

ASSESSMENT OF WATER QUALITY IN SHALLOW WELLS AND BOREHOLES IN MANASE IN BLANTYRE SOUTHERN MALAWI

HILDA DAFTER

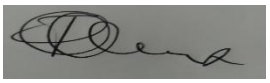
Thyolo, Malawi

Dissertation submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology in partial fulfilment of the requirements for the Bachelor of Science degree in Water Quality and Management

July, 2021

DISSERTATION APPROVED BY:

SUPERVISOR:

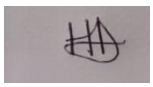
Title, Initials, Name Signature: 

ASSESSOR:

Title, Initials, Name Signature: _____

DECLARATION

I Hilda Dafter declare that this research project represents my work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged

Signature: 

Date: 18/07/2021

DISCLAIMER

This document describes work undertaken as part of a programme of study at Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology. All views and opinions expressed therein remain the sole responsibility of the author(s) and do not necessarily represent those of the School.

COPYRIGHT STATEMENT:

This copy of the dissertation has been supplied on condition that anyone who consults it is understood to recognize that its copyright rests with its author and that no quotation from the dissertation and no information derived from it may be published without acknowledgment.

ABSTRACT

Groundwater provides a vital source of drinking water for rural and peri-urban communities in many parts of Africa, particularly in the dry season when there are few safe alternative sources. This study aimed at assessing water quality in shallow wells and boreholes in Manase village. Water samples were collected from selected seven shallow wells and one borehole on 8th May during the wet season. Water samples were analyzed for 13 selected physicochemical and 2 biological parameters including turbidity, temperature, electrical conductivity, pH, total dissolved solids, calcium, magnesium, chloride, nitrate, fluoride, carbonate, bicarbonate, alkalinity, total coliform and fecal coliform using standard methods recommended by APHA. Results were subjected to statistical evaluations using Excel 2013 for descriptive statistics and water quality index. The level of alkalinity ranged from 193.87 to 374.45mg/L and was above the maximum permissible limit for WHO at all sampling points. The level of turbidity ranged from 0.97±0.085 to 28.9±0.416NTU. Turbidity at SW2 and USW5 were above the recommended standards for WHO and USW5 for MBS. The level of fecal coliform and total coliform ranged from 46 to 529cfu/100ml and 338 to 1578cfu/100ml respectively and were above the maximum permissible limit for WHO at all shallow wells. At borehole, the level of fecal coliform and total coliform was 2cfu/100ml and 20cfu/100ml respectively and were within the maximum permissible limit for MBS. The water quality index indicated that the water was highly contaminated in shallow wells hence it was not fit for human consumption without treatment and it also indicated that water was good at a borehole and fit for domestic purposes. Therefore, it is recommended that water from these sources should be treated before use for domestic purposes and government should be more effective in controlling the point source of pollution in the area.

ACKNOWLEDGEMENTS

Firstly, I thank God for making this project successful from an ideology into reality. I also thank my supervisor Mr. F. Chauluka who has put much effort into helping and giving me direction throughout the research period. The water Quality department at southern region irrigation and water development should also feel much appreciated for allowing me to perform sample analysis in their water quality laboratory. Mr. H. Yapuwa, Mr. N. Tepeka, Mr. C. Chidankana, Mrs. Glory, and many more who I may not have mentioned on this list deserve to be thanked for their many forms of help to the success of this project. God bless you all.

Table of Contents

1. CHAPTER ONE: INTRODUCTION 1
1.1. Background 1
1.2. Problem statement 3
1.3. Main Objective 4
1.3.1. Specific objective 4
1.4. Research questions 5
1.5. The significance of the study 5
2. CHAPTER TWO: LITERATURE REVIEW 7
2.1. Water quality 7
2.2. Groundwater 8
2.3. Assessment of groundwater quality 10
2.3.1. Physical and chemical water quality parameters 11
2.3.2. Microbiological water quality parameters 11
2.4. Sources of groundwater contamination 12
3. CHAPTER THREE: METHODOLOGY 13
3.1. Methodology 13
3.2. Research design 13
3.3. Study area 14
3.4. Materials 15
3.5. Methods 16
3.5.2. Sample analysis 17
3.6. Statistical analysis 21
3.7. Ethical consideration 22
4. CHAPTER FOUR: RESULTS AND DISCUSSIONS 22
4.1. Results and discussions 22

4.1.1. To analyse physical and chemical parameters for shallow wells and boreholes compared to WHO and MBS 25
4.1.2. Determination of the level of microbial contaminants in shallow wells and boreholes 35
4.1.2.1. Water quality index 36
4.1.3. Correlation of physicochemical and microbial parameters of water quality in shallow wells and boreholes 38
5. CHAPTER FIVE: CONCLUSION AND RECOMMENDATION 40
5.1. Conclusion 40
5.2. Recommendation 40
6. REFERENCES 43
7. APPENDICES 46

ACRONYMS/ABBREVIATION

TC	Total Coliform
FC	Fecal Coliform
WHO	World Health Organization
MBS	Malawi Bureau of Standards
BH	Borehole
SW	Shallow Well
USW	Unprotected Shallow Well
EC	Electrical Conductivity
TDS	Total Dissolved Solids
NTU	Nephelometric Turbidity Units
CFU	Colony Forming Units
SD	Standard Deviation
Max	Maximum
Min	Minimum
APHA	American Public Health Association
WQI	Water Quality Index

List of figures

Figure 1: Flow chart for research design.....14
Figure 2: Map of Manase Village, Blantyre district 15
Figure 3: Variation of the physical parameters of water samples at different sampling points include temperature **(a)**, pH**(b),** turbidity**(c),** total dissolved solids **(d)** and electrical conductivity **(e).** 30
Figure 4: The variation of the nitrate of water samples at different sampling points. 30
Figure 5: Variation of the chloride of water samples at different sampling points. .31
Figure 6: Variation of the fluoride of water samples at different sampling points. 32
Figure 7: Variation of the calcium (a) and magnesium (b) of water samples at different sampling points. 33
Figure 8: Variation of the carbonate (a) and bicarbonate (b) of water samples at different sampling points. 34
Figure 9: Variation of the alkalinity of water sample at different sampling points. 35
Figure 10: Variation of the level of total coliform (a) and fecal coliform(b) at different sampling points..... 37

LIST OF TABLES

Table 1 : Summary statistics for physical parameters in shallow wells and borehole. 23

Table 2: Summary of results for chemical and biological parameters of shallow wells and borehole water samples compared to the recommended standards for WHO and MBS (MS733:2005 for boreholes and shallow wells). 24

Table 3: Summary statistics for chemical parameters of shallow wells and a borehole. 24

Table 4: Summary statistics for microbial parameters of shallow wells and a borehole 25

Table 6: Water quality index(WQI) and status of water quality (Adeokola et al, 2015) 38

Table 7:Summary of water quality index of shallow well water and borehole water 39

Table 8: The correlation between physicochemical and microbial parameters of water quality. 40

1. CHAPTER ONE: INTRODUCTION

This chapter highlights the background information about water quality in shallow wells and boreholes water sources. It also covers the problem statement, main objective and specific objectives, research questions and significance of the study.

1.1. Background

Groundwater is one of the most vital resources on earth because it plays an important role in supporting human life (Stefanakis et al., 2015). It provides water to almost 2 billion people, countless farmers, and several industrial facilities around the world (UNDP, 2010). In many regions of Africa, groundwater is a critical supply of drinking water for rural and peri-urban communities, especially during the dry season when there are few safe alternatives (Donald et al., 2020). The world population cannot be sustained without access to safe water (Getso et al., 2018). Many developing countries struggle with a lack of clean drinking water, although providing high-quality drinking water is one of the most significant strategies to improve human health (Mbaka et al., 2017). There are two main sources of water for human consumption surface water (lakes, reservoirs, and rivers) and groundwater (boreholes and wells)(Andy & Stanly, 2003). Groundwater is accessed through shallow wells either protected or unprotected and boreholes. Groundwater quality comprises the physical, chemical and biological characteristics of groundwater (Eucharista, 2016). Water quality is the suitability of water for its intended use, for example, irrigation, recreation, industrial purpose, domestic purpose and other use (Weiner & Francis, 2007).

A borehole and shallow well water become unsuitable for domestic use as a resource due to contamination that makes them unfit for many purposes. Contamination of water bodies has increasingly become an issue of serious environmental concern (Getso et al., 2018). In the case of underground waters such as boreholes and shallow

wells, this can be caused by indiscriminate waste disposal, poor agricultural practices, septic tanks, pit latrines, polluted rivers and graves near boreholes, and poor construction, all of which contribute to the degradation of borehole water quality. (William, 2014). This may be leading to an outbreak of water-related diseases such as cholera and diarrhea. Microbiological contamination is a major concern in underdeveloped countries when it comes to drinking water quality (Sorlini et al., 2013). As a result, people use untreated groundwater from boreholes or shallow wells, which pose a threat to their health. Potable water is an essential ingredient for good health and the socio-economic development of man but it's lacking in many societies (Getso et al., 2018). After decades of pollution and waste, man has only recently come to value clean water as a valuable and finite resource. Groundwater sources in Africa are frequently used for drinking water and cooking with no or no treatment, hence determining the raw chemical and microbiological quality of these sources remains a top issue from a human health standpoint (Donald et al., 2020).

A large part of the sub-region of Malawi is characterized by small towns, villages and dispersed rural settlements (Grain & Botolo Ben, 2010). At any given time, just 40% of Malawi's population has access to safe drinking water (Pritchard et al., 2009). Water shortages are more likely in Malawi's unplanned high-density residential areas (where the majority of low-income people live) than in low-density, high-income ones (Maoulidi, 2015). Unreliable water supplies in low-income communities are forcing some residents to rely on unimproved water sources such as shallow wells, streams, and drainage ditches, posing health and safety issues (Maoulidi, 2015). However, the majority of shallow wells and boreholes are near pit toilets, septic tanks, dirty waterways, and damping sites. (Mbaka et al., 2017) because some people may find it practical to have their well-constructed close to their houses or latrine (Arjen Van der Wal, 2010). According to Abera et al., (2017), the increasing human population coupled with poor sanitation and infrastructure is undermining the quality of shallow well water and boreholes. The majority of people in rural areas and high-density townships in urban areas use pit latrines which are often in a state

of disrepair and without hygiene (Abera et al., 2017). Although water is one of life's most necessary components, a substantial portion of the population does not have access to it in the recommended quality. (Christine et al., 2018).

Most of the research undertaken on the water in the Blantyre district has focused on surface water quality, whereas limited work is available on boreholes and shallow wells water, yet boreholes and shallow wells are important sources of water in the rural and peri-urban area (Pritchard et al., 2009). This study, on the other hand, proved useful in generating data on water quality in shallow wells and boreholes. The information gathered will aid in the management and monitoring of water resources. The objective of this study was to assess the water quality of shallow wells and boreholes if it meets the prescribed limit for domestic purposes of the Malawi Bureau of Standards and World Health Organization.

1.2. Problem statement

Inadequate water supply is still one of the major challenges in developing countries (Pritchard et al., 2009). Lack of access to safe water for domestic use such as drinking, cooking, bathing and washing is a major concern in Malawi especially in peri-urban areas and rural areas where access to the water supply system is limited (Maoulidi, 2015). Access to reticulated surface water resources has been limited because of the high costs and long distances that need to be covered to establish infrastructure for formal water services (Pritchard et al., 2009). In Malawi, Water supply shortages are more prevalent in high-density unplanned residential areas (where most low-income communities reside) than in low-density, high-income areas (Maoulidi, 2015). Blantyre district is a city of over 800,264 people live in an urban and rural area (Malawi, 2018). Water supplied by Southern Water Board is the source of water for domestic use in urban and peri-urban areas. Few studies have been done within Blantyre whose results have revealed that there is a high level of contamination in groundwater sources (Chimphamba & Phiri, 2014; Kaonga et al., 2013; Pritchard et

al., 2007). However, most of these studies were conducted in Bangwe, Chemusa, Mtopwa and Blantyre rural and the data available concerning water quality of shallow wells and boreholes is scarce in Blantyre. Therefore, there is still a data gap regarding the quality of water from shallow wells and boreholes for domestic use in other areas. As such it was important to conduct subsequent studies in the other areas to have a comprehensive understanding of the water quality in Blantyre.

Manase is a peri-urban area with high-density unplanned residential. WaterAid, (2014) reported that people in the settlement collect water from different sources including public water kiosks (presenting 69.2 percentage), boreholes (presenting 3.7 percentage), compound well (presenting 2.20 percentage). The percentage presents the number of households with access to the mentioned source (WaterAid, 2014). Kiosks were established so that those people with low-income levels should be able to access safe water but the challenge is that these taps are most of the time dry due to water supply inconsistency and some do not function. This leaves some people with no choice but to rely on groundwater such as shallow wells and boreholes as the main sources of water available and accessible for domestic purposes including cooking and drinking and for other sanitation purposes of which its water quality is not known. Therefore, there might be a high chance that groundwater quality is unsafe for human consumption due to other activities such as poor sanitation, microbial contamination from septic tanks and pits latrine. It is for this reason; this study was conducted in Manase to assess water quality in shallow wells and boreholes.

1.3. Main Objective

This study aimed to assess the water quality of shallow wells and boreholes if it meets the prescribed limit for Malawi Bureau of Standards and World Health Organization for domestic purposes.

