and water supply system.

Majority of water samples collected from source, reservoir after disinfection and distribution and all samples collected from public tap were contaminated by TC and FC. In addition, the number total and fecal coliforms in disinfection reservoir and distribution system were lower than that of recorded for the source water and public tap. On the other hand, the majority of water samples from reservoir after disinfection point were not contaminated with TC and FC. This implies that water contamination by indicator bacteria is both at the source, reservoir and in the distribution system. So that, the presence of indicator bacteria might be associated with poor waste disposal systems and management of water sources. So, there is a need to establish an effective waste disposal system and catchment area management system around the sources of water.

Water quality parameters varying widely due to seasonal fluctuation. This study was limited to assessing physico chemical and bacteriological quality from source to public tap connections of the water supply system in wet season. Similar study should be conducted during the dry season of the year.

7.2. Recommendations

For Boshkoro Municipal water supply and Malle woreda Water, Mines and Energy office

- It should be searched for multiple barriers to avoid contamination.
- Watershed protection programs should be established.

For the community

- Proper handling of the drinking water sources and catchment area cleaning is required to alleviate its safety

For Lemogento Municipality and Malle woreda Water, Mines and Energy office

- The municipal water supply office is expected to increase drinking water quality status for bacteriological quality by checking cross-contamination in treatment pipelines.

For Lemogento community

- Highly recommended that the water sources must be treated or boiled at a household level before being used for domestic purposes.
- Remedial actions such as improvement of water sanitation and hygiene practices should be applied.

For Kella kebele and Malle woreda Water, Mines, and Energy office

- From source to household tap treatment plant strategies should be developed to deliver safe water to reduce health risks in a human.
- Water quality parameters should be applied prior to supply drinking water to community specially ground water sources.

REFERANCES

Abegaz, M. T. (2021). *Quality and Safety of Rural Community Drinking Water Sources in Guto Gida District , Oromia , Ethiopia*. *2021*.

Alemu, Z. A., Teklu, K. T., Alemayehu, T. A., Balcha, K. H., & Mengesha, S. D. (2015). Physicochemical quality of drinking water sources in Ethiopia and its health impact : a retrospective study. *Environmental Systems Research*, *4*(22), 1–8.

Ameya, G., Zewdie, O., Mussema, A., Amante, A., & Asmera, B. (2018). Bacteriological quality of drinking water obtained from main sources, reservoirs and consumers' tap in Arba Minch town, Southern Ethiopia. *African Journal of Microbiology Research*, *12*(24), 567–573.

Bain, R., Cronk, R., Wright, J., Yang, H., Slaymaker, T., & Bartram, J. (2014). Fecal Contamination of Drinking-Water in Low- and Middle-Income Countries: A Systematic Review and Meta-Analysis. *PLoS Medicine*, *11*(5), 1–23.

Behailu, T. W., Badessa, T. S., & Tewodros, B. A. (2018). *Analysis of physical and chemical parameters in ground water consumed within Konso area , Southwestern Ethiopia*. *12*(March), 106–114. https://doi.org/10.5897/AJEST2017.2419

Berhanu, A., & Hailu, D. (2015). Bacteriological and Physicochemical Quality of Drinking Water Sources and Household Water Handling Practice Among Rural Communities of Bona District , Sidama Zone Southern, Ethiopia. *Science Journal of Public Health*, *3*(5), 782–789.

Damtie, D., Endris, M., & Tefera, Y. (2014). *Assessment of microbiological and physico-chemical quality of drinking water in North Gondar Zone , Northwest Ethiopia*. *October*. https://doi.org/10.5455/jeos.20140924105123

Desalegn, A., Sissay, M., & Tesfaye, G. (2013). Microbiological Quality of Drinking Water Sources and Water Handling Practices among Rural Communities of Dire Dawa Administrative Council. *International Journal of Current Research and Academic Review*, *1*(2), 29–54.

Dessie, A. Y., & Science, A. A. (2020). *Assessment of Selected Physico-Chemical Parameters of Different Water Assessment of Selected Physico-Chemical Parameters of Different Water Sources Quality*. *August*.

Desye, B., Belete, B., Gebrezgi, Z. A., & Reda, T. T. (2021). *Efficiency of Treatment Plant and Drinking Water Quality Assessment from Source to Household , Gondar City , Northwest Ethiopia*. *2021*.

Dohare, D., Deshpande, S., & Kotiya, A. (2014). Analysis of Ground Water Quality Parameters : A Review. *Research Journal of Engineering Sciences*, *3*(5), 26–31.

