

ASSESSMENT OF GROUNDWATER WATER QUALITY FROM SHALLOW WELLS AND BOREHOLES:

A CASE STUDY IN GUMBI VILLAGE T/A MAKWANGWALA NTCHEU DISTRICT

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CERTIFICATE OF APPROVAL

The concept, research organization and writing of this research paper is entirely truly that of the candidate, Thomson Mpondagaga has been carried out at Malawi university of science and technology, under the supervision of Mrs.T. Mtewa and Dr.V. Msadala

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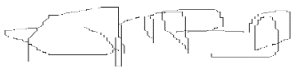
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DECLARATION

I, **Thomson Mpondagaga**, hereby declare that the work presented in this research report is an outcome of my own research effort and that the use of all materials from other sources has been properly and duly acknowledged by reference. No part of it has been submitted previously for a Degree at Malawi University of science and technology or any other institution for a degree or any award.

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DEDICATION

I dedicate this work to my Father, Aubrey Thomson Mpondagaga, my Mother, Eneless Mpondagaga and my grandmother for their continued support and encouragement financially, emotionally and spiritually during the period of my study. May the Almighty richly bless you!!

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God bless you all!!

ABSTRACT

Access to drinking water from unsafe sources is widespread amongst communities in rural areas such as Gumbi village in traditional authority Makwangwala Ntcheu District part central Malawi. This situation puts many individuals and communities at risk of waterborne diseases and teeth problems. Despite Mpira water supply trust (MWST) supplying piped water to the area, most of these residents heavily rely on groundwater sources due to financial constraints and insufficient water supply. However, there are problems associated with drinking contaminated water. There still remains a gap regarding the quality of drinking water from such unsafe sources. This study was conducted in July 2021 to determine the microbial and physico-chemical quality of drinking water from shallow wells and boreholes in Gumbi village, Ntcheu T/A Makwangwala. Water samples (n=30) were collected in pre-cleaned 1L polyethylene bottles from shallow wells (n=9) and borehole (n=1) in July 2021. For microbial analyses, water samples were collected in 250ml autoclaved glass jars. Membrane filtration was used to determine *E.coli* and Total coliforms. pH, total dissolved solids (TDS), electrical conductivity (EC), turbidity, total alkalinity (carbonates and bicarbonates), total hardness, calcium and magnesium hardness, chlorides and fluorides were analyzed. Excel and Minitab (version 17.1) was used to analyze the microbial, chemical and physical parameters and results were subjected to a one way analysis of variance (ANOVA). Results obtained showed that 90% of the sources were contaminated with faecal matter due to the presence of *E.coli* above recommended Malawi bureau of standards, 100% of the samples were contaminated with total coliforms. Levels of pH, EC, TDS, total alkalinity (carbonates and bicarbonates), total hardness, calcium and magnesium hardness and chlorides were within the recommended standards of MBS while some sources failed to meet the MBS recommended standards for turbidity and fluorides. Based on results from the study, water from shallow wells and boreholes was not suitable for drinking in terms of its microbial quality, turbidity levels and fluoride concentrations as they were higher than the recommended guideline values.

TABLE OF CONTENTS

1.0 CHAPTER ONE: 10

1.1. INTRODUCTION 10

1.2. BACKGROUND INFORMATION.....11

1.3. PROBLEM STATEMENT 12

1.4. MAIN AND SPECIFIC OBJECTIVES 13

1.5. RESEARCH QUESTIONS.....13

1.6. SIGNIFICANCE OF THE STUDY 14

2.0 CHAPTER TWO: 15

LITERATURE REVIEW 15

3.0 CHAPTER THREE: METHODOLOGY 21

3.1. RESEARCH DESIGN 21

3.2 STUDY AREA 21

3.3.0 MATERIALS AND METHODS 25

3.3.1 DATA COLLECTION 26

3.3.2 SAMPLING TECHNIQUE 27

3.3.3 SAMPLE SIZE 28

3.3.4 DATA ANALYSIS 28

4.0 **CHAPTER FOUR**: RESULTS AND DISCUSSIONS.....29

4.1. INTRODUCTION 27

5.0 **CHAPTER FIVE**: CONCLUSSIONS AND RECOMMENDATIONS.....33

6.0 **REFERENCES**.....61

7.**0 APPENDIX**.....62

LIST OF FIGURES

FIGURE1: women drawing water from shallow wells..... **Xvi**

FIGURE2: map of the study area.....**xxii**

FIGURE3: Determination of pathogenic organisms.....**xxv**

FIGURE4: Biological count for *e. coli*.....**xxvi**

FIGURE5: On site measuring of pH during field work.....**xxix**

FIGURE6: Measuring of EC and TDS.....**xxx**

FIGURE7: measuring of hardness..... **xxxvi**

FIGURE8; E coli contamination levels for groundwater in Gumbi area.....**XXXX**

FIGURE9: Total coliform counts for groundwater in Gumbi area.....**xxxxi**

FIGURE10: pH levels for groundwater in Gumbi area……xxxxii

FIGURE11: Variation of NTU levels for groundwater area in comparison with WHO……XXXIII

FIGURE12:EC and TDS levels for groundwater in Gumbi area……XXXXIV

FIGURE13; Carbonate and Bicarbonate values for groundwater in Gumbi area……XXXXV

FIGURE14: T/hardness/ hardness and values for groundwater in Gumbi area…….. XXXXVI

FIGURE15: Chloride levels for groundwater in Gumbi area……XXXXVII

FIGURE16: Fluoride levels for groundwater in Gumbi area in comparison to the MBS acceptable……XXXVIII

LIST OF TABLES

Table1: Drinking water guidelines adopted from WHO and MBS 214:2013,733:2005)……XXXXIX

ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
APHA	American Public Health Association
BH	Borehole
EC	Electrical conductivity
EPA	Environmental Protection Agency
GoM	Government of Malawi
MBS	Malawi Bureau Standards
MS	Malawi Standards
MWST	Mpira water supply trust
NTU	Nephelometric Turbidity Units
ODNR	Ohio Department of Natural Resources
pH	power of Hydrogen
T/A	Traditional Authority
TDS	Total dissolved solids
UNICEF	United Nations International Children's Fund
UN	United Nations
SW	Shallow well
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
MUST	Malawi university of science and technology

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION TO THE STUDY

Access to safe and sufficient water and improved sanitation is a basic human need and is essential to human wellbeing (United Nations (UN), 2006). An estimated 663 million people are still without access to improved sources of drinking water (UNICEF and WHO, 2015). Portable water is essential for sustainable development. Most of the surface water used for domestic purposes is highly contaminated therefore requiring a lot of treatment before distributing it for consumption. For areas where surface water is very scarce or costly to access, the alternative is groundwater from boreholes and shallow wells is probably the cheapest and safest portable water source (Foster, 1986; Kai-Shek, 2017) hence it doesn't require complicated treatment. Malawi's population is growing rapidly, and in just 57 years, has increased from 13.1 million people in 208 to 17 million in 2019 (Population Reference Bureau, 2020) and this puts a stress on groundwater as a major source of water supply. Malawi is one of the countries in the Sub-Saharan region that has made fair progress in provision of safe and potable water by about 60% (WHO/UNICEF JMP Report, 2015). Despite this achievement, the majority of Malawians in rural areas depend on groundwater for domestic purposes (GoM, 2015). This is so because most rural areas are not connected to piped water that is supplied by the utility providers (Water Boards) due to limitation in capacity (Mkwate et al., 2016). In 2010, studies conducted by UNICEF and WHO indicated that 996 million people from rural areas use water from boreholes and dug wells respectively for drinking (UNICEF and WHO, 2012). Shallow wells are far cheaper to construct compared to boreholes and they are extensively located in low-income or rural areas. Throughout Malawi countless shallow wells are neither lined nor covered and are

located close to the surface, near to waste dumps or pit latrines, making the water susceptible to high levels of contamination (Pritchard et al, 2008). In Malawi, for borehole water quality to satisfy the requirements of wholesomeness it must be safe from water-borne or associated disease, free from toxic chemicals and be aesthetically and organoleptically acceptable to the consumer (MSB, 2005). Unfortunately, a study conducted by BGS (2004) states that the chemical quality of groundwater in the aquifers of Malawi has been little documented. A study conducted by the EPA (2008), indicates that there are health problems associated with intake of water with high concentrations of chemical compounds from groundwater. Dental fluorosis is common in some parts of Malawi but studies on fluoride levels of drinking water sources have not been adequately done (Sajidu et al., 2007). Knowledge about water quality is critical if there is a need to develop strategies for improving the quality of drinking water in rural areas, especially those who are not able to purchase any treatment methods for their household water.
Some contaminants can take years to appear in the groundwater and thus initial satisfactory reports will not guarantee a safe source of drinking water for subsequent years. Regular monitoring of groundwater is needed to prevent any form of adverse health outcomes (Sarkar et al., 2012).

1.2 PROBLEM STATEMENT

The quality of groundwater used for human consumption in developing countries is a significant, but neglected public health issue (Grimason et al., 2013). In Malawi boreholes are regarded as the main source of rural drinking water as evidenced by an incredible 14, 943 number of boreholes drilled across the country between 2016 and 2020 with 808 for Ntcheu district (Truslove P.T., Miller V.M., Mannix N., et, al., 2019). However, there are health problems associated with intake of water with abnormal concentrations of chemical compounds from groundwater accessed from shallow wells and boreholes leading to unimproved level of service according to SDG 6.1 (EPA, 2008; Kushe, 2009). Much as water quality problems are common, they vary based on different factors and village Gumbi is one of the many villages affected by the problem in question. Mpira dam in

Ntcheu district is the main source of portable piped water though Mpira Water Supply Trust but not sufficient for the people in Gumbi village so that people started using unprotected shallow wells and boreholes frequently leading to a heavy reliance on groundwater. As evidenced by an increase in cases of diarrhoea, stomach ache in infant and adult, and teeth problems reported by Nsiyarudzu healthy centre and initial visits as shown in the photos, salty tastes, these sources are prone to contamination. The actual cause and levels of water contamination have not been established, Furthermore, it is not known if the extent of contamination or abnormal water quality parameter are largely contributed from the shallow wells or the boreholes to determine the kind of intervention in the comparative results. Therefore, this study was focus on assessing ground water quality in terms of their physico-chemical and biological characteristics in Gumbi village T/A Makwangwala in Ntcheu district.

RESEARCH OBJECTIVES

1.3 MAIN OBJECTIVE

The main objective of this study was to find out the physico-chemical and microbiological characteristics of ground water from wells and boreholes in Gumbi village.

1.3.1 SPECIFIC OBJECTIVES

1. To determine the levels of biological microorganisms in ground water sources for Gumbi area.
2. To analyze the physical characteristics of groundwater in Gumbi area.
3. To analyze the chemical characteristics of ground water in Gumbi area
4. To compare the extent of contamination between boreholes water and shallow wells waters in Gumbi area.

1.3.2 RESEARCH QUESTIONS

- What are the physico-chemical and biological characteristics of groundwater from wells and boreholes in group village headman Gumbi?

- What are the levels of pathogenic microorganism's faucal coliforms and E. coli bacteria in the groundwater sources of the village?
- What are the levels of the physical characteristics in terms of levels of pH, EC, TDS and TSS?
- What are the levels of chemical contamination in terms of levels of calcium hardness, magnesium hardness, total hardness, alkalinity (carbonates and bicarbonates)?