1.3.1. Specific objective

- To analyze physicochemical parameters of water quality of shallow wells and boreholes.
- To determine the level of microbial contamination of shallow wells water and boreholes
- To determine the correlation of physicochemical and microbial parameters of water quality of shallow wells and boreholes.

1.4. Research questions

- What are the physicochemical parameters of water quality in shallow wells and boreholes in Blantyre, Manase?
- How much is the level of microbial contamination in shallow wells and boreholes in Manase?
- What can be the correlation of physicochemical and microbial parameters of water quality?

1.5. The significance of the study

The results obtained from this study will contribute to the body of knowledge on how the availability of clean water to all populations can be achieved as it is listed on sustainable development goals number 6. This research is helpful to the government and other administrative bodies to have a basic platform of developing and adopting new better approaches towards water quality management thereby increasing economic benefit of the country as the minimum that will be spent on achieving water sanitation, more will be saved that could have been used to deal with the impacts of water contamination on human health. This research will also help people to have a better understanding through visualization of how poor

sanitation is impacting them and help them to be open-minded to migrate from this usual tradition to better alternative

2. CHAPTER TWO: LITERATURE REVIEW

This chapter has been organized to recognize the work of what other researchers did relate to this study. The chapter looks into the related theories and findings of other scholars on water quality, groundwater quality, shallow wells, boreholes, the possible sources of groundwater contamination and water quality in shallow wells and boreholes.

2.1. Water quality

Water quality is the suitability of water for its intended use, for example, irrigation, recreation, industrial purpose, domestic purposes and other use (Weiner & Francis, 2007). Water quality for its use is indicated by its physical, chemical and biological characteristics. Physical, chemical, and biological aspects of water indicate its suitability for usage. Suspended solids, turbidity, color, taste and odor, and temperature are examples of physical qualities that respond to the senses of sight, touch, taste, and smell. Chemical parameters include total dissolved solids, alkalinity hardness, fluorides, metals, organics, and nutrients parameters of concern in water quality (Mohamed & Kitwana, 2018). These characteristics of water quality can tell whether the quality is good or bad for its use.

Water quality degradation is caused by a variety of anthropogenic and natural pollution sources (Stefanakis et al., 2015). With the advent of industrialization and rising populations, the range of water requirements has expanded, as have the demands for higher quality water (Stefanakis et al., 2015). According to Gray, (2005), water quality varies spatially and temporally. Dilution, water temperature, which affects biological activity and oxygen solubility, and seasonal fluctuations are the key variables influencing quality variance. (Gray, 2005). The quality of water

depends upon the quality and quantity of inorganic and organic salts present in water (Deshpande, 2012). Because water is so important to human life, it also has a high risk of transmitting a wide range of diseases and ailments if it becomes contaminated (Tebbutt, 2002).

Human activities, such as industrial waste discharges and spills, petroleum leaks and spills from storage tanks, pipelines, tankers, and trucks, and agricultural applications of chemical fertilizers, herbicides, and pesticides, have been documented in several studies. Some important sources are construction and mining where freshly exposed soils and minerals can contact flowing water. Good water quality is essential for the economic development of the country and human consumption. Malawi's economy is primarily reliant on agriculture, and bad agricultural practices are a key contributor to the degradation of water quality.

2.2. Groundwater

Groundwater refers to the water that is found beneath the surface of the earth. According to Stefanakis et al.,(2015) Groundwater is freshwater held underground in saturated geological formations under the earth's surface (Stefanakis et al., 2015). Precipitation is the primary source of water on the planet. Groundwater makes up around 4% of the water in the hydrologic cycle and can flow into bodies of surface water including oceans, lakes, and rivers (Andy & Stanly, 2003). This process establishes a base flow for a surface water body, which contributes significantly to both groundwater and surface water (Andy & Stanly, 2003). Groundwater makes up a significant portion of the overall global freshwater supply. It contains 29.9% of the world's freshwater resources and 99 percent of the world's blue water (GW Mate-UNDP, 2010). Groundwater reserves account for about 90% of the world's easily available freshwater (Jakeman et al., 2016). However, only groundwater storage that exists in connected bores or openings or fractures is accessible for use. Surface and groundwater water is the most commonly used sources of water because they are readily available. Groundwater storage is large (more than 97 percent of

freshwater reserves), but recharge is limited and mostly limited to shallower aquifers, which can also be severely contaminated by pollutants (Vaessen & Brentfuhrer, 2015).

2.2.1. Shallow wells and boreholes water

Groundwater can be accessed through shallow wells and boreholes. According to Mbaka et al., (2017) Boreholes are mechanically boring holes between 20 to 80 meters (m) deep, with widths ranging from 0.1m to 0.2m. Water is extracted from the borehole using hand pumps. Defective borehole surface sealing can result in surface water influx, and improper borehole casing can result in contamination from top layers of soil lateral percolating into the well, as well as contamination of samples after sampling (Christine et al., 2018). Shallow wells range in diameter from 0.9 to 1.8 meters and are drilled to a depth of 4.5 to 10 meters, depending on the location of the water-bearing deposit or groundwater (Orebiyi et al., 2010). A shallow well taps the groundwater above the first impermeable stratum. If this stratum is close to the surface, the water laying on it is vulnerable to pollution from the surface. If the water is deep, the contaminants are flushed out of it as it sinks by the heavy layer of dirt (Orebiyi et al., 2010).

Boreholes and wells locally alter the natural flow field and establish a conduit for heat and mass transfer between rock formations or aquifers, the surrounding environment, and the atmosphere (William, 2014). This can occur in underground waters such as boreholes and shallow wells due to the drilling process, drilling fluids, chemical casings, and other things that may find their way into the well and pollute the water (Getso et al., 2018). Because of their proximity to sanitary facilities like unimproved pit latrines, the water quality of most shallow wells and boreholes is at risk of contamination (Mbaka et al., 2017 and Elijah, 2013). The high concentration of iron and turbidity outside the prescribed limits of borehole water quality in the rainy season (Adekola et al., 2015) and (Kaonga et al., 2013). The number of victims

of water-related diarrhea increases every rainy season because the flooding rivers are contaminated, and the overflow from latrines pollutes groundwater in boreholes and wells (Wright, 2016).

Shallow wells are the most important water sources for home use in Malawi. (Msilimba & Wanda, 2013). However, the quality of shallow well water is being harmed by the growing human population, as well as poor sanitation and infrastructure (Elijah, 2013). These groundwater sources are found to have potential contamination and may therefore provide unsafe water for domestic and drinking purposes (Mohamed & Kitwana, 2018).

2.3. Assessment of groundwater quality

Natural processes (mineral dissolution and precipitation, groundwater velocity, recharge water quality, and interaction with other types of water aquifers) and anthropogenic activities both influence groundwater quality in a location (Abera et al., 2017). The natural chemical quality of groundwater is generally good, but elevated concentrations of several constituents can cause problems for water use. According to Bruce et al., (2017) groundwater quality is a function of the natural characteristics of the water together with any changes that occur as a result of human activities. The anthropogenic activities on the groundwater pose a serious threat to groundwater users. Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the sources (Saracino & Phipps, 2002). Groundwater quality can be significantly affected by intensive irrigated agriculture flows into the groundwater(S. Bytyçi et al., 2018).The presence of pollutants and contaminants in the environment can have an impact on the water quality to a level that in such cases it cannot be used for drinking, cooking and other domestic use (S. Bytyçi et al., 2018).

Groundwater quality can be assessed in terms of its main physical, chemical and biological characteristics (Bruce et al., 2017). Physicochemical groundwater quality parameters are assessed and analyzed and the values obtained are compared with the permissible or desirable values prescribed by the World Health Organization (WHO) guidelines to ensure the quality of groundwater for its use in domestic purposes (Abera et al., 2017).

2.3.1. Physical and chemical water quality parameters

Many studies have shown that total dissolved solids, pH, electrical conductivity, temperature and turbidity are essential physical parameters that should be determined when assessing groundwater quality. Fluoride, chloride, carbonate, bicarbonate, magnesium, calcium and nitrate are essential chemical parameters that are analyzed when assessing groundwater quality to determine its overall quality. The natural chemical quality of the mentioned parameters of groundwater is generally good, but elevated concentrations of several constituents can cause problems for water use. Groundwater quality can be significantly affected by intensive irrigated agriculture flows into the groundwater(Adekola et al., 2015).
Apart from that, groundwater dissolves some minerals that can also negatively affect water quality by changing its physicochemical parameters such as water hardness, salinity, fluoride, chloride, calcium, magnesium, carbonate and bicarbonate (Mohamed & Kitwana, 2018). Many studies conducted in some parts of Malawi have confirmed the increase in physicochemical parameters. An increase in the concentration of the chemical parameters in water can affect human health, especially heavy metals. The natural water analysis for physical and chemical parameters including trace element content is very important for public health studies.

2.3.2. Microbiological water quality parameters

According to Lapworth et al., (2020) microbiological quality of the groundwater sources remains a key priority from a human health perspective. Fecal coliform and total coliform are indicators of microbiological water quality. Coliform bacteria are a wide group of disease-causing bacteria that live in people's and animals' intestines (Tebbutt, 2002). According to Getso et al., (2018), the presence or absence of pathogenic microorganisms, as shown by the presence of coliforms, determines the sanitary nature of water. Many studies have proved that microbial contaminants increases during the rainy season whereby the level of microbial contaminants such as fecal coliform and total coliform exceed the permissible standard for the World Health Organization(Lapworth et al., 2020; Msilimba & Wanda, 2013; William, 2014). This is due to the overflow from latrines that contaminate groundwater in boreholes and wells (Wright, 2016).

2.4. Sources of groundwater contamination

Human activity is almost invariably the cause of groundwater contamination. Groundwater is particularly sensitive in locations where population density is high and land use is heavy(Kresic, 2020). Almost any operation that involves the purposeful or unintentional release of chemicals or wastes into the environment has the potential to pollute groundwater (Kresic, 2020). Groundwater pollution occurs with the presence of several contaminants such as heavy metals, pathogenic microorganisms, pesticides, nitrate, pharmaceuticals and others, which can also harm human health and ecosystem preservation (Stefanakis et al., 2015). Degradation of the water quality in shallow wells and boreholes is the result of various pollutant sources both anthropogenic and natural. Borehole water contamination is caused by indiscriminate waste disposal, bad agricultural practices, septic tanks, pit latrines, and burials near boreholes, as well as faulty construction (William, 2014).

Moreover, groundwater dissolves minerals, resulting in undesirable characteristics, such as hardness, and contamination with toxicants and microorganisms (Mbaka et al., 2017). Groundwater salinity is an issue for both drinking water and irrigation water use (Wright, 2016). Waterborne disorders such as gastroenteritis, cholera, hepatitis, typhoid fever, and giardiasis have been linked to the use of untreated groundwater, with bacteria, viruses, and protozoa as the causal agents (Arjen Van der Wal, 2010). Unfortunately, people may be unaware that a well near a toilet could be contaminated with bacteria, viruses, and parasites (Arjen Van der Wal, 2010). Even if no source of anthropogenic contamination may exist, there is potential for natural levels of metals and other chemicals to be harmful to human health (Eucharista, 2016). The natural water analysis for physical and chemical parameters including trace element content is very important for public health studies.

3. CHAPTER THREE: METHODOLOGY

3.1. Methodology

This chapter is based on research design, methods and materials that were used to achieve the specific objectives, the study area and data analysis.

3.2. Research design

Research design is based on the processes that were involved during the study. The processes are presented in the flow chart.

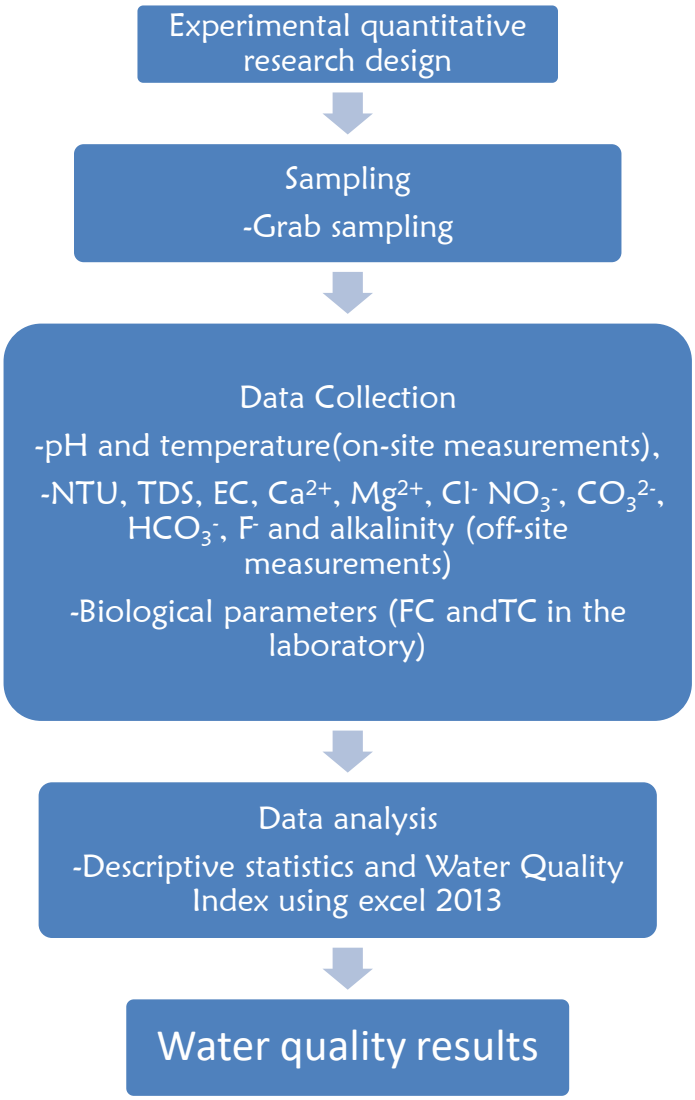


Figure 1: Flow chart for research design

3.3. Study area

The study was conducted in Manase peri-urban area in the Southern region of Malawi specifically located at the Blantyre city south. Manase is a peri-urban area and highly populated with a compacted type of settlement. The area has access to piped water supplied by the Blantyre water board but the taps are most of the time

dry due to water supply inconsistency and this leaves the people with no other option but to rely on groundwater sources as the main source of water available and accessible for domestic purposes including cooking and drinking and other sanitation purposes. It is for this reason; this study was conducted in Manase to assess water quality in shallow wells and boreholes for domestic purposes. Most shallow wells are owned by individuals and people pay for access to water from these shallow wells. Boreholes are owned by the community and people pay as well for them to access water. Some of the shallow well water sources are included in Appendix F.