Duresa, G., Assefa, F., & Jida, M. (2019). *Assessment of Bacteriological and Physicochemical Quality of Drinking Water Assessment of Bacteriological and Physicochemical Quality of Nekemte , Oromia , Ethiopia*. *February*. https://doi.org/10.13140/RG.2.2.10517.99040

Duressa, G., Assefa, F., & Jida, M. (2019). *Assessment of Bacteriological and Physicochemical Quality of Drinking Water from Source to Household Tap Connection in Nekemte , Oromia , Ethiopia*. *2019*.

Dvorak, B., & Schuerman, B. (2021). *NebGuide*. *May*, 1–6.

Eliku, T., & Sulaiman, H. (2015). *Assessment of physico-chemical and bacteriological quality of drinking water at sources and household in Adama Town , Oromia Regional State , Ethiopia*. *April 2018*. https://doi.org/10.5897/AJEST2014.1827

Farhaoui, M., & Derraz, M. (2017). *Review on Optimization of Drinking Water Treatment Process*. *January 2016*. https://doi.org/10.4236/jwarp.2016.88063

Gara, T., Fengting, L., Nhapi, I., Makate, C., & Gumindoga, W. (2017). Health Safety of Drinking Water Supplied in Africa: A Closer Look Using Applicable Water-Quality Standards as a Measure. *Water Quality Exposure and Health*, *5*, 1–10. https://doi.org/10.1007/s12403-017-0249-7

Garoma, B., Kenasa, G., & Jida, M. (2019). *Drinking Water Quality Test of Shambu Town (Ethiopia) from Source to Household Taps Using Some Physico-chemical and Biological Parameters*. *6*(4), 82–88.

Gonfa Duressa, 1 Fassil Assefa, 2 and Mulissa Jida. (2019). *Assessment of Bacteriological and Physicochemical Quality of Drinking Water from Source to Household Tap Connection in Nekemte, Oromia, Ethiopia*.

Guduru, Tamiru, M., Asfaw, D., & Olika, E. (2020). *Assessment of Physic-Chemical and Bacteriological Quality of Drinking Water Scholars Academic Journal of Biosciences Assessment of Physic-Chemical and Bacteriological Quality of Drinking Water in Horo Guduru Wollega , Ethiopia*. *September*. https://doi.org/10.36347/SAJB.2019.v07i09.003

Gwimbi, P., George, M., & Ramphalile, M. (2019). Bacterial contamination of drinking water sources in rural villages of Mohale Basin, Lesotho: exposures through neighbourhood sanitation and hygiene practices. *Environmental Health and Preventive Medicine*, *24*(33), 1–7.

Hassane, A., Boubacar, I., Seyni, S., Rabani, A., & Liersch, S. (2020). Physico-chemical and bacteriological quality of groundwater in a rural area ofWestern Niger : a case study of Bonkoukou. *Journal of Water and Health*, *18*(1), 77–90.

Health, M. (n.d.). *Optimisation of Small Drinking-water Treatment Systems Resources for the Drinking-water Assistance Programme*.

Homaida, M. A., & Goja, A. M. (2013). Microbiological Quality Assessment of Drinking Water at Ed-Dueim Town, Sudan. *New York Science Journal*, *6*(5), 10–16.

Igibah, C. E., & Tanko, J. A. (2019). Assessment of urban groundwater quality using Piper trilinear and multivariate techniques: a case study in the Abuja, North-central, Nigeria. *Environmental Systems Research*, *8*(14), 1–14.

Ijumulana, J., Ligate, F., Irunde, R., Bhattacharya, P., Prakash, J., Ahmad, A., & Mtalo, F. (2021). Groundwater for Sustainable Development Spatial uncertainties in fluoride levels and health risks in endemic fluorotic regions of northern Tanzania National Bureau of Statistics. *Groundwater for Sustainable Development*, *14*(June), 100618. https://doi.org/10.1016/j.gsd.2021.100618

Iwar, R. T. (2018). *Fluoride levels in deep aquifers of Makurdi , North-central , Nigeria : An*

Appraisal based on multivariate statistics and human health risk analysis. 1–15.

Jessoe, K. (2013). Improved source, improved quality? Demand for drinking water quality in rural India. *Journal of Environmental Economics and Management*, *66*(3), 460–475.