1.4 SIGNIFICANCE OF THE STUDY

The rationale of this study was centered around the existing need to fill specific knowledge and data gap on effective health risks on groundwater sources from boreholes and shallow wells and also provide a base information on the quality of the water from study area which will help in future water resources planning. The findings will help to choose the appropriate intervention in mitigating the health risks posed by water from the groundwater sources hence the data that has been collected will be used as future reference.

CHAPTER TWO
LITERATURE REVIEW

2.0 Groundwater water sources

Groundwater may be found almost anywhere in the world and in almost all types of geological formations however, its distribution in terms of quality and quantity varies from one place to another and from one geological formation to another (Fetter, 1994; Kushe, 2009). Malawi is endowed with vast expanses of water systems which include widespread groundwater sources whose occurrences are associated with two major aquifers namely the basement complex aquifers which are extensive but low yielding ranging from 0.2 to 4 litres per second and alluvial aquifers (which are localized to lakeshore plains and the Shire Valley) which are high yielding with recorded yields in excess of 10 litres per second (National Water Policy, 2005). High yielding of groundwater from boreholes can results of into drinking water with high concentration of chemicals such as fluorides and chlorides. This can cause different healthy problems such dental fluorosis.

2.1 shallow wells water sources

Most of the people also uses shallow well as another alternative in Gumbi village for domestic purpose which is not assessed or monitored. Shallow wells are not privileged to such improvements as there is no one that is directly held accountable for sourcing water from un-treated wells. shallow well water is mostly prone to contaminations and pollution when are not protected although most of the people ignore and only focus on the color of the water as major indicator for contamination but which is not the fact. Figure show a woman draw water from unprotected shallow wells in Gumbi village.


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FIGURE1: Shows women drawing water from unprotected shallow wells in Gumbi village

2.1.2: Groundwater Characteristics

physical parameters

2.1.3 pH

The pH value of water indicates the hydrogen ion concentration in water. It is expressed as the negative logarithm of the reciprocal of the hydrogen ion concentration in moles/ litre at a given temperature. So, to say, it indicates the degree of acidity or alkalinity of water. The pH scale extends from 0 (very acidic) to 14 (very alkaline) with 7 corresponding to exact neutrality at 25^0 C (R Sreemahadevan, 2009).

Many chemical reactions are controlled by pH and biological activity is usually restricted to a fairly narrow pH range of 5-8. Highly acidic or highly alkaline waters are undesirable because of corrosion problems and possible difficulties in treatment (Tebbbutt, 1998). (WHO, 2011) argues that, although pH has no direct impact on consumers, it is one of the most important operational quality parameters. Careful attention to pH control is necessary. WHO continues to add that for effective disinfection with chlorine, the pH should preferably be less than 8; however, lower pH water (approximately pH 7 or less) is more likely to be corrosive Failure to minimize corrosion can result in the contamination of drinking water and in adverse effects on its taste and appearance.

2.1.4 Turbidity

Turbidity is the measure of the scattering of light by particles in a suspension (WHO, 1996; Shaina, 2015). (Tebbutt, 1998) defines turbidity as the presence of colloidal solids which gives liquids a cloudy appearance which is aesthetically unattractive and may be harmful. According to (WHO, 2011), turbidity is caused by suspended particles or colloidal matter that obstructs light transmission through the water. It may be caused by inorganic or organic matter or a combination of the two. WHO continues that turbidity in some

groundwater sources is a consequence of inert clay or chalk particles or the precipitation of non-soluble reduced iron and other oxides when water is pumped from anaerobic waters, whereas surface waters may be the result of particulate matter of many types and is more likely to include attached microorganisms that are a threat to health. (Nozaic, 2002) argues that apart from a displeasing appearance, the particles which create turbidity also provide adsorption site for chemicals that may be harmful or cause undesirable taste and odor, and also allow adsorption of biological organisms, which shield the organisms and interferes with disinfection. Turbidity is measured by nephelometric turbidity units (NTU) and can be initially notice by the naked eye above approximately 4.0 NTU. In small water supplies where resources are very limited and where there is limited or no water treatment may not be able to achieve turbidity levels as low as 0.5.

2.1.5 Electrical Conductivity (EC)

Conductivity is a material's ability to conduct an electric current (WHO, 1996). A study that was conducted in Nigeria (Water Aid, 2006-2007) showed that 17 % of boreholes and 35% of hand-dug wells had electrical conductivity values that exceeded published guidelines (WaterAid, 2006-2007). The shallow depth of these wells and geology of the environment may have been responsible for this. For health purposes drinking water should not have very high electrical conductivity as it is related to the concentration of ions originating from inorganic compounds (Younger, 1989). In study that was conducted in Nkhotakota district, on the western shores of Lake Malawi, in central Malawi, Bath (1980) reported electrical conductivity values of 180–4600 µS/cm; total dissolved solids of up to 2900 mg/L) in weathered basement and colluvium.

chemical parameters

2.1.6 Total Hardness

Hardness is a measure of the capacity of water to react with soap Subba Rao, 2006). Hard water requires considerably more soap to produce lather (Subba Rao, 2006) than soft water. Hardness is caused by dissolved polyvalent metallic ions, predominantly calcium

and magnesium cations (Subba Rao, 2006). It is expressed as milligram of calcium carbonate per litre. Pritchard *et al.* (2008) reported hardness values ranging from 38-850 mg/L for dry season and 6-1370 mg/L for wet season for borehole and shallow well water samples in Chikwawa. Some reported values were above the WHO maximum limit of 500 mg/L (Pritchard *et al.*, 2008).