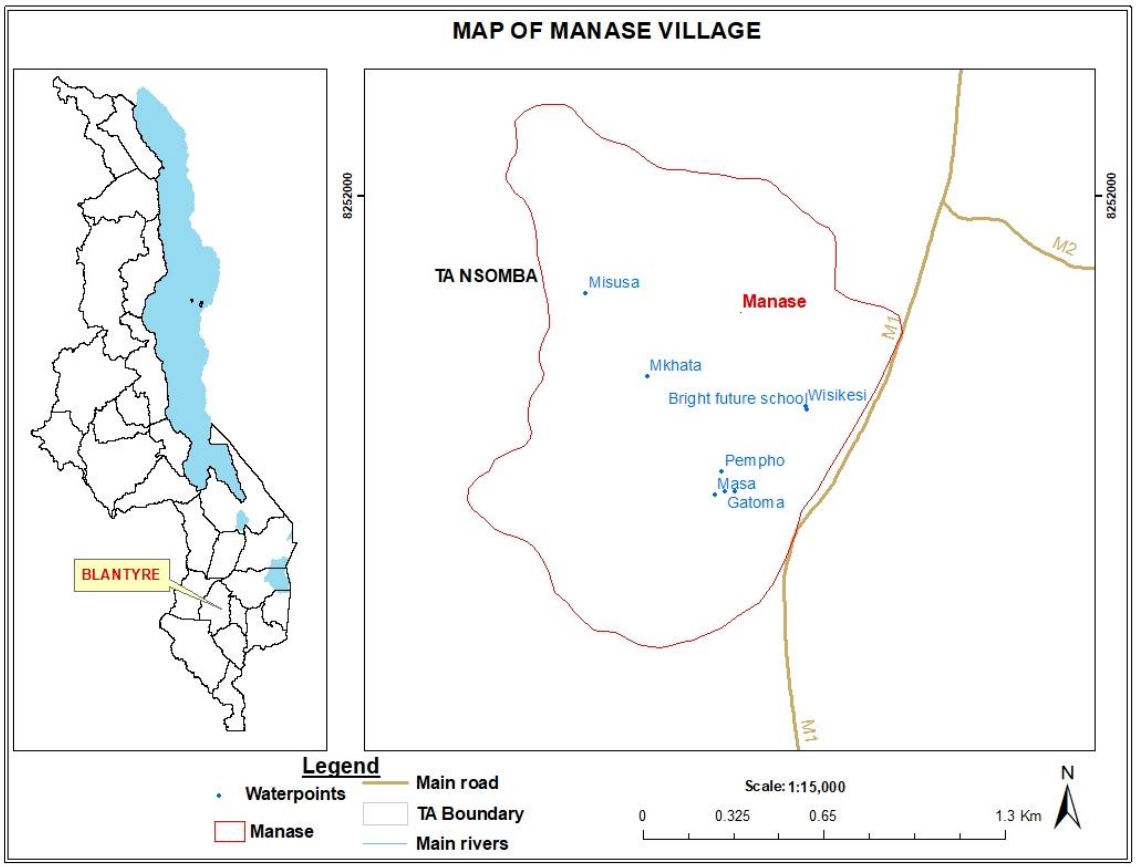


Figure 2: Map of Manase Village, Blantyre district

3.4. Materials

In accomplishing the objective of this research, several materials were used for data collection and analysis. On the data collection, a handheld GPS was used for collecting the coordinates of the sampling points and are indicated in appendix B. During the water quality assessment, several materials were needed such as the covered plastic containers as recommended by (EPA, 2016). The bucket contained icebox was used for preserving and transporting the samples in a conducive environment to avoid tampering with the water quality parameters to be tested. During the actual process of testing the parameters, the laboratory equipment such as burettes, droppers test tubes, beakers, graduated cylinders, dilution bottles, pipettes, Petri dishes, membrane filters, filtration unit, absorbent pads, spirit lamps, forceps, an incubator and conical flasks and tape measure were used.

3.5. Methods

Different techniques were used in the data collection process of which some involved quantitative research approaches where direct measurement of physical or chemical and microbial parameters on a phenomenon of interest be done and it involved experiments. Sampling points were purposively selected because that's where most people collect water for domestic purposes. The standard analytical methods that were used for the determination of physical, chemical and biological parameters of water were from the American Public Health Association series of Standard Methods of Examination Water and Wastewater(APHA, 2005). Water samples were collected in selected boreholes and shallow wells. Microsoft Office Excel 2013 was used for all statistical analyses.

3.5.1. Sample collection

Water samples were collected randomly in seven selected shallow wells (protected and unprotected shallow wells) and one borehole during the wet season on 8th May

2021 and analyzed for thirteen physicochemical parameters including pH, electrical conductivity (EC), temperature, total dissolved solids (TDS), turbidity (NTU), calcium (Ca^{2+}), magnesium (Mg^{2+}), fluoride, chloride(Cl^-), nitrate(NO_3^-), alkalinity, carbonate(CO_3^{2-}) and bicarbonate(HCO_3^-). Microbiological parameters were analyzed for fecal coliforms (FC) and total coliforms (TC). The shallow wells and boreholes were spatially located using a Global Positioning System (GPS), which also measured altitude.

3.5.1.1. Sample collection for physicochemical parameters

Water samples for the physicochemical parameters were collected in 1 litre of plastic bottles at each sampling point and two bottles were used at each sampling point. The samples were collected in the morning hours. When collecting the sample from the borehole, the water was waited to flow out for about 5 minutes before collecting the sample into the polyethylene sample collection bottles to make sure that the sample that is to be collected should be water direct from the aquifer and not from the pipes. Likewise, on shallow wells, the water was let to settle down before collecting the sample from them to ensure that the sample parameters are not manipulated by the disturbed water state.

The bottles were rinsed using the water sample three times before collecting the sample. 1ml of Hydrochloric acid was added into one bottle after collecting the sample for sample preservation. One bottle was acidified and the other bottle was not acidified. The bottles of water samples were labeled before collecting the sample to show the owner and date of sampling and then transported to the laboratory at Malawi University of Science and Technology and Southern Region irrigation and water development laboratory for analysis. The analyses were conducted according to standard methods of water and wastewater examination (APHA, 2005).

3.5.1.2. Sample collection for Microbiological parameters

Bacteriological water samples were collected in sterilized glass bottles and rinsed twice with source water before sample collection, to minimize the risk of external contamination. The samples were labeled to show the owner and date of sampling, stored in an ice bucket at less than 4°C, and transported to the laboratory and analyzed before 24hours (USEPA, 2016).

3.5.2. Sample analysis

The analysis of the selected physical, chemical and biological parameters are of relevance to health. The majority of water quality problems are related to the parameters selected below. The analyses of these parameters are important because they help to examine the water quality of shallow wells and boreholes.

3.5.2.1. Determination of physical parameters

The pH of the water sample was measured at the site and in the laboratory using calibrated pH portable meter. The pH meter was dipped into a bucket that was used to collect samples and the measurements were taken after it stabilizes and recorded in the notebook. Both pH and temperature measurements were taken using the pH meter. The EC and TDS were estimated by aqua meter instrument. The aqua meter was dipped into the beaker containing the water sample and the measurements were taken after the values stabilized.

Turbidity was measured using Hydro test Photometer (HT1000). 10ml of water sample was transferred into the 10ml vial. The vial was placed into a hydro test photometer and then press test and waited for a while for the measurements to start. The results displayed in NTU for turbidity were recorded in the notebook.

3.5.2.2. Determination of fluoride

Fluoride was analyzed using the photometric method. 10ml of water sample was measured using a 10ml test tube and 2ml of SPADNS were added into the test tube containing the sample and then shake. After shaking, the test tube was placed into a hydro test photometer and then press test and waited for a while for the measurements to start. The results displayed in mg/L for Fluoride were recorded in the notebook.

3.5.2.3. Determination of chloride

Chloride was analyzed using the titration method. 50ml of a nonacidified sample was added into a conical flask. 1ml of potassium chromate was added into a conical flask of every sample and the yellow color developed. Silver nitrate was transferred into a burette and filled to zero marks. Then the sample was titrated until the slight red color was produced. The initial and final volumes were recorded in the notebook and were used to find the concentration. The slight red color indicates the presence of chloride. A blank sample (distilled water) was used as a control. The titration setup for chloride is included in appendix E. The formula below was used for chloride calculation.

Chloride (mg/L) = (T-B) * N*35,450/ volume of sample

Where T is volume titration for sample, B is volume titration for blank and N is the normality of silver nitrate.

Normality of Silver nitrate($AgNO_3$) solution (N) =(20*0.0141)/(volume of titre)

3.5.2.4. Determination of nitrate

Nitrate was analyzed through the spectrophotometric method. A hydro test photometer (HT 1000) was used to measure nitrate. The nitrate test tube was filled with 20ml of the water sample and 1 spoon of nitrate test powder was added then mixed for one minute. One nitrate test tablet was added to the sample and mixed

for one minute and allow the contents to settle for two minutes. Then, the decant 10ml of the treated solution was transferred into the 10ml vial. One nitrate LR tablet straight from the foil was added to the water sample and it was crushed using a clean stirring rod until no large pieces are visible and swirl until the tablet was dissolved. The vial was placed in the sample chamber and ensured that the mark of the instrument and vial are aligned. Then, press the test key and waited the reaction period of ten minutes. After the reaction period, the measurements started and the results were displayed in mg/l Nitrate. All the nitrate values for all the samples were recorded in the results recording tables.

3.5.2.5. Determination of calcium and magnesium

Calcium and magnesium were analyzed using the titration method. 50ml of the acidified sample was added into two beakers labeled A and B for calcium and magnesium respectively. 1ml of total hardness was added in beaker A and then little eriochrome black tea was added until purple color develops. The sample was titrated using Edta until the blue color was produced. The initial and final volumes were recorded. 1ml of calcium buffer was added into beaker B and then murexide was added until pink color is produced. The sample was titrated using EDTA until the purple color was produced. The initial and final volume of titre was used to get the concentration for calcium and magnesium of each sample. The titration setup for magnesium and calcium is shown in Appendix D. The concentration of calcium and magnesium were calculated using the formula below

Total hardness= ((final volume-initial volume)*1000)/sample volume

Calcium hardness= ((total volume-final volume)*1000)/sample volume

Calcium concentration =calcium hardness *0.4

Magnesium concentration =(total hardness – calcium hardness) *0.24

3.5.2.6. Determination of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-)

Carbonate and bicarbonate were analyzed using the titration method. 50ml of nonacidified water sample was added into 250ml conical flask. 3 drops of phenolthlaen indicator were added to the water sample using the dropper and the pink color developed which indicated the presence of carbonate and if there was no development of pink color, it indicated the absence of carbonate. Then, the water sample was titrated with hydrochloric acid (HCl) working solution until the pink color disappear and the initial and final volume was recorded. Bromocresol indicator was added and the water sample was titrated with HCl until light pink color developed indicating the presence of bicarbonate. The initial and final volumes were recorded in the notebook. The initial and final volumes of titre were used to find the concentration of carbonate and bicarbonate for each sample. Below are the formulas that were used to find a concentration of carbonate and bicarbonate.

[carbonate]= 2*P*N*30000/sample volume
Where P = Phenolphathlein solution and
N= Normality of acid= 0.02*25.00/(final volume-initial volume of HCl)

[Bicarbonate]=(T-2P)*N*61000)/(final volume- initial volume of HCl)

3.5.2.7. Determination of alkalinity

The measured concentration for bicarbonate and carbonate were used to compute the concentration for alkalinity at each point. Below is the formula for alkalinity

Alkalinity as $CaCO_3$ = MF* [carbonate] + MF*[bicarbonate]
Alkalinity as $CaCO_3$ = 1.667*[carbonate] +0.82*[bicarbonate]

3.5.2.8. Determination of fecal coliform and total coliform

Total and fecal coliform were analyzed by filtration membrane method in the laboratory. Media was prepared using the standard methods suggested by the American Public Health Association (APHA, 2005). A filter paper was placed on the filter and 100ml of water sample was added to the filter and filter the sample. After filtration, the filter paper was removed using sterilized forceps and placed in the sterilized petri dish containing the media and it was immediately covered. The Petri dishes were transferred to an incubator and incubated at a temperature of 44 °C for fecal coliform and waited for 18 hours. For total coliform, the oven was settled at a temperature of 35 °C and waited for 24 hours. The samples were taken out from the oven according to the required time of each parameter and then counted manually using a microscope. The results were recorded in a notebook. The setup for fecal coliform and total coliform analysis is shown in Appendix C.