Kausley, S. B., Dastane, G. G., Kumar, J. K., Desai, K. S., Doltade, S. B., & Pandit, A. B. (2018). Clean Water for Developing Countries : Feasibility of Different Treatment Solutions Clean Water for Developing Countries : Feasibility of Different Treatment Solutions. In *Encyclopedia of Environmental Health, 2nd Edition* (2nd ed., Issue January). Elsevier Inc. https://doi.org/10.1016/B978-0-12-409548-9.11079-6

Khan, N., Hussain, S. T., Khan, A., & Kim, K. S. (2013). Physiochemical investigation of drinking water sources fromTehsil Lachi, Kohat. *American Journal of Research Communication*, *1*(5), 170–190.

Kilonzo, W., Home, P., & Sang, J. (2019). *The Storage and Water Quality Characteristics of Rungiri Quarry Reservoir in Kiambu , Kenya , as a Potential Source of Urban Water*.

Krishnan, R., Dharmaraj, K., & Kumari, B. D. (2007). A comparative study on the physicochemical and bacterial analysis of drinking, borewell and sewage water in the three different places of Sivakasi. *Journal of Environmental Biology*, *28*(1), 105–108.

Li, P., & Wu, J. (2019). Drinking Water Quality and Public Health. *Exposure and Health*, *11*(2), 73–79.

Macdonald, A. M., Bonsor, H. C., Dochartaigh, B. É. Ó., & Taylor, R. G. (2012). Quantitative maps of groundwater resources in Africa. *Environmental Research Letters*, *7*, 1–7.

Maleki, A., Roshani, B., & Karakani, F. (2015). *Study on the Efficiency of the Different units for Removing Metallic ions in Isfahan Water Treatment Plant*.

Malhotra, S., Sidhu, S. K., & Devi, P. (2015). Assessment of bacteriological quality of drinking water from various sources in Amritsar district of northern India. *The Journal of Infection in Developing Countries*, *9*(8), 844–848.

Martínez-Santos, P., Martín-Loeches, M., García-Castro, N., Solera, D., Díaz-Alcaide, S., Montero, E., & García-Rincón, J. (2017). A survey of domestic wells and pit latrines in rural settlements of Mali: implications of on-site sanitation on the quality of water supplies. *International Journal of Hygiene Environment Health*, *220*, 1179–1189.

Massoud, M. A., Al-Abady, A., Jurdi, M., & Nuwayhid, I. (2010). The challenges of sustainable access to safe drinking water in rural areas of developing countries: case of Zawtar El-Charkieh, Southern Lebanon. *Journal of Environmental Health*, *72*, 24–30.

Mekonnen, G. K., Mengistie, B., Sahilu, G., Mulat, W., & Kloos, H. (2019). Determinants of microbiological quality of drinking water in refugee camps and host communities in Gambella Region, Ethiopia. *Journal of Water, Sanitation and Hygiene for Development*, *09*(4), 671–682.

Meride, Y., & Ayenew, B. (2016). Drinking water quality assessment and its effects on residents health in Wondo genet campus , Ethiopia. *Environmental Systems Research*, 1–7. https://doi.org/10.1186/s40068-016-0053-6

Mishra, V. P., Twanabasu, S., Kusma, S., & Hogade, S. A. (2019). Assessment of Bacteriological Quality of Drinking Water in Belagavi City, India. *MicroMedicine*, *7*(1), 19–25.

Mohsin, M. (2014). *Assessment of Drinking Water Quality and its Impact on Residents Health in Bahawalpur City Assessment of Drinking Water Quality and its Impact on Residents Health in Bahawalpur City*. *March 2015*.

Nzung, O. (2019). Physico-chemical and bacteriological quality of water sources in rural settings , a case study of Kenya , Africa. *Scientific African*, *2*, e00018. https://doi.org/10.1016/j.sciaf.2018.e00018

Of, I., Water, D., From, Q., To, S., Of, P., Oromia, I. N., & State, R. (2015). *A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Degree of Master of Science in Civil & Environmental Engineering (Major in Water Supply & Environmental Engineering) By Gurmessa Oljira Erena Advised By Dr . Ing . Geremew Sahilu Addis Ababa 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 Civil & Environmental Engineering (Major in Water Supply & Environmental Engineering) By Gurmessa Oljira Erena*. *June*.

Ogbiye, S. A., Coker, O. A., & Diwa, D. I. (2018). *WATER SUPPLY , SANITATION AND HEALTH RISK IN A TROPICAL SUB-SAHARAN REGION*. *228*, 175–186. https://doi.org/10.2495/WP180181

Pant, N. D., Poudyal, N., & Bhattacharya, S. K. (2016). Bacteriological quality of bottled drinking water versus municipal tap water in Dharan municipality, Nepal. *Journal of Health, Population and Nutrition*, *35*(17), 1–6.