2.1.7 Chlorides

Chlorides are soluble mineral compounds that are dissolved by the water as it filters through the earth (WHO, 1996). The amounts of chlorides in water are determined by the type of rocks and soils it has contacted but in coastal areas, the leaking of sea water into a well can also be a cause of increased chlorides (Fetter, 1994). The presence of chlorides in drinking water is generally not considered to be harmful to humans or animals. The most noticeable effect of high chloride levels is a salty taste (WHO, 1996). Chlorides contribute to the corrosion of household appliances and domestic plumbing by preventing the formation of protective oxide films on exposed surfaces (ODNR, 1997). Chloride concentrations up to 4000 mg/L and sodium up to 3600 mg/L have been reported in Shire Valley (Bath, 1980).

2.1.8 Fluorides

Fluorides are one of the most serious chemical contaminants that occurs naturally in drinking water (UNICEF, 2008). Traces of fluorides are present in many waters, with higher concentrations often associated with ground waters. High fluoride levels in groundwater are primarily caused by interactions with rock and sediments, and can occur in a wide range of geological environments, including the foothills of large mountains, areas of ancient marine deposits, and areas impacted by geothermal waters (UNICEF, 2008). The East African Valley is well recognized as a high-fluoride province and many countries in the region have significant groundwater fluoride problems (BGS, 2004). This could result in most Malawian groundwater in the Rift zone to be most affected. Bath (1980) observed fluoride concentrations in the range of 0.1 mg/L to 7.6 mg/L in basement aquifers of the Nkhotakota area of Northern Malawi though only one sample exceeded the WHO

guideline value of 1.5 mg/L. Further studies conducted by Chimphamba et al (2014) in rural communities of Malawi observed values of fluoride of up to 63 mg/L. In addition to this, the study further observed that there were more than 139 boreholes in Malawi with fluoride concentrations above 1.5 mg/L concluding that rural communities are at risk to suffering from dental fluorosis, skeletal and crippling fluorosis and mental retardation since they continuously ingest borehole water with high levels of fluoride concentrations. Fluoride is beneficial at ow doses; higher rates of dental carries are observed below approximately 0.5 mg/L and in many countries, fluoride is routinely added to drinking water (from 0.7 mg/L to 1.2 mg/L) to improve dental health (UNICEF, 2008). However, Tebbutt (1999), says fluoride in excess of 1.5 mg/L may cause yellow staining of teeth and at even much higher levels there is the danger of bone damage through fluorosis. Hence fluoride is thus an example of a constituent of water which can be beneficial at low concentrations but harmful at higher concentrations.

biological indicators

Bacteriological analysis of drinking water supplies usually provides the most sensitive quality assessment and must be considered as the most paramount importance (WHO, 2011). Securing the microbial safety of drinking water supplies is based on the use of multiple barriers, from catchment to consumer, to prevent the contamination of drinking water or to reduce contamination to levels not injurious to health (WHO, 2011). Microbial risks are associated with ingestion of water that is contaminated with faeces from humans or animals which can be a source of pathogenic bacteria (Tebbutt, 1999). Presence of total coliforms alone is not a good indicator of poor quality rather coliforms that come from faecal matter and the most specific indicator of faecal coliforms is Escherichia coli (E.coli) (UNICEF, 2008). Pritchard et al (2007) observed that 80% of the shallow wells tested in the dry season and 100% of the wells tested in the wet season did not meet the temporary drinking water guidelines for total coliforms. 50% of these shallow wells failed to meet the faecal coliforms drinking water guidelines in the dry season while the figure increased to 94% of the wells failing to meet the standard in the wet season. This increase was concluded that it could have been attributed to the fact that pollutants are easily

transported to water points by rain water. A study conducted by Kamanula et al (2014) in Ndirande Township, Blantyre observed that all waters analyzed from shallow wells and boreholes in the study area contained high levels of E.coli, suggesting that the water sources were heavily polluted by faecal matter and not suitable for human consumption and that there were 176 cases of cholera throughout the study area.

2.2.1: Common Mitigation Measures

In most of developing countries such as Malawi the common way of treating water is through chlorination or boiling of water just to kill pathogenic bacteria's but forgetting about chemical concentrations. As Malawi there are so many common mitigation measure that can be taken into account in order to prevent contamination of groundwater sources such the enforcement of Water Resources Act that stipulate in the water pollution control regulations that all water points must be sited 100m upstream of sanitation facilities (e.g. pit latrines) (Lakudzala et al, 2005; Pritchard et al 2007), civic education to people in rural areas on protecting water resources, proper waste disposal, educate people in rural area to practice personal hygiene, promoting water resources planning projects in rural areas just to mention few.

2.3.2: Global Perspective on Groundwater Contamination

The availability of a reliable, clean and safe supply of drinking water is one of the most important determinants of our health. WHO (2011) defines safe drinking water as water that does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. The UN millennium development goal (Goal 7, target 3) obligation to ensure adequate and portable water supply to everyone has necessitated the exploitation of groundwater resources for domestic water supplies in most developing countries especially in small towns and rural regions, where it represents the cheapest water source. In these regions, groundwater supply schemes consist typically of a large number of hand pumped boreholes, often drilled

on an uncontrolled basis, providing untreated and often unmonitored supplies (Hiscock, 2009; Wanda et al, 2011). Due to increase in world population growth cases of pollution and contamination in groundwater sources are also increasing with increase in industries and this has put threat in most groundwater catchment areas.

2.2.3: Status of Groundwater in Malawi

Generally, groundwater from boreholes is of better microbiological quality than groundwater from shallow wells, which tend to be more vulnerable to contamination. Groundwater is widely used across Malawi for both domestic and agricultural purposes. There were about 30,000 water boreholes and 8,000 protected shallow wells in 2012. However, most rural Malawians are the one mostly relies on groundwater for their domestic supply and groundwater is increasingly used for irrigation by smallholder farmers. There is lack of information about the quantitative status of groundwater across Malawi, because there is relatively little groundwater level monitoring. The natural quality of groundwater across much Malawi is thought to be generally suitable for drinking (Chavula 2012). However, groundwater chemistry is highly dependent on aquifer lithology (rock type and mineralogy), and so it is highly variable spatially.