3.6. Statistical analysis

The data were analyzed using Microsoft Office Excel 2013 for descriptive analysis to compute means and standard deviations between variables and water quality index. Tables and graphs were used to present the patterns between variables of the results.

3.7. Ethical and professionalism

The participant's participation in this study was not compulsory but the participant was approached and briefed him or her to understand what the whole study was about and that it was by his or her choice either to give the permission or not. Before starting collecting samples in the area of study, written consent was given to the village authorities and they were approached to ask for their approval as well. To obtain this approval, the authorities were not bribed or materially influenced.

4. CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. Results and discussions

This chapter explains the summary of the results obtained after the laboratory analysis. A summary of the results of each parameter is presented in tables and compared to the recommended standards for the World Health Organization and Malawi Bureau of Standards as presented in the Appendix A.

Table 1 : Summary statistics for physical parameters in shallow wells and borehole.

Sampling point	pH (mean ± SD)	Turbidity (NTU)	EC (μS/cm) (mean ± SD)	TDS(mg/L) (mean ± SD)	Temperature (mean ±SD)
BH1	7.68±0.078	1.5±0.474	932.3 ±16.77	598 ± 45.04	22.86±3.004
SW2	7.53±0.095	21±0.306	460.6 ± 6.66	264.6±20.56	21.96±2.409
SW3	6.79±0.055	0.97±0.085	1120 ± 44.17	566.3±32.34	21.26±1.89
SW4	7.12±0.300	1.41±0.356	1372.3±41.17	893±28.58	21.23±2.458
USW	8.09±0.025	28.9±0.416	1152 ± 46.78	762.6±2.3	19.46±2.663
SW6	7.38±0.228	1.8±0.877	777.3± 38.4	519.3±2.08	21.03±0.702
SW7	7.38±0.090	1±0.3	760.6 ± 3.21	353 ± 61.48	24.87±2.055
SW8	7.86±0.188	1.05±0.064	651.3±39.27	428.6±18.77	21.8±1.734
WHO	6.5-8.5	5	2500	1000	-
MBS (MS733:2005)	6.0-9.5	25	3500	2000	-

The table above is showing the results that were obtained from the descriptive analysis. The computed mean values and standard deviations are presented in the table of each physical variable at each sampling point.

Table 2: Summary of results for chemical and biological parameters of shallow wells and borehole water samples compared to the recommended standards for WHO and MBS (MS733:2005 for boreholes and shallow wells).

Parameters	BH1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	WHO	MBS
NO_3^-(mg/l)	0.276	7.705	13.88	3.802	6.84	2.094	0.52	0.384	45	45
F^-(mg/l)	0.64	0.05	0.59	0.44	0.05	0.23	0.69	0.38	1.5	6.0
Cl^-(mg/l)	20.4	21.2	86.81	50.61	71.21	18.8	15.6	16.8	600	750
CO_3^{2-}(mg/l)	13.3	7.10	0	6.09	10.5	8.13	5.87	8.12	-	-
HCO_3^-(mg/l)	209.4	222.8	382.6	421	435.3	200.3	185.1	190.2	-	-
Ca^{2+}(mg/l)	80	75.2	156	125.2	129.6	60.6	60.8	58.80	200	250
Mg^{2+}(mg/l)	3.28	4.73	13.2	25.58	37.10	12.24	4.45	8.20	150	200
Alkalinity (mg/L)	193.88	194.53	313.73	355.73	374.45	177.8	161.57	169.5		120
TC(cfu)	20	1578	676	560	1214	1014	338	864	0	50
FC(cfu)	2	529	213	173	316	288	46	216	0	50

The table above presents the average value for each chemical parameter measured at each sampling point and the actual measurement of the microbial parameter at each sampling point.

Table 3: Summary statistics for chemical parameters of shallow wells and a borehole.

Parameter	Mean	Median	STD	Min	Max
Fl^-	0.38	0.41	0.25	0.05	0.69
Ca^{2+}	93.28	77.6	37.96	58.8	156
Mg^{2+}	13.6	10.22	11.93	3.28	37.1
CO_3^{2-}	7.39	7.61	3.86	0	13.3
HCO_3^-	280.84	216.1	110.97	185.1	435.3

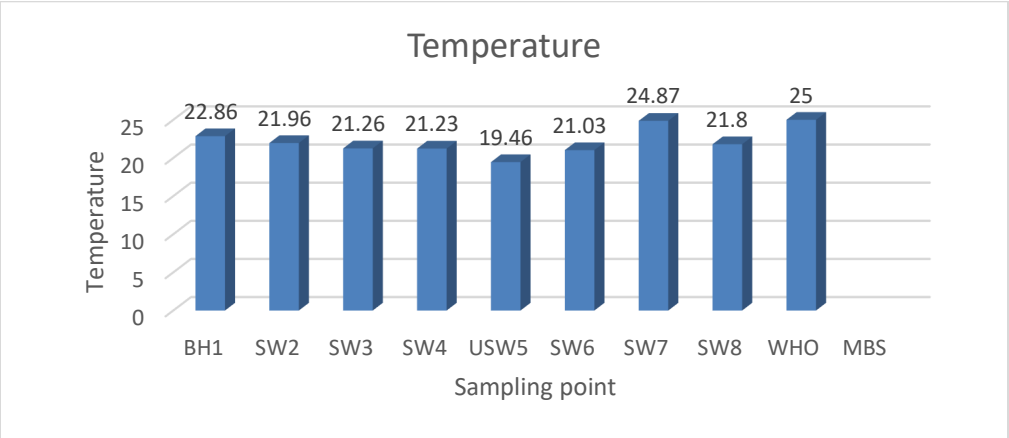
The table above presents the mean, standard deviation, maximum and minimum of each chemical variable at all sampling points.

Table 4: Summary statistics for microbial parameters of shallow wells and a borehole

Parameter	Mean	Median	STD	Min	Max
FC	222.88	214.5	164.46	2	529
TC	783	770	495.56	20	1578

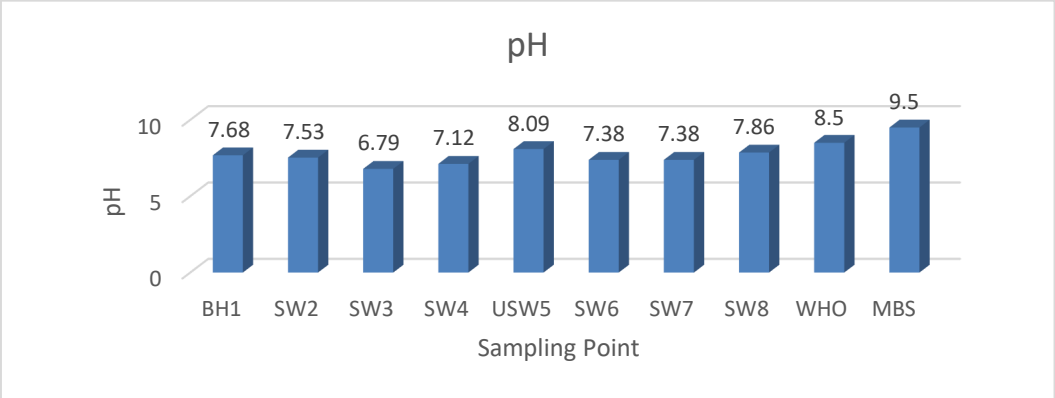
The table above presents the mean, standard deviation, maximum and minimum of each microbial variable at all sampling points.

4.1.1. To analyze physical and chemical parameters for shallow wells and boreholes compared to WHO and MBS



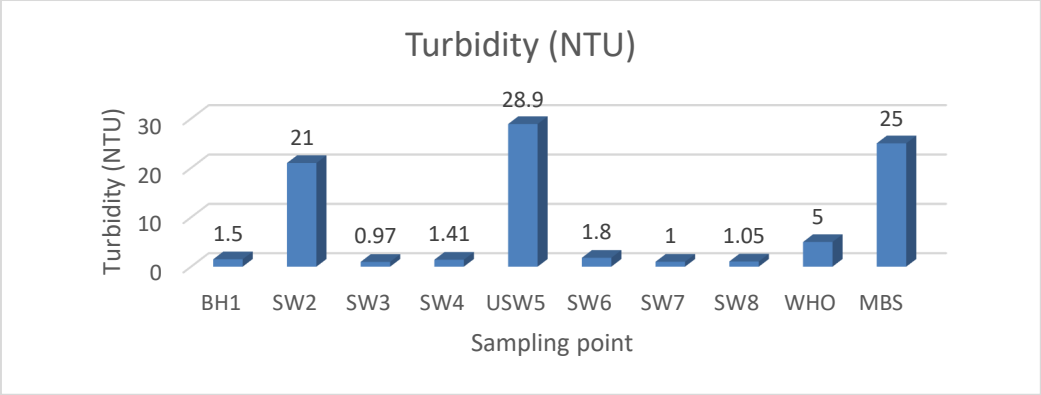
(a)

The mean value for temperature ranged from 19.46±2.663 to 24.87±2.055 °C for shallow wells water. The mean value for temperature was 22.86±3.004°C for the borehole. The lowest mean value of temperature was 19.46±2.663 °C at the unprotected shallow well (USW5) and the maximum level of temperature was 24.87±2.055 °C at the shallow well (SW7). Water temperature at less than 29°C may affect the chemistry of groundwater as well as metals toxicity hence capable of causing significant health problems such as cancer (Chimphamba & Phiri, 2014). This may be acceptable because of the meteorological conditions in the location at the time the sample was taken.



(b)

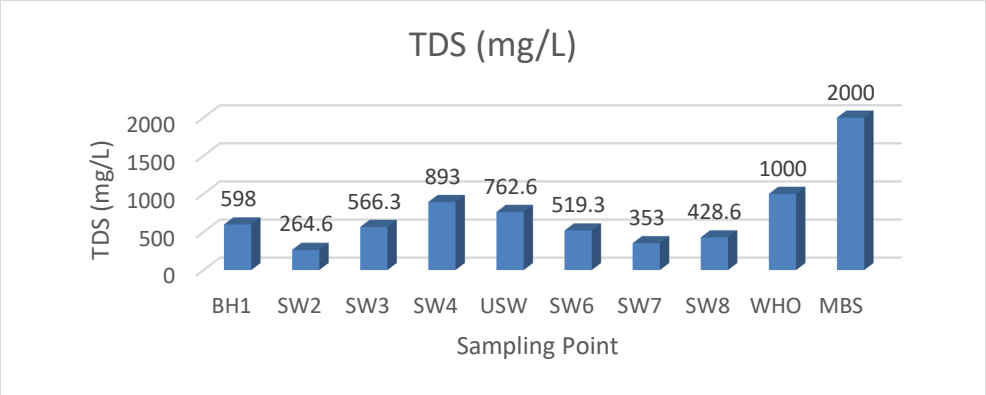
The term pH is used to describe the strength of an acidic or alkaline condition in water (Oko et al., 2014). The mean pH of the water sample ranged from 6.79±0.055 to 8.09±0.025 for shallow wells. The mean pH for the borehole was 7.68±0.078. The highest mean for pH was 8.09±0.025 at an unprotected shallow well (USW5). The pH at boreholes and shallow well water were within the maximum permissible limit for WHO (2008) and MBS (2005). pH measures the hydrogen ion concentration; pH of 7.0 indicates a neutral solution, pH values smaller than 7.0 indicate acidity, pH values larger than 7.0 indicate alkalinity. Water gets more corrosive as the pH decreases, however, highly alkaline water can also be corrosive (Adekola et al., 2015).