Pantaleo, P. A., Komakech, H. C., Mtei, K. M., & Njau, K. N. (2018). *Contamination of groundwater sources in emerging African towns : the case of Babati town , Tanzania*. *13*(4), 980–990. https://doi.org/10.2166/wpt.2018.104

Sajitha, V. (2016). Study of Physico Chemical Parameters and Pond Water Quality Assessment by using Water Quality Index at Athiyannoor Panchayath , Kerala, India. *Emer Life Science Research*, *2*(1), 46–45.

Salifu, A., Essandoh, H. M. K., Traore, A. N., & Potgieter, N. (2019). Water source quality in Ahenema Kokoben , Ghana. *Journal of Water, Sanitation and Hygiene for Development*, *09*(3), 450–459.

Shan, L., Li-Guang, T., Qin, L., Men-Bao, Q., Qing, F., Peter, S., & Xiao-Nong, Z. (2013). Water-Related Parasitic Diseases in China. *International Journal of Environmental Resource and Public Health*, *10*, 1977–2016.

Sisay, T., Beyene, A., & Alemayehu, E. (2017). *Journal of Environmental Science and Pollution Research Assessment of Drinking Water Quality and Treatment Plant Efficiency in Southwest Ethiopia*. *3*(3), 208–212.

Sorlini, S., & Torretta, V. (2017). *Overview of the Main Disinfection Processes for Wastewater and Drinking sustainability Overview of the Main Disinfection Processes for Wastewater and Drinking Water Treatment Plants*. *March 2018*. https://doi.org/10.3390/su10010086

Subedi, M., Magar, M. G., & Rajbhandari, G. S. (2017). Assessment of Quality of Underground

Drinking Water: Very near (≤ 20 meters) and Far (> 50 meters) from the River. *Nepal Journal of Biotechnology*, *5*(1), 21–26.

Szabo, J., & Minamyer, S. (2014). Decontamination of biological agents from drinking water infrastructure: A literature review and summary. *Environment International*, *72*, 124–128.

Tamrakar, P., Shakya, S. K., & Baniya, C. B. (2017). Physico-Chemical and Bacteriological Composition in a Metropolitan Drinking Water Distribution System in Kathmandu. *Journal of Institute of Science and Technology*, *22*(1), 159–164.

Teklemariam, D. G., Banerjee, S., & Taye, M. (2020). *Husbandry and Breeding Practices of Malle Cattle Reared in Malle District South Omo Zone of Southwest Ethiopia Husbandry and Breeding Practices of Malle Cattle Reared in Malle District South Omo Zone of Southwest Ethiopia*. *May*. https://doi.org/10.36478/javaa.2019.323.338

Teklu, K. T. (2018). *Water quality survey on improved community supply units in the southern region of Ethiopia*. *July*.

Toxicol, J. E. A., & Reda, A. H. (2016). *Environmental & Analytical Toxicology Physico-Chemical Analysis of Drinking Water Quality of Arbaminch Town*. *6*(2). https://doi.org/10.4172/2161-0525.1000356

UNICEF and WHO. (2017). *Launch version July 12 Main report Progress on Drinking Water, Sanitation and Hygiene 2017. Available online: http://www.who.int/mediacentre/news/releases/2017/launch-version-reportjmp-water-sanitation-hygiene.pdf.*

Wakuma, B., & Fita, T. (2017). Physico-Chemical Analysis of Drinking Water (in case of. *International Journal of Scientific and Research Publications*, *7*(4), 364–370.

WHO. (2008). Guidelines for Drinking-water Quality. *WHO Library Cataloguing-in-Publication Data Guidelines*, *1*.

WHO. (2011). *Guidelines for Drinking-water Quality- 4th edn. Printed in Malta by Gutenberg.*

Yasin, M., Ketema, T., & Bacha, K. (2015a). Physico – chemical and bacteriological quality of drinking water of different sources , Jimma zone , Southwest Ethiopia. *BMC Research Notes*, 1–14. https://doi.org/10.1186/s13104-015-1376-5

Yasin, M., Ketema, T., & Bacha, K. (2015b). Physico ‑ chemical and bacteriological quality of drinking water of different sources , Jimma zone , Southwest Ethiopia. *BMC Research Notes*, 1–13. https://doi.org/10.1186/s13104-015-1376-5

Zebire, D. A., & Gelgelo, S. (2019). *Effect of phosphorus fertilizer levels on growth and yield of haricot bean (Phaseolus vulgaris . L .) in South Ommo Zone , Ethiopia*.