CHAPTER THREE

METHODOLOGY

This chapter described the basic plan that was carried out to achieve the purpose of the research project. All Standard methods and procedures were adopted from Standard Methods for the Examination of Water and Wastewater (APHA, 1198 & 2011)

3.1 study area

The study was conducted in Gumbi village in T/A Makwangwala in Ntcheu district central part of Malawi. This area was particularly selected because it is one of the areas that is mostly affected due to insufficient water supply by Mpira water supply trust hence people heavily rely on Groundwater sources especially from unprotected shallow wells which are prone to contamination and pollution. Densely populated 10 water points was sampled from the area. These water points were selected randomly. Global Positioning System (GPS) of these water points was collected and recorded. The fiure2 below shows the map of the study constructed from arc global positioning system.

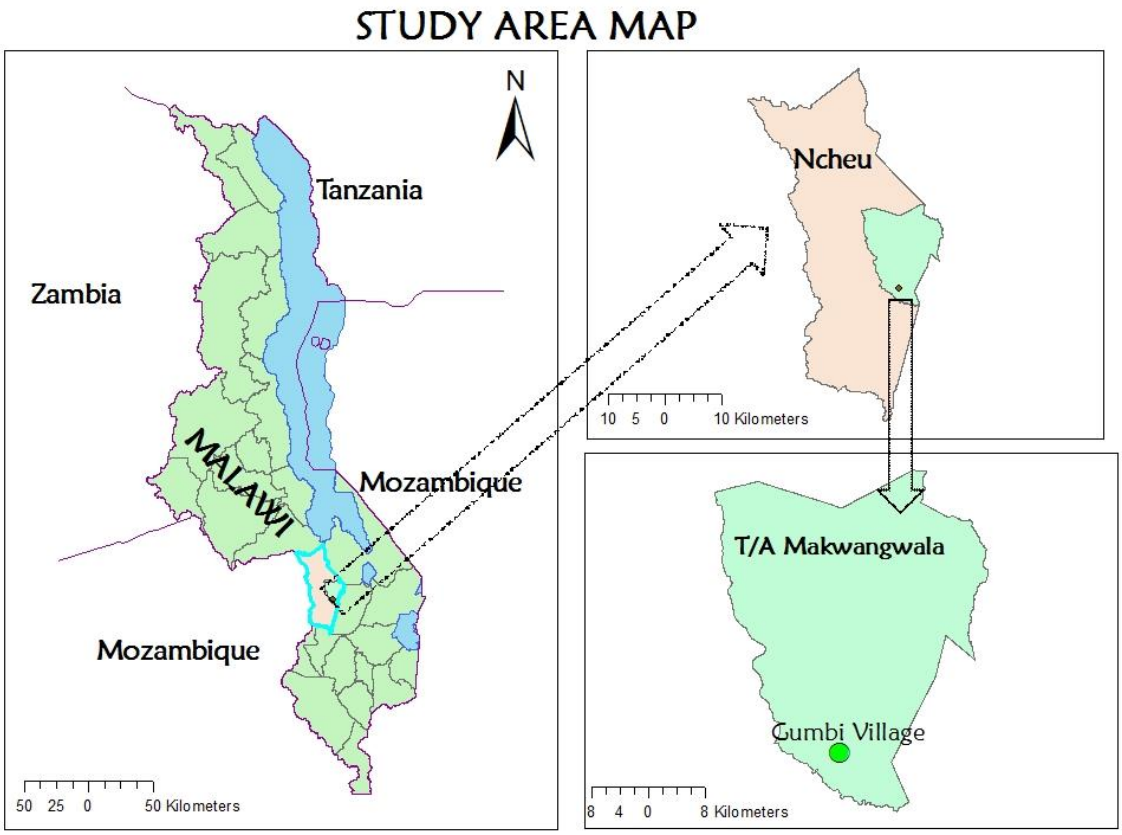


FIGURE2: Showing Map for the study area from ArcGIS

3.2 study design

The research study was quantitative, however onsite observations such as photos, open ended-questions which may aid in discussion may be considered as quantitative. In a sense that both the physico-chemical parameters and the microbial characteristics was determined through numerical values.

3.3 Sampling method

Random sampling scientific method was used to select the sample sites. For each water point, three samples in 1L bottles and 250ml was collected. At every site, for every biological analysis, a new pair of latex gloves was used to avoid sample contamination

and all apparatus required for the analysis was sterilized using methanol upon arrival at every site before use. Grab sampling method was used and it was adopted in Standard Methods for the Examination of Water and Wastewater (APHA, 1198 & 2011).

3.4 Data Collection methods

Water samples (n=10) were collected in triplicate using standard sampling procedures (APHA, 2011). Water samples for physico-chemical parameter analysis were collected in pre-cleaned1L polyethylene bottles which were rinsed twice with the sample site water prior to collection. For microbial analyses, water samples were collected in 250ml autoclaved glass jar that were obtained from the environmental quality testing laboratory at Malawi university of science and technology. At every site, for every biological analysis, a new pair of latex gloves was used to avoid sample contamination.

Sampling Procedure

Determination of levels of pathogenic microorganisms. The figure 3 below is picture taken during incubation of biological organisms.