(c)

Turbidity was an important consideration in determining the suitability of water for

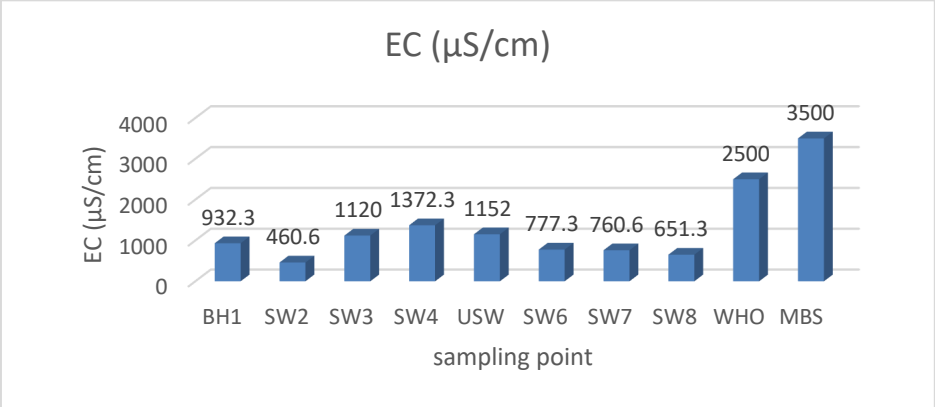
domestic purposes because it is a major concern to public health. The mean value for turbidity of the water sample ranged from 0.97±0.085 to 28.9±0.416 NTU for shallow wells. The mean value for turbidity was 1.5±0.474 NTU for borehole water. The lowest mean value for turbidity was 0.97±0.085 NTU at the shallow well (SW3) and it was within the maximum permissible limit, while the highest mean value for turbidity was found to be 28.9±0.416 NTU at unprotected shallow (SW5) and it exceeded the maximum permissible limit for turbidity of both WHO and MBS. The turbidity at boreholes and shallow well water were within the maximum permissible limit for WHO except for two shallow wells. According to MBS (2005), only the unprotected shallow well (USW5) exceeded the maximum permissible limit of 25 NTU. This is due to the type of soil and weather. Human activities, such as logging, may have influenced the wells examined by causing periodic pulses or chronic levels of suspended material in the water (Mbaka et al., 2017). The usage of a manual pump due to corrosion is also a probable explanation for high turbidity. Corrosion may cause the hand pump's permeability to decrease, allowing soil particles to penetrate the water, resulting in excessive turbidity levels. High turbidity might increase the level of microbes that get attached to the colloidal matter(Tebbutt, 2002).



(d)

TDS was an essential parameter in determining the suitability of water for domestic use because it is of health concern when directly consumed. The mean TDS of the

water sample ranged from 264.6 ±20.56 to 893±28.58mg/L for shallow wells. The mean value for TDS was 598 ± 45.04mg/L at borehole water. The highest mean value for TDS was found to be 893±28.58mg/L at the shallow well (USW4). All shallow wells and borehole water analyzed had TDS value within the recommended limit WHO, (2008) and MBS, (2005) drinking water standard as indicated in table 1, hence not capable of causing significant health problems. The total dissolved solids at both boreholes and shallow well water were within the maximum permissible limit for WHO. The high TDS values in the study area might be a result of the dissolution of weathered materials from the rock formation in the study area or pollution through leaching from pit latrines into the shallow wells due to the unprotected nature of the shallow wells and borehole (Rabah, 2013). Water containing high concentration solids may also cause the effect of laxatives and constipation.



(e)

Electrical conductivity is a measurement of water's ability to conduct an electric current. It is based on the number of ions or charged particles in the water and is determined by conducting a current between two electrodes (positioned at a predetermined distance apart) in a sample of water (Australia, 2009). The mean values for EC ranged from 460.6 ± 6.66 to 1372.3 ±41.17 μs/cm for shallow wells. The mean value for EC was 932.3 ± 16.77μS/cm at the borehole. The highest mean value for EC was 1372.3 ±41.17 μS/cm at the shallow well (SW4). The EC at

boreholes and shallow well water were within the maximum permissible limit for WHO and MBS. The ionic strength of a solution increases as the concentration of dissolved solids rises.

Figure 3: Variation of the physical parameters of water samples at different sampling points include temperature **(a)**, pH**(b),** turbidity**(c),** total dissolved solids **(d)** and electrical conductivity **(e).**

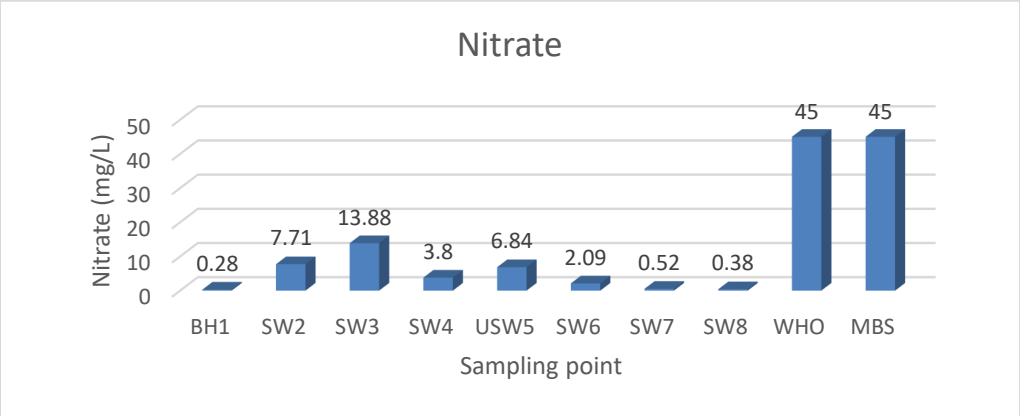


Figure 4: The variation of the nitrate of water samples at different sampling points.

Nitrate was an important consideration in determining the suitability of water for domestic use because it is a major concern to public health. The concentration level of nitrate was 0.28mg/L at the borehole and from 0.38 to 13.88 of shallow wells. The minimum concentration of nitrate was found to be 0.28mg/L at the borehole (BH1), while the maximum nitrate concentration was found to be 13.88 mg/L at the shallow well water source (SW3). The nitrate content in the study area at both shallow wells and borehole was found to be within the prescribed limit for both MBS and WHO as indicated in table 2. Excess nitrates can result in cancer, goiter methemoglobinemia, or blue baby syndrome in young children(WHO, 2008). Groundwater contains nitrate due to the leaching of nitrate with the percolating water. Groundwater can also be contaminated by sewage and other wastes rich in

nitrates (Weiner & Francis, 2007). Nitrate commonly occurs naturally in groundwater, but high concentration might be associated with animal and human waste, open septic or sewage systems and fertilization of farms (Vigil, 2003).

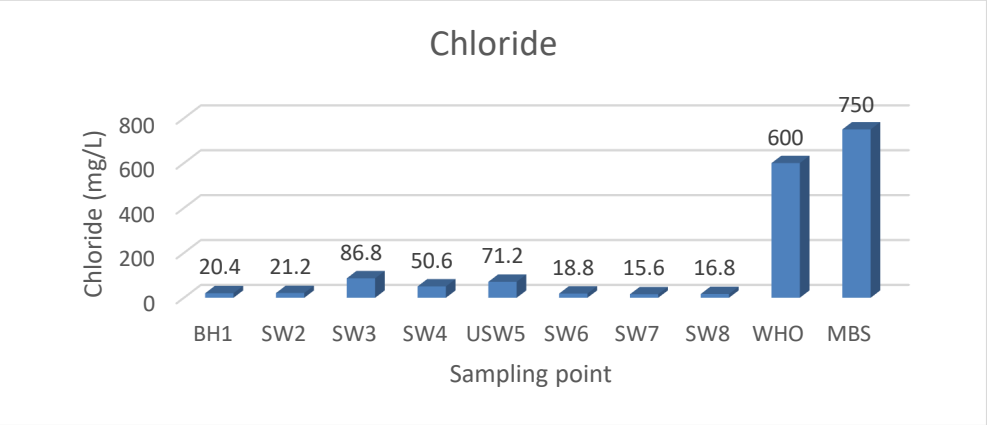


Figure 5: Variation of the chloride of water samples at different sampling points.

Chloride was an important consideration in determining the suitability of water for domestic purposes because its excess presence might create health problems. The level of chloride in the water sample was 16.8 to 86.8 mg/L for shallow wells and 20.4 mg/L for borehole water. The minimum level of chloride was found to be 16.8mg/L at a shallow well numbered eight (SW8) and the maximum level of chloride was found to be 86.8mg/L at a shallow well numbered three (SW3). In the present study, the chloride values for all samples analyzed were within the permissible limits of 250mg/L and 200mg/L set by MBS and WHO. It occurs naturally in all types of waters(Appavu et al., 2016). Large amounts of chloride are due to natural processes such as the passage of water through natural salt formations in the earth by intrusion most these wells are near to the sea or it may be an indication of pollution from seawater, it is quite evident from the study that there are evident(Mohamed & Kitwana, 2018).

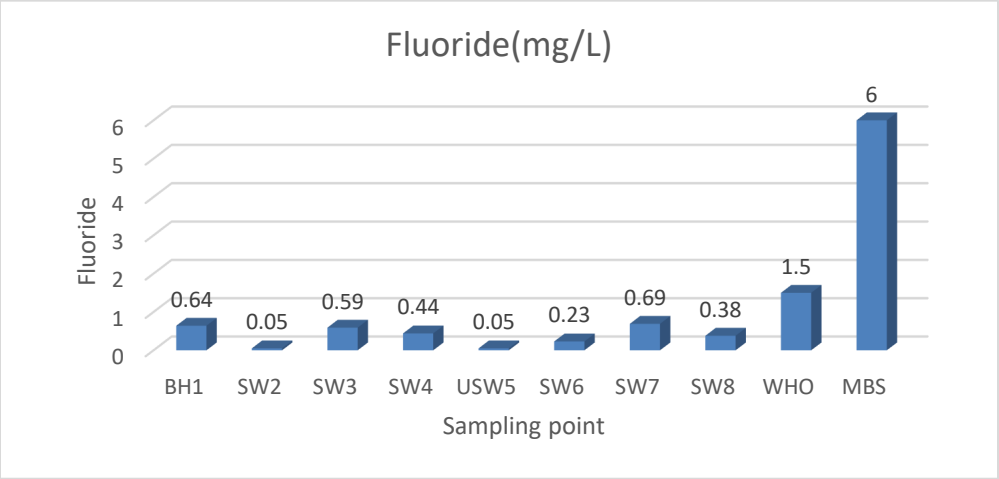
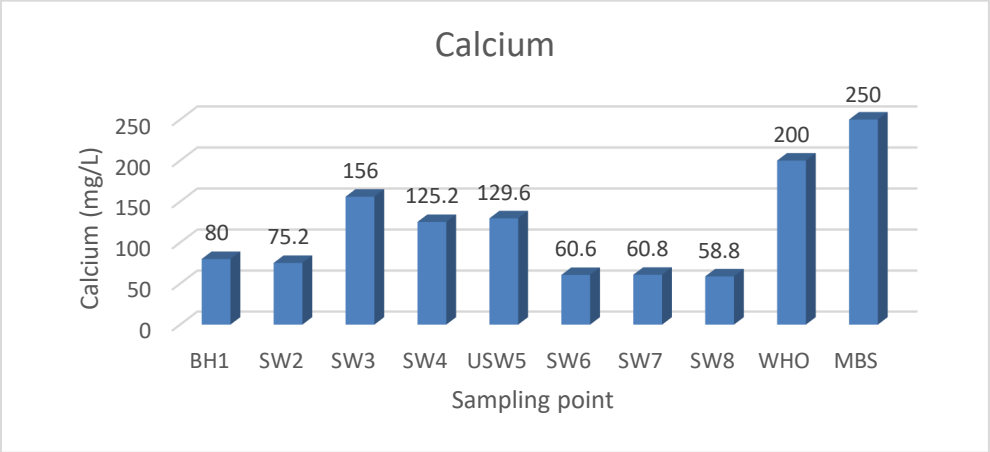
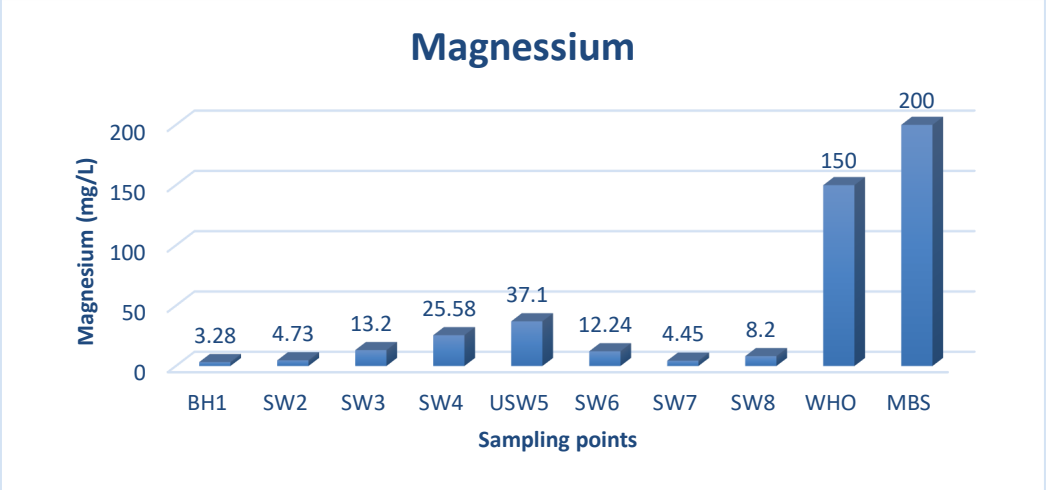


Figure 6: Variation of the fluoride of water samples at different sampling points.

Fluoride was an essential consideration when determining the suitability of water for domestic purposes. All water samples had acceptable levels of fluorides. The minimum concentration of fluoride was 0.05mg/L at shallow good number two (SW2) and unprotected shallow well (USW5). The maximum concentration of fluoride was 0.69mg/l at the shallow well (SW7). The level of fluoride was within the maximum permissible level for WHO and MBS. High concentrations of fluoride contaminants in groundwater tend to be found in association with crystalline rocks containing fluoride-rich minerals especially granite and volcanic rocks(Adekola et al., 2015). Fluoride has long been found to have a beneficial effect on dental health as such it is an additive to toothpaste and food. However, when present in drinking water at a concentration much above the guideline of 1.5mg/L then long-term use can result in the development of fluorosis or at its worst crippling skeletal fluorosis(Adekola et al., 2015).