ANNEX

Annex-1 Raw water quality data for different water sources

Southern Nations, Nationalities and People's Regional State
Water, Mine and Energy Bureau
Water Resouce Study and Management Directorate

Physico-Chemical Analysis Report
(Drinking Water Quality)

Client	South Omo Zone Water, Mines and Energy Departent	Zone	South Omo
Contact person		Woreda	Malle
Sample Number	8021C	Kebele	Boshekro
Date of Sampling	16/2/2014 (Ethiopian, EC)	Village	Ketema
Date of Testing (dd/mm/yyyy)	19/2/2014 (Ethiopian, EC) 29/10/2021 (International)	Site Name	
		GPS (UTM) Northing	258268
Nature of Sample	treated	GPS (UTM) Easting	649243
Source	SW	Altitude [m]	1182 M
Depth [m]		Sample taken by	Kebru Philmon

Analysis results

Item	Unit	Result	Standard
pH	-	7.1	6.5 - 8.5
Temperature	[°C]	21.4	-
Conductivity	[μS/cm]	313	-
TDS	[mg/L]	157	1000
Turbidity	[NTU]	1	5
Total Chlorine [Cl_2]	[mg/L]	0.1	5
Total Hardness	[mg/L as $CaCO_3$]	140	300
Calcium Hardness	[mg/L as $CaCO_3$]	90	-
Magnesium Hardness	[mg/L as $CaCO_3$]	50	-
Total Alkalinity	[mg/L as $CaCO_3$]	160	500
Bicarbonate Alkalinity	[mg/L as $CaCO_3$]	160	-
Carbanate Alkalinity	[mg/L as $CaCO_3$]	0	-
Hydroxide Alkalinity	[mg/L as $CaCO_3$]	0	-
Dissolved NH_3	[mg/L]	0.07	1.5
NH_4^+ Ammonium	[mg/L]	0.09	-
Na Sodium	[mg/L]	13.2	-

Item		Unit	Result	Standard
K^+	Potassium	[mg/L]	4.3	-
Ca^{2+}	Calcium	[mg/L]	36.0	100
Mg^{2+}	Magnesium	[mg/L]	12.2	30
Fe	Iron	[mg/L]	0.03	0.3
Cu^{2+}	Copper	[mg/L]	0.06	2
Mn^{2+}	Manganese	[mg/L]	<0.1	0.5
Cr^{6+}	Chromium	[mg/L]	<0.01	0.05
Cl^-	Chloride	[mg/L]	<10	250
F^-	Fluoride	[mg/L]	0.32	1.5
Br_2	Bromine	[mg/L]	0.28	-
NO_2^-	Nitrite	[mg/L]	0.02	3
NO_3^-	Nitrate	[mg/L]	1.6	50
SO_4^{2-}	Sulfate	[mg/L]	3	250
PO_4^{3-}	Phosphate	[mg/L]	0.67	-
HCO_3^-	Bicarbonate	[mg/L]	195	[illegible]
CO_3^{2-}	Carbonate	[mg/L]	0	-

Note:
Values that exceed WHO guidline are underlined.

Remark:
The test result indicates that all the parameters measured meet the WHO guideline and Ethiopian standard set for drinking water. Therefore, the water is suitable for drinking purpose. Note that the water sample was taken by the client.

Analyzed on 19/2/2014 *by* Yewbdar Tesfaye *Signature*

Approved on 19/2/2014 *by* *Signature*

Habtemariam Tilahun Beyene
Water Resource Study & Manag...

Client	South Omo Zone Water, Mines and Energy Departent	Zone	South Omo
		Woreda	Malle
Sample Number	8022C / LGPT1	Kebele	Lemogento
Date of Sampling	16/2/2014 (Ethiopian, EC)	Village	Selam
Date of Testing (dd/mm/yyyy)	19/2/2014 (Ethiopian, EC)	Site Name	
	29/10/2021 (International)	GPS (UTM) Northing	258274
Nature of Sample	Treated	GPS (UTM) Easting	649269
Source	SW	Alttitude [m]	1183 M
Depth [m]		Sample taken by	Kibru Philmon

Analysis results

Item	Unit	Result	Standard
TDS	[mg/L]	101	1000
Turbidity	[FTU]	1	5
Total Chlorine [Cl_2]	[mg/L]	0.04	5
Total Hardness	[mg/L as $CaCO_3$]	85	300

Item		Unit	Result	Standard
Fe	Iron	[mg/L]	0.05	0.3
Cu^{2+}	Copper	[mg/L]	0.05	2
Mn^{2+}	Manganese	[mg/L]	<0.1	0.5
Cr^{6+}	Chromium	[mg/L]	<0.01	0.05