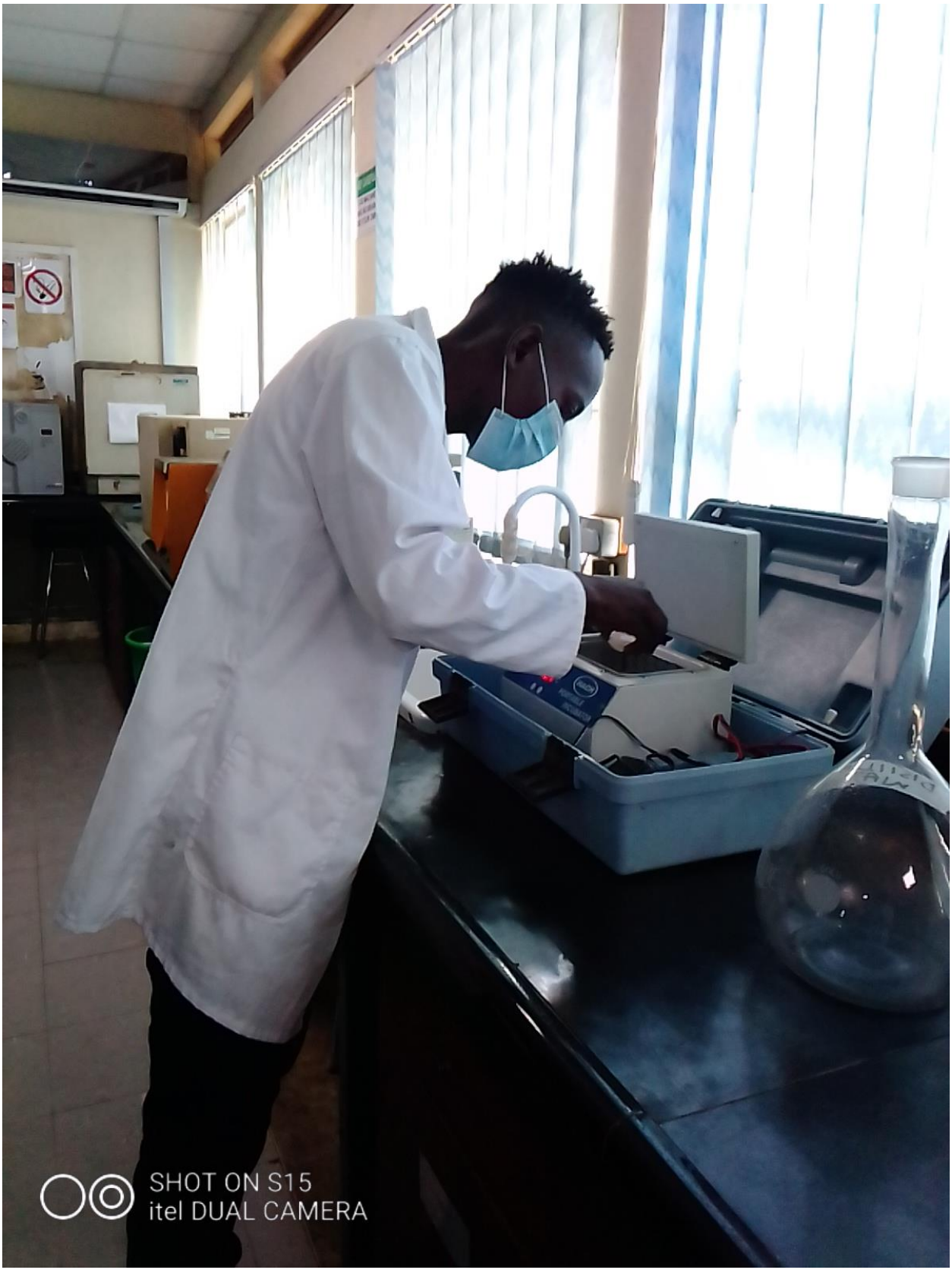

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FIGURE3: Incubation of pathogenic organisms at Malawi university of business and applied sciences laboratory.

Method: Membrane Filtration Method

Apparatus: Incubator, a stainless steel 47 mm filter holder assembly, vacuum syringe with tubing, stainless steel forceps, stainless steel graduated sampling cup, plastic bottles (for alcohol and rinse water), Pre-sterilized filters, petri dishes, Membrane Filtration coliform Broth (MFC), and Disposable pipettes.

Preparation: A phosphate buffer dilution and rinse waters were prepared prior to sample collection at the water quality laboratory.

Procedure

The numbers of total coliforms and *E.coli* were determined using membrane filtration technique. A measured volume of water (100ml) was filtered through a membrane. Bacteria were retained on the membrane and incubated at 37^0C for total coliforms and 44^0C for *E.coli* for 24 hours. When bacteria were present, they grew into visible colonies that were counted manually. Each test was duplicated for consistency. The results were presented as count per 100ml. All supplies were sterilized to ensure sterile conditions.

Samples were analyzed using membrane filtration method and were analyzed in triplicate. *E.coli* samples were incubated at 44^0C while for total coliforms, the samples were incubated at 37^0C. All samples were analyzed in triplicate for both *E.coli* and total coliforms.


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FIGURE4: *E.coli* counts at Malawi university of business and applied science laboratory.

Analysis of physical characteristics of groundwater

Determination of pH

The figure 4 below shows onsite measurement of pH during field work.


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FIGURE 5: shows onsite measuring of pH

The pH of water was determined using an Auto pH meter calibrated using a buffer solution of pH 4 and 7.

Determination of Turbidity

The turbidity of water was determined using a Microprocessor Nephelo/Turbidity Meter which was calibrated using distilled water, hydrazine sulphate $(NH_2)_2H_2SO_4$ and Hexamethylenethylenetetramine, $(CH_2)6N_4$.

Determination of EC and TDS

The figure5 below shows the determination of EC and TDS in MUST laboratory



FIGURE6. Determination of EC and TDS MUST laboratory.

EC and TDS were determined using an Auto-Cond- TDS- Temp^{0}C meter which was calibrated using a solution of potassium chloride (0.1M).

Analysis of the chemical characteristics of groundwater

Determination of Alkalinity, Carbonates and Bicarbonates, Titrimetric method was used to achieve the purpose of the study.

Apparatus: Tripod stand, burette, pipette, Erlenmeyer flasks, measuring cylinder.