(a)

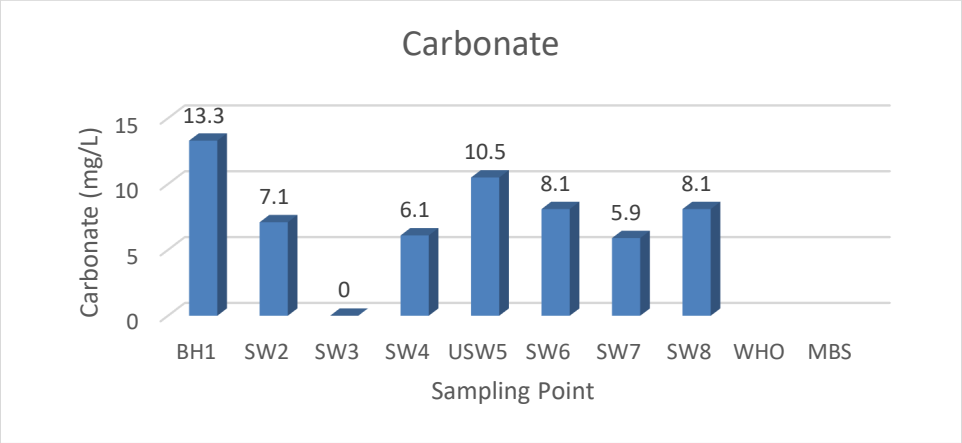


(b)

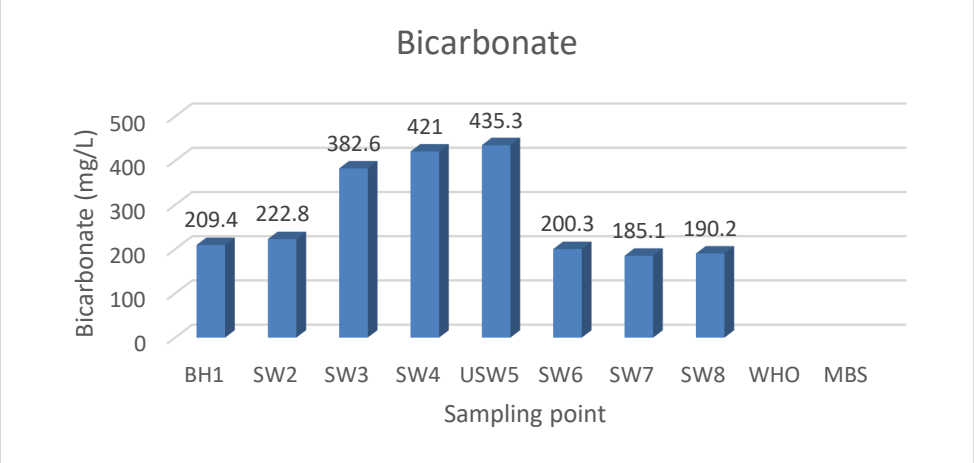
Figure 7: Variation of the calcium (a) and magnesium (b) of water samples at different sampling points.

Calcium and magnesium are directly related to hardness. Calcium ion concentration ranged between 58.8mg/L at shallow well water (SW7) and 156mg/L at the shallow well water source (SW3)) and was found to be below the permissible limit for MBS and WHO. The magnesium ion content in the water samples ranged from 3.28mg/L at the shallow well water source (SW1) to 37.1mg/L at the unprotected shallow well (SW5) and was found to be within the recommended standards for MBS and WHO. It was essential to analyze these water quality indicators for domestic purposes

because they contribute to the hardness of which high concentrations of calcium and magnesium may cause water to be hard. If hard water is used for domestic purposes such as washing it consumes more soap and it also causes scales in pots.



(a)



(b)

Figure 8: Variation of the carbonate (a) and bicarbonate (b) of water samples at different sampling points.

The minimum concentration for carbonate was zero at the shallow well (SW3). The maximum level concentration for carbonate was 10.5mg/L at an unprotected shallow well (USW5). The concentration level for carbonate was 13.3mg/L at the borehole (BH1). The minimum concentration for bicarbonate was 185.1mg/L at the shallow

well (SW7). The maximum level concentration for bicarbonate was 435.3mg/L at an unprotected shallow well (USW5). The concentration level for bicarbonate was 209.4mg/L at borehole number one (BH1). Bicarbonate and carbonate are species responsible for alkalinity. An increase in the concentration level of carbonate and bicarbonate will increase the concentration of alkalinity. Many minerals are deposited as salts of the carbonate ion (Mahan, 2000). A water sample having a pH greater than 8.3 is titrated with acid and measures phenolphthalein alkalinity. Phenolphthalein alkalinity primarily measures the amount of carbonate ion (CO_3^{2-}) present in water (Weiner & Francis, 2007). It was essential to determine these water quality indicators because they contribute to alkalinity. Alkalinity buffers pH and make water to be at the required recommended standard for domestic use.

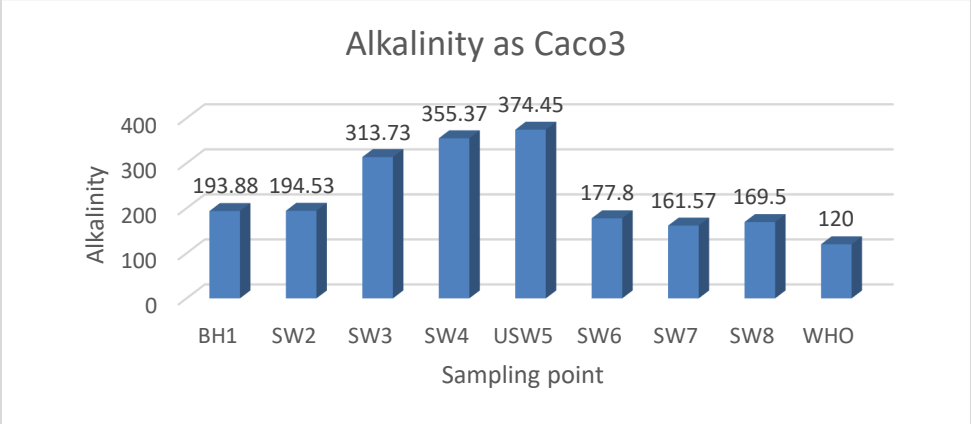
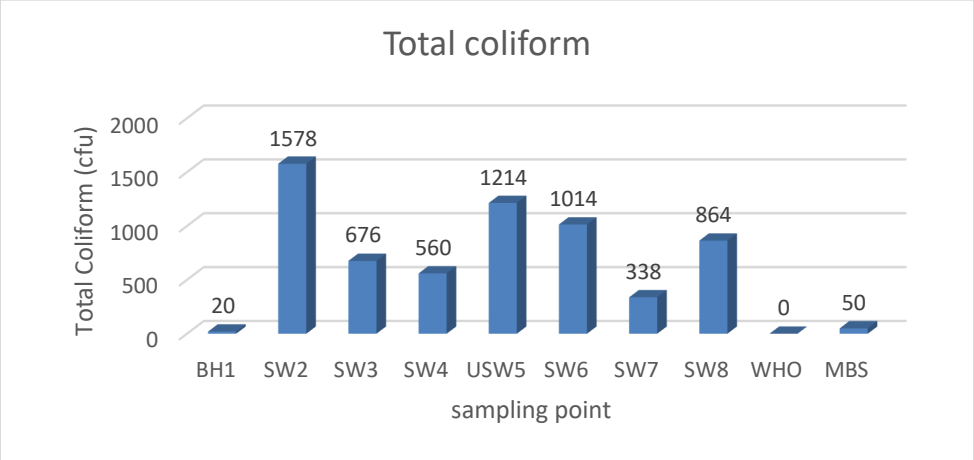


Figure 9: Variation of the alkalinity of water sample at different sampling points.

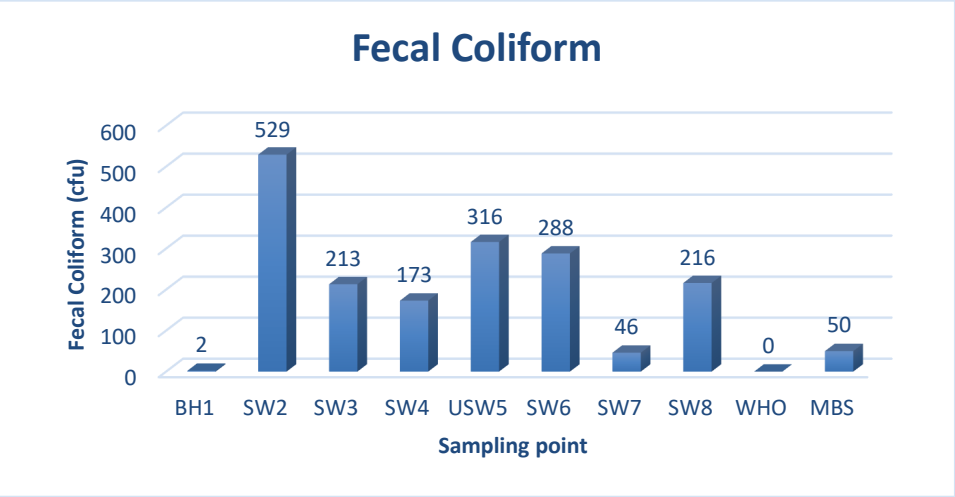
Alkalinity is essential in determining the suitability of water for domestic use. The values for alkalinity ranged from 161.57mg/L to 374.45mg/L in shallow wells water sources. The value for alkalinity was 193.88mg/L at the borehole. The maximum value for alkalinity for shallow wells was 374.45 at the unprotected shallow well (USW5) and the minimum value was 194.53mg/L at the shallow well (SW2). The alkalinity of all shallow wells and the borehole exceeded the maximum permissible limit for WHO (2008). A measure of an unfiltered water's ability to neutralize acid

(Weiner & Francis, 2007). In almost all natural waters alkalinity is produced by the dissolved carbon dioxide species, bicarbonate and carbonate (Weiner & Francis, 2007). Typically expressed as mg/L CaCO3. The excessive alkalinity may be due to dissolved mineral rocks and the dissolution of carbon dioxide which may cause stomach upset (Eucharista, 2016). The maximum permissible limit is 120mg/L for WHO (Eucharista, 2016).

4.1.2. Determination of the level of microbial contaminants in shallow wells and boreholes



(a)



(b)

Figure 10: Variation of the level of total coliform (a) and fecal coliform(b) at different sampling points.

Fecal coliform and total coliform were essential in determining the suitability of water for domestic purposes such as drinking and bathing. The values of bacteria count ranged from 46 to 529 CFU/100 mL for fecal coliform at shallow wells and 2cfu/100ml at the borehole. All shallow wells exceeded the recommended standards for WHO (2008) and MBS (2005) except shallow well(SW7) and borehole(BH1) were within the maximum permissible limit for MBS. The values for total coliform ranged from 338 to 1578 CFU/100 mL at shallow wells and borehole total coliform was 20cfu/100ml. All shallow wells exceeded the recommended standards for WHO (2008) and MBS (2005) except the borehole(BH1) was within the maximum permissible limit for MBS. This indicates that microbial parameters are extremely high in groundwater to be used for domestic purposes such as drinking and bathing. Based on the results obtained from this study, the microbial water quality indicators of borehole water sources differed from that of shallow wells. From shallow wells, the counts of both fecal coliform and total coliform were extremely high than in boreholes because boreholes are sanitary sealed and when locating boreholes some drillers consider the factor of distance from pit latrine to a borehole. The distance from pit latrines to shallow wells in all sampling points was close. It is recommended

that shallow wells and boreholes should be 30meters away from the pit latrines (Maweru, 2014). The presence of bacteria and total coliform in well water suggests that it has been contaminated by human or animal feces. Infants, young children, and persons with extremely weakened immune systems may be particularly vulnerable to these bacteria (USEPA, 2016). The value recommended by WHO for fecal coliform and the total coliform count is zero in domestic purposes such as drinking water. Therefore it was essential to assess microbial water quality indicators because when they are present in water, they can negatively affect human health. They can cause diseases such as diarrhea, cholera, and other water-related diseases.

4.1.2.1. Water quality index

The weighted arithmetic index method was used for the calculation of WQI of the water body (Adekola et al., 2015). Further, quality rating or sub-index (qn) was calculated using the following expression.

Qn=100[Vn-Vio]/[Sn-Vio]

Qn=Quality rating for the n^{th} water quality parameter

Vn= Estimated value of the n^{th} parameter at a given sampling

Sn= Standard value of the n^{th} parameter

Vio=Ideal value of the n^{th} parameter in water

Unit weight was manipulated by a value of a parameter inversely proportional to the standard value of the parameter.

Sn of the corresponding parameter.

Wn= K/Sn

Wn= Unit weight for the n^{th} parameter

Sn= Standard value for n^{th} parameter

K= Constant for proportionality.

The overall water quality index was calculated by aggregating the quality rating with the unit weight linearly as indicated in Appendix G. $WQI=\Sigma QnWn/\Sigma Wn$ (Adekola et al., 2015).

Table 6: Water quality index(WQI) and status of water quality (Adeokola et al, 2015)

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

Table 7:Summary of water quality index of shallow well water and borehole water

Sampling site	Water Quality Index Level (WQI)	Water Quality Status
BH1	38.25485063	Good water quality
SW2	234.1158669	Unsuitable for drinking
SW3	119.1504313	Unsuitable for drinking
SW4	103.8186536	Unsuitable for drinking
USW5	187.5127023	Unsuitable for drinking

SW6	152.2985482	Unsuitable for drinking
SW7	71.187	Poor water quality
SW8	133.648	Unsuitable for drinking

The water quality index of the present study was established from the physic-chemical and biological parameters. The values of the water quality index at each sampling point were represented in table 7. The water quality status indicated that at borehole(BH1), the quality of water was suitable for domestic purposes compared to all shallow wells that indicated unsuitable for drinking except shallow well (SW7) indicated poor water quality as shown in Table 6.

4.1.3. Correlation of physicochemical and microbial parameters of water quality in shallow wells and boreholes

Table 8: The correlation between physicochemical and microbial parameters of water quality.

	pH	Turbidity	EC	TDS	Temperature	Nitrate	Fluoride	Chloride	Carbonate	Bicarbonate	Calcium	Magnesium	Alkalinity	Total coliform	Fecal c
pH	1														
Turbidity	0.55995293	1													
EC	-0.2926414	-0.0783169	1												
TDS	-0.0553844	0.02762091	0.93893602	1											
Temperature	-0.1900855	-0.5122348	-0.4101653	-0.560236	1										
Nitrate	-0.4642876	0.34124506	0.26485372	0.09346518	-0.4647766	1									
Fluoride	-0.4761391	-0.80471	0.22557021	0.01110567	0.685719	-0.2197227	1								
Chloride	-0.3231981	0.26585095	0.72336721	0.57931346	-0.6025128	0.81486799	-0.0606735	1							
Carbonate	0.8081911	0.27950384	-0.1483067	0.11578618	-0.0368428	-0.6624026	-0.2339314	-0.484056	1						
Bicarbonate	-0.1891873	0.35747538	0.84624974	0.79448641	-0.666721	0.61326042	-0.193678	0.90064968	-0.2798655	1					
Calcium	-0.3911559	0.21202815	0.78889723	0.64940328	-0.5478251	0.78488693	0.00663417	0.97432168	-0.4534414	0.92689853	1				
Magnesium	0.19767508	0.51176346	0.71496345	0.78709336	-0.7704467	0.29994667	-0.4483903	0.67522247	0.03414267	0.86295883	0.64242388	1			
Alkalinity	-0.1343521	0.38394854	0.85060285	0.81693443	-0.6812109	0.57645195	-0.2139574	0.88179127	-0.2128308	0.99760782	0.91070898	0.88074606	1		
Total coliform	0.24970476	0.71416709	-0.3671534	-0.2492306	-0.5598138	0.41005099	-0.9209188	0.10403948	-0.1054381	0.12846762	0.01287496	0.28138539	0.12315222	1	
Fecal coliform	0.12936854	0.67273653	-0.3648257	-0.2585688	-0.5324379	0.48053637	-0.885243	0.11049855	-0.1472737	0.13082294	0.05544726	0.1985244	0.12253476	0.977051612	

Table 8 showed the result of the correlation analysis of parameters tested in this study. Correlation between parameters is essential to understand the relationship between parameters or how parameters are influenced by the presence of other variables. When the value is greater than or equal to ±0.9, 0.7 and 0.5, there is a very strong, strong and moderate correlation between the parameters respectively and less than 0.5, there is weak correlation.

The shaded boxes show the very strong and strong relationship between variables as indicated in table 8. TDS has a very strong positive correlation with EC (0.9389). Chloride has a strong positive correlation with EC (0.7234) and nitrate (0.8149). carbonate has a strong positive correlation with pH (0.8082). Bicarbonate has a strong positive relationship with EC (0.8462), TDS (0.7945) and has a very strong positive correlation with chloride (0.9006). Calcium has a very strong positive correlation with EC and nitrate and a strong positive relationship with nitrate and bicarbonate as shown in table 8. Magnesium has a strong positive relationship with EC, TDS and bicarbonate. Alkalinity has a very strong positive relationship with bicarbonate and calcium and a strong positive relationship with EC, TDS and

magnesium. Total coliform has a strong positive relationship with turbidity and a very strong negative relationship with fluoride. Fecal coliform has a strong negative relationship with fluoride and a very strong correlation with total coliform.

5. CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In this study, water samples from seven shallow wells and one borehole water source at different points were taken. From these water samples, 13 selected physicochemical parameters and 2 microbial parameters were analyzed to assess the water quality of the Manase area in Blantyre. From the analysis performed, most of the physicochemical parameters analyzed were within the national and international drinking water guidelines (MBS and WHO respectively), except for turbidity, alkalinity, fecal coliform and total coliform. In this study, two sampling points exceeded the maximum permissible level of turbidity for domestic purposes such as drinking water. The level of alkalinity ranged from 193.87 to 374.45mg/L and was above the maximum permissible limit for WHO at all sampling points. The level of turbidity ranged from 0.97±0.085 to 28.9±0.416NTU. Turbidity at SW2 and USW5 were above the recommended standards for WHO and USW5 for MBS. The level of fecal coliform and total coliform ranged from 46 to 529cfu/100ml and 338 to 1578cfu/100ml respectively and were above the maximum permissible limit for WHO at all shallow wells. A borehole, the level of fecal coliform and total coliform was 2cfu/100ml and 20cfu/100ml respectively and were within the maximum permissible limit for MBS. The water quality index indicated that the water was highly contaminated in shallow wells hence it was not fit for human consumption without treatment and it also indicated that water was good at a borehole and fit for human consumption.

5.2. Recommendation

This study, therefore, recommended that water from should be the source that can be used for domestic purposes and water from shallow wells should be treated before consumed either by boiling or adding chlorine. It is also recommended that shallow wells should not be dug near contamination sources and also that, the wells should always be properly lined and covered. Another recommendation is that appropriate regulatory agencies should carry out a quality assessments of existing shallow wells and boreholes to ascertain their quality level of the water before allowing for public consumption. This will ensure that the incidence of contamination is noticed earlier for remedial action to be taken.

6. REFERENCES

Abera, D., Geremew, S., Dejene, L., Irge, D., & Ahmad, T. (2017). Assessment of physico-chemical quality of borehole and spring water sources supplied to Robe Town , Oromia region , Ethiopia. *Applied Water Science*, *7*(1). https://doi.org/10.1007/s13201-016-0502-4

Adekola, O., Bashir, A., & Kasimu, A. (2015). *Physico-chemical characteristics of borehole water quality in Gassol Taraba State , Nigeria*. *9*(2), 143–154. https://doi.org/10.5897/AJEST2014.1794

Andy, W. D., & Stanly, T. W. (2003). *ENVIRONMENTAL HYDROLOGY* (SECOND EDI).

APHA. (2005). *Standard Methods for the Examination of Water and Wastewater* (21st Editi).

Appavu, A., Thangavelu, S., Jesudoss, J. S., & Pandi, B. (2016). STUDY OF WATER QUALITY PARAMETERS OF CAUVERY RIVER WATER. *Journal of Global Biosciences*, *5*(9), 4556–4567.

Arjen Van der Wal. (2010). *UNDERSTANDING GROUNDWATER AND WELLS*.

Australia, G. of W. (2009). *Surface water sampling methods and analysis — technical appendices Standard operating procedures for water sampling-*.

Chimphamba, J. B., & Phiri, O. L. (2014). *Borehole Water Pollution and its Implication on h ealth on the Rural Communities of Malawi*. *10*(1).

Christine, A. A., Kibet, J. K., Kiprop, A. K., & Were, M. L. (2018). The assessment of bore - hole water quality of Kakamega County , Kenya. *Applied Water Science*, *8*(1), 1–8. https://doi.org/10.1007/s13201-018-0688-8

Donald, A. M. Mac, Kebede, D. J. S., Owor, M., & Chavula, G. (2020). *Drinking water quality from rural handpump- boreholes in Africa OPEN ACCESS*.

EPA. (2016). Quick Guide To Drinking Water Sample Collection. In *Golden* (Second Edi).

Eucharista, E. I. (2016). *ASSESSMENT OF WATER QUALITY OF BORE HOLE WATER IN TIRUCHENDUR*. *4*(12).

Getso, B. U., Mustapha, A., Abubakar, M. M., & Tijjani, A. (2018). *Assessment of Borehole Water Quality for Domestic Use in Three Selected Wards in Wudil Local Government Area , Kano State*. *1*(1), 1–5. https://doi.org/10.20849/jess.v1i1.394

Grain, M. W., & Botolo Ben. (2010). *Malawi State of Environment and Outlook Report Environment for Sustainable Economic Growth*.

GW Mate- UNDP. (2010). Groundwater Management in IWRM: Training manual. In *Cap Net* (Issue February).

Kaonga, C. C., Kambala, C., Mwendera, C., & Mkandawire, T. (2013). *Water quality assessment in Bangwe Township , Blantyre City , Malawi*. *7*(5), 259–266. https://doi.org/10.5897/AJEST12.196

Kresic, N. (2020). Groundwater Contamination. In *Hydrogeology and Groundwater Modeling* (pp. 425–468). https://doi.org/10.1201/9781420004991-9

Lapworth, D. J., MacDonald, A. M., & Kebede, S. (2020). *Drinking water quality from rural handpump- boreholes in Africa OPEN ACCESS*.

Mahan, S. E. (2000). *ENVIRONMENTAL SCIENCE, TECHNOLOGY, AND CHEMISTRY "*.

Malawi, G. of. (2018). *Preliminary Report*. *December*.

Maoulidi, M. (2015). *WATER AND SANITATION NEEDS ASSESSMENT FOR BLANTYRE CITY , MALAWI N ° 27 / 2012 MALAWI Prepared by : Moumié Maoulidi , PhD October 2012*.

Mbaka, P. K., Mwangi, J. K., Kiptum, C. K., Mbaka, P. K., Mwangi, J. K., & Assessment, C. K. K. (2017). Assessment of water quality in selected shallow wells of Keiyo Highlands , Kenya. *African Journal of Science, Technology, Innovation and Development*, *00*(0), 1–10. https://doi.org/10.1080/20421338.2017.1327476

MBS. (2005). STANDARDS FOR DRINKING WATER.pdf. *MS733:2005*.

Mohamed, A. A. J., & Kitwana, T. M. (2018). *Water quality from hand-dug wells and boreholes in Micheweni District of Pemba Island , Zanzibar*. *7*(6). https://doi.org/10.15406/japlr.2018.07.00300

Msilimba, G., & Wanda, E. M. . (2013). *Microbial and geochemical quality of shallow well water in high-density areas in Mzuzu City in Malawi*.

Oko, O. J., Aremu, M. O., Odoh, R., Yebpella, G., & Shenge, G. A. (2014). *Assessment of Water Quality Index of Borehole and Well Water in Wukari Town , Taraba State , Nigeria*. *4*(5), 1–9.

Owamah, H. I. (2019). GROUNDWATER QUALITY PARAMETERS-CORRELATION AND MICROBIAL ANALYSIS. *H. I. Owamah*, *38*(2), 526–531.

Pritchard, M., Mkandawire, T., & Neill, J. G. O. (2009). *Groundwater Pollution in Shallow Wells in Southern Malawi and a Potential Indigenous Method of Water Purification*. 169–170.

Pritchard, M., Mkandawire, T., & O'Neil, J. G. (2007). Biological , chemical and physical drinking water quality from shallow wells in Malawi : Case study of Blantyre , Chiradzulu and Mulanje. *Physics and Chemistry of the Earth 32*, *32*, 1167–1177. https://doi.org/10.1016/j.pce.2007.07.013

Rabah, F. (2013). Water Treatment Technology. *Water Resources Engineering*, 1–27.

Sorlini, S., Palazzini, D., Sieliechi, J. M., & Ngassoum, M. B. (2013). *Assessment of Physical-Chemical Drinking Water Quality in the Logone Valley (Chad-Cameroon)*. https://doi.org/10.3390/su5073060

Stefanakis, A. I., Zouzias, D., & Marsellos, A. (2015). *Groundwater Pollution : Human and Natural Sources and Risks*. *December*.

Tebbutt, T. H. Y. (2002). Principles of water quality control. In *Principles of water quality control. Fourth edition* (Fifth Edit).

WaterAid. (2014). Building citywide sanitation strategies from the bottom up. A situational analysis for Blantyre City ,. *Centre for Community Organisation and Development (CCODE) Malawi*, 1–41.

Weiner, E. R., & Francis, G. (2007). *Applications of Environmental Aquatic A*

Practical Guide (2nd Editio).