Reagents:

i. Hydrochloric Acid solution (HCl), 0.02N: 8.3mlof HCl (S.G., 1.18) was pipetted into 1000ml volumetric flask and diluted to the mark with distilled water. Then 200ml of this stock solution was pipetted and diluted to 1000mL with distilled water.
ii. Sodium carbonate solution, Na_2CO_3, 0.02N: 1.0599±0.001 of anhydrous, Na_2CO_3 (dried at 250-300^{0}C) was dissolved in 300mL and diluted to 1000mL. Solution was stored in a polythene bottle.
iii. Phenolphthalein indicator solution (1% w/v in ethanol)
iv. Mixed bromocresol green/ methyl red indicator solution (either aqueous or alcoholic):

100mg bromocresol green sodium salt and 20mg methyl red sodium salt was dissolved in 100mL distilled water. Then, 100mg bromocresol green and 20mg methyl red in 100mL of ethanol was dissolved.

Standardization Procedure:

i. 25.0mL of Na_2CO_3 (0.02N) was transferred into a 250mL beaker and 25mL distilled water was added to it.
ii. After immersing the electrode, it was titrated with HCL to pH 5.5-5.0.

iii. The electrode was then rinsed with distilled water and the beaker covered with a wash glass and boiled gently for 3-5 minutes.

After letting it cool to room temperature, the cover was rinsed with distilled water. Titration was completed to a pH of 4.5. The volume used was recorded as (S).

Calculation

Normality (N) = $\frac{0.02x25.00}{S}$

Sample Titration:

i. 50mL of sample was transferred into a 250mL conical flask.
ii. 4 drops of phenolphthalein indicator solution were added to the sample. If pink color was produced, the sample was titrated with HCl (0.02N) until pink color discharged. Volume of the titrant used was recorded as (P). If no pink color was produced after addition of phenolphthalein, (P) was recorded as zero.
iii. In the same sample solution, 4 drops of bromocresol green/methyl red indicator was added and titrated against until a light pink color was obtained. Total volume of titrant used will was recorded as (T) i.e. (T) includes (P).

Calculation

These formulae used were adopted in from Standard Methods for the Examination of Water and Wastewater (APHA, 1198 & 2011).

CO_3^{2-} mg/L = $\frac{2xPxNx30000}{V}$

HCO_3^- mg/L = $\frac{(T-2P)xNx61000}{V}$

Alkalinity (mg $CaCO_3$/L) to phenolphthalein (pH 8.3) = $\frac{PxNx50000}{V}$

Total Alkalinity (mg$CaCO_3$/L) (pH 4.5) = $\frac{TxNx50000}{V}$

Determination of Total Hardness

Method: EDTA Titrimetric method

Apparatus: Tripod stand, burette, pipette, Erlenmeyer flasks, measuring cylinder

Reagents:

i. Buffer solution: 16.9g ammonium chloride was dissolved in 143mL concentrated ammonia solution. 1.25g magnesium salts of EDTA was added and diluted to 250mL with distilled water. The solution was stored in a plastic container and the container was tightly closed to prevent the loss of NH_3 or picking up of carbon dioxide.

ii. Indicator: Eriochrome Black T indicator. 200mg of powdered dye and 100mg of solid NaCl was grinded together in a mortar to 40 to 50 mesh. The mixture was stored in a tightly stoppered bottle. 0.2g of this ground mixture was used for titration.

iii. Standard EDTA titrant, 0.01M: 3.723g analytical reagent grade disodium EDTA dehydrate was weighed, dissolved in distilled water and diluted to 1000mL. The solution was then standardized against standard calcium solution.

iv. Standard Calcium Solution: To prepare this, 1.000g anhydrous $CaCo_3$ powder (primary standard) was weighed and placed into a 500mL Erlenmeyer flask. The funnel was placed in the flask neck and little by little, 1+1 HCL was added until all the $CACO_3$ dissolved. 200mL distilled water was added to it and the foil boiled for a few minutes to expel CO_2.

v. After cooling, a few drops of methyl red indicator were added and adjusted to intermediate orange color by adding 1+1 HCl. The mixture was transferred quantitatively and diluted with distilled water to 1000mL (1mL=1.00mg $CaCO_3$)

vi. Sodium hydroxide, NaOH, 0.01N

Procedure

Titration of sample: 25.0mL of sample was diluted with distilled water up to 50mL. 1mL of buffer solution was added to the sample.

Half a scoop of dry powder indicator formulation was then added to the sample. The sample was titrated against standard EDTA slowly until reddish tinge disappeared.

Calculation

Total hardness (EDTA) as mg $CaCO_3$/L = $\frac{\text{AxBx1000}}{\text{mL sample}}$

Where A = mL titration for sample and

B = mg $CaCO_3$ equivalent to 1.00mL EDTA

Determination of Calcium Hardness


SHOT ON S15
itel DUAL CAMERA

FIGURE 7.shows measuring of hardness

Method: EDTA Titrimetric method

Apparatus: Tripod stand, burette, pipette, Erlenmeyer flasks, measuring cylinder.

Reagents:

i. Sodium hydroxide, NaOH, 1N
ii. Indicator: Eriochrome Black T
iii. Standard EDTA titrant, 0.01M

Procedure

Sample preparation: 50mL sample was used.

Titration: to the sample, 2.0mL NaOH solution was added. After stirring the solution, 0.1mL indicator mixture was added to the sample. EDTA titrant was slowly added, with continuous stirring to the proper end point.

Calculation

$$\text{mg Ca/L} = \frac{\text{AxBx400.8}}{\text{mL sample}}$$

$$\text{Calcium hardness as mg } CaCO_3\text{/l} = \frac{\text{AxBx1000}}{\text{mL sample}}$$

Where A = mL titrant of sample and

B = mg $CaCO_3$ equivalent to 1.00mL indicator endpoint

Determination of Magnesium Hardness

Magnesium hardness was estimated as the difference between total hardness and calcium hardness as $CaCO_3$ interfering metals are present in non-interfering concentrations in the calcium titration and suitable inhibitors are used in the hardness titration.