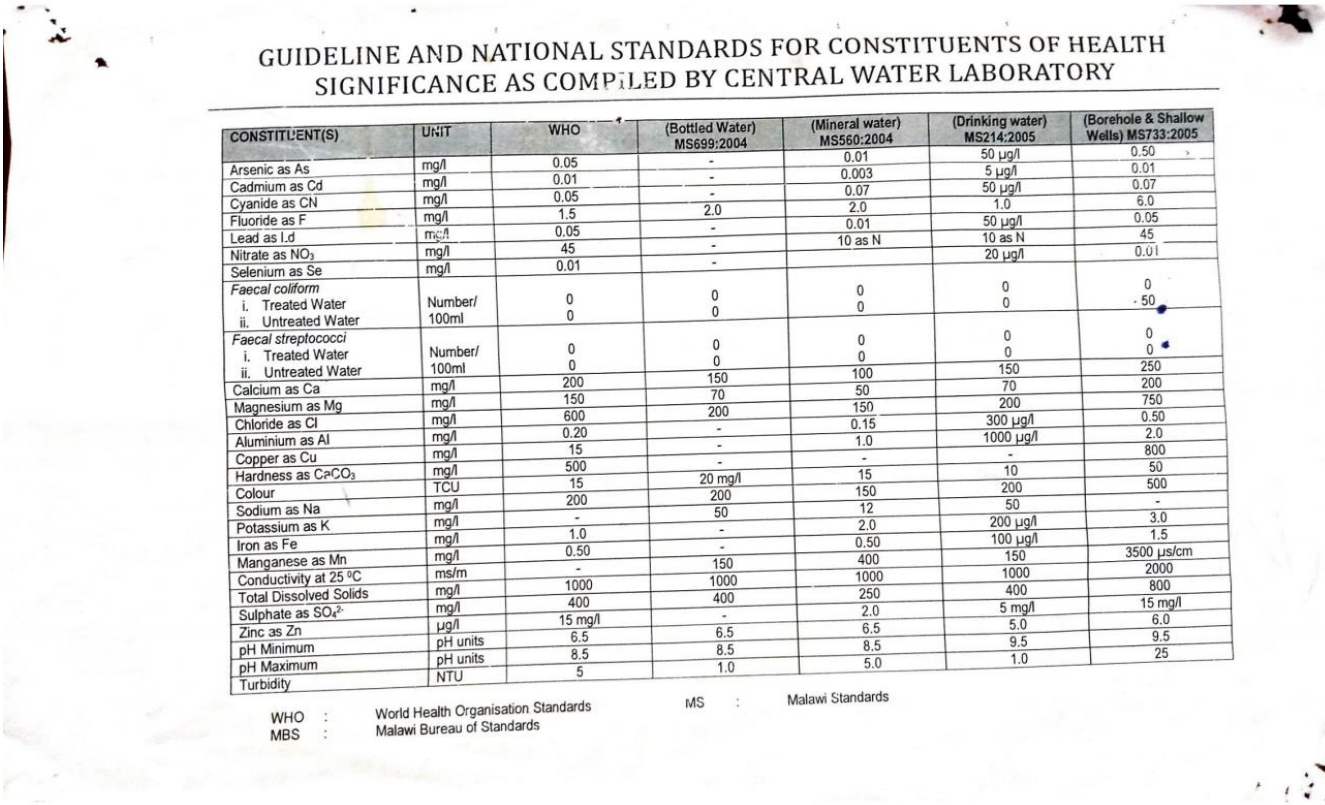
WHO. (2008). Guidelines for Drinking water Quality. In *World health organisation* (THIRD EDIT, Vol. 1).

William, L. (2014). ASSESSMENT OF BOREHOLE WATER QUALITY AND CONSUMPTION IN YEI COUNTRY SOUTH SUDAN. *A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS OF SCIENCE DEGREE IN ENVIRONMENT AND NATURAL RESOURCES OF MAKERERE UNIVERSITY*.

Wright, G. (2016). *Shire River Basin Plan Volume 4 : Thematic Planning*. *4*.

7. APPENDICES

Appendix A. Showing the recommended standards for MBS and WHO.



GUIDELINE AND NATIONAL STANDARDS FOR CONSTITUENTS OF HEALTH SIGNIFICANCE AS COMPILED BY CENTRAL WATER LABORATORY

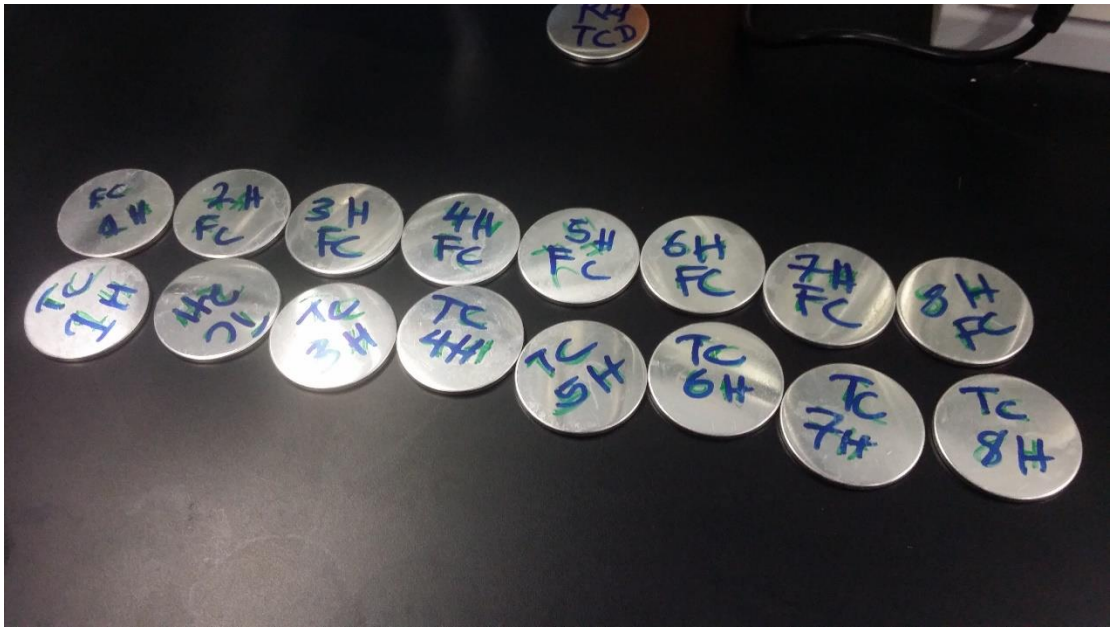
CONSTITUENT(S)	UNIT	WHO	(Bottled Water) MS699:2004	(Mineral water) MS560:2004	(Drinking water) MS214:2005	(Borehole & Shallow Wells) MS733:2005
Arsenic as As	mg/l	0.05	-	0.01	50 µg/l	0.50
Cadmium as Cd	mg/l	0.01	-	0.003	5 µg/l	0.01
Cyanide as CN	mg/l	0.05	-	0.07	50 µg/l	0.07
Fluoride as F	mg/l	1.5	2.0	2.0	1.0	6.0
Lead as l.d	mg/l	0.05	-	0.01	50 µg/l	0.05
Nitrate as NO_3	mg/l	45	-	10 as N	10 as N	45
Selenium as Se	mg/l	0.01	-		20 µg/l	0.01
Faecal coliform i. Treated Water ii. Untreated Water	Number/ 100ml	0 0	0 0	0 0	0 0	0 0
Faecal streptococci i. Treated Water ii. Untreated Water	Number/ 100ml	0 0	0 0	0 0	0 0	0 0
Calcium as Ca	mg/l	200	150	100	150	250
Magnesium as Mg	mg/l	150	70	50	70	200
Chloride as Cl	mg/l	600	200	150	200	750
Aluminium as Al	mg/l	0.20	-	0.15	300 µg/l	0.50
Copper as Cu	mg/l	15	-	1.0	1000 µg/l	2.0
Hardness as $CaCO_3$	mg/l	500	-	-	-	800
Colour	TCU	15	20 mg/l	15	10	50
Sodium as Na	mg/l	200	200	150	200	500
Potassium as K	mg/l	-	50	12	50	-
Iron as Fe	mg/l	1.0	-	2.0	200 µg/l	3.0
Manganese as Mn	mg/l	0.50	-	0.50	100 µg/l	1.5
Conductivity at 25 °C	ms/m	-	150	400	150	3500 µs/cm
Total Dissolved Solids	mg/l	1000	1000	1000	1000	2000
Sulphate as SO_4^{2-}	mg/l	400	400	250	400	800
Zinc as Zn	µg/l	15 mg/l	-	2.0	5 mg/l	15 mg/l
pH Minimum	pH units	6.5	6.5	6.5	5.0	6.0
pH Maximum	pH units	8.5	8.5	8.5	9.5	9.5
Turbidity	NTU	5	1.0	5.0	1.0	25

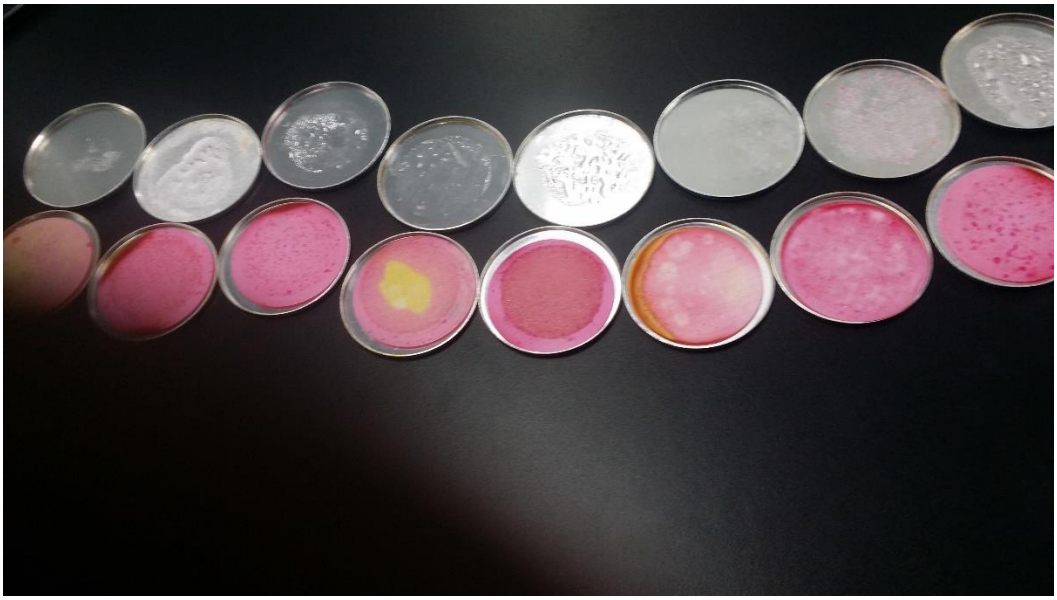
WHO : World Health Organisation Standards
MBS : Malawi Bureau of Standards
MS : Malawi Standards

Appendix B. The coordinates of each sampling point that were taken during sampling.

Sampling site	Misusa	Mkhata	Pempho	Gatoma	Masa	Masamba	Wisikesi	Bright future school
Label	BH1	SW2	SW3	SW4	USW5	SW6	SW7	SW8
X(m) coordinate	0713142	0713361	0713630	0713641	0713605	0713675	0713931	071393
Y(m) coordinate	8251649	8251354	8251013	8250942	8250928	8250941	8251246	825123
Elevation(m)	949	977	989	986	985	988	996	1003




TCD
FC 1H
2H FC
3H FC
4H FC
5H FC
6H FC
7H FC
8H FC
TC 1H
TC 2H
TC 3H
TC 4H
TC 5H
TC 6H
TC 7H
TC 8H



Appendices C. Showing membrane filtration method setup and apparatus



Appendices D. Showing the titration setup for magnesium and calcium.



Appendix E. Showing the titration setup for chloride.



Appendix F: the water sources for domestic purposes

parameter	Vn	Sn	1/Sn	∑(1/Sn)	$K = 1/(\sum[\frac{1}{Sn}])$	Wi=K/Sn	Vn/Sn	Vn/SN*100=Qn	Wn*Qn	WQI=(∑Wn*Qn/∑Wn)
Ph	7.12	9.5	0.105263158	0.433604428	2.306249512	0.242763107	0.74947368	74.94736842	18.19445599	103.818653
EC	1372.3	3500	0.000285714	0.433604428	2.306249512	0.000658928	0.39208571	39.20857143	0.025835642	
Turbidity	1.41	25	0.04	0.433604428	2.306249512	0.09224998	0.0564	5.64	0.52028989	
TDS	893	2000	0.0005	0.433604428	2.306249512	0.001153125	0.4465	44.65	0.05148702	
temperature	21.23	25	0.04	0.433604428	2.306249512	0.09224998	0.8492	84.92	7.833868343	
Nitrate	3.802	45	0.022222222	0.433604428	2.306249512	0.051249989	0.08448889	8.448888889	0.433005464	
Chloride	50.61	750	0.001333333	0.433604428	2.306249512	0.003074999	0.06748	6.748	0.020750096	
Fluoride	0.44	6	0.166666667	0.433604428	2.306249512	0.384374919	0.07333333	7.333333333	2.818749404	
Magnesium	25.58	200	0.005	0.433604428	2.306249512	0.011531248	0.1279	12.79	0.147484656	
Calcium	125.2	250	0.004	0.433604428	2.306249512	0.009224998	0.5008	50.08	0.461987902	
Alkalinity	355.372	120	0.008333333	0.433604428	2.306249512	0.019218746	2.96143333	296.1433333	5.691503484	
Total coliform	560	50	0.02	0.433604428	2.306249512	0.04612499	11.2	1120	51.65998908	
feacal coliform	173	50	0.02	0.433604428	2.306249512	0.04612499	3.46	346	15.95924663	
						1			103.8186536	

Appendix G: shows how water quality index was calculated