Magnesium hardness = total hardness (as mg $CaCO_3$/L) – calcium hardness (as mg $CaCO_3$/L) x 0.243

Determination of Chlorides

Method: Argentometric method

Apparatus: Tripod stand, burette, pipette, Erlenmeyer flask, measuring cylinder

Reagents:

i. Potassium chromate indicator solution: 50g potassium chromate, $KrCrO_4$ was dissolved in a little distilled water. Then silver nitrate, $AgNO_3$ solution was added until a definite red precipitate was formed. The solution was left to stand for 12 hours after which it was filtered and diluted to 1L with distilled water.

ii. Standard silver nitrate titrant, 0.0141N (0.0141M): 2.395 $AgNO_3$ was dissolved in distilled water and diluted to 1000mL. It was standardized against NaCl by the procedure described below; 1.00mL = 5000ug Cl and then stored in a brown bottle.

iii. Standard sodium chloride 0.0141N (0.0141M): 8424.0mg NaCl (dried at 140^0C) was dissolved in distilled water and diluted to 1000mL; 100mL = 500ugCl

Procedure:

i. Sample preparation: A sample of 100mL (or suitable portion diluted to 100mL) will was used.

ii. The sample was directly titrated in the pH range 7.0 and 10.0. 1.0mL K_2CrO_4 indicator solution was then added to the sample. Titration was done with standard $AgNO_3$ titrant to pinkish yellow end point.

Calculation

$$\text{mg Cl/L} = \frac{(A-B)x\ 35450}{V}$$

Where: A = mL titration for sample

B = mL titration for blank

N = normality of $AgNO_3$

V = sample volume

mg NaCl/L = (mg Cl/L) x 1.65

Determination of Fluorides

Apparatus: Fluoride Test kit (product #: 25131-00), 150 mL ampule breaker, pocket colorimeter II, AccuVac SPADNS 2 reagent for fluoride, 100 mL of sample water, deionized water, 2 beakers.

Procedure

The pocket colorimeter was switched on and set to channel 2. A beaker labelled blank was filled with deionized water while beaker number 2 was filled with sample water each filled with 40mL. An ampul was placed in each beaker and placed in an inverted manner. Ampul in beaker 1 was broken by pressing down and when the water filled the ampul, it was quickly removed and turned back upright. A cap was placed on top and the contents were mixed by inverting the ampul. After 1 minute the ampul was placed in a cell holder of the pocket colorimeter II. The blank sample was then covered with the instrument cap and read on the colorimeter. The process was repeated for all samples in triplicate and measurements were recorded in mg/L.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This chapter presents the results of the water quality analysis for Gumbi village on their sources of drinking water. The results presented are in comparison with the permissible guidelines of WHO and MSB (MS 214:2013; MS 733:2005).

4.0 RESULTS

4.1. DETERMINATION OF PATHOGENIC MICROORGANISMS

The results in Figure 8 show that there were significant differences ($p<0.05$) in the number of *E.coli* counts in the 10 samples. The mean *E.coli* coliform count ranged from 0 cfu/100ml to 417.67±8.74 cfu/100ml with a total mean *E.coli* coliform count of 171.50±8.09 cfu/100ml. SW9 registered the highest levels of *E.coli* coliform counts (417.67 cfu/100 mL) while BH and SW1 registered the lowest *E.coli* coliform count (0 cfu/100 m/L).

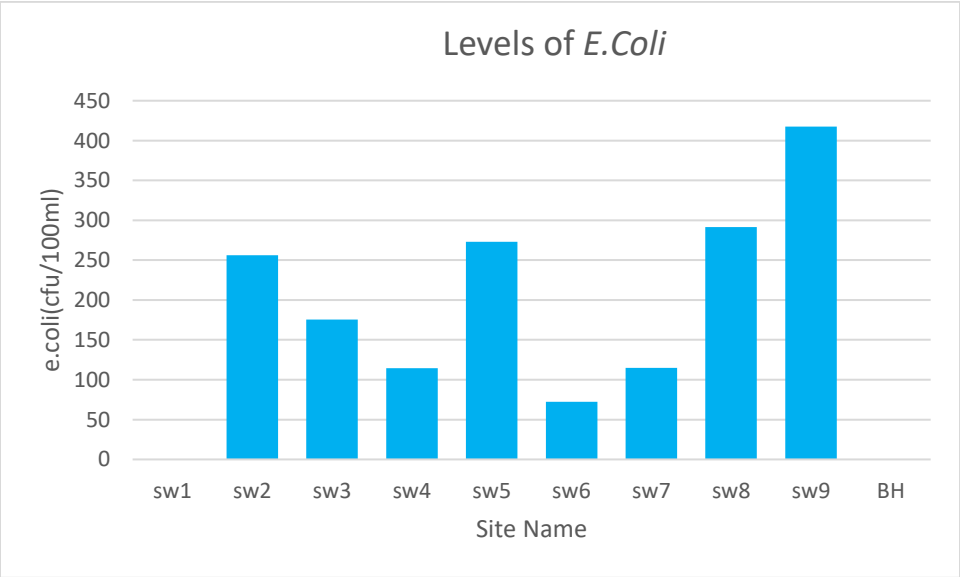


Figure *8:* *E.coli* contamination levels for groundwater in Gumbi area.

The results in Figure 9 indicate that there were significant differences (P<0.05) obtained in the number of total coliform counts in the 10 samples. The mean total coliform count ranged from 47.33±3.21 /100mL to 281±26.1 /100mL with a total coliform mean value of 158.74±16.60 /100mL. SW2 had the highest (281 /100 mL) total coliform count while SW7 registered the lowest (47.33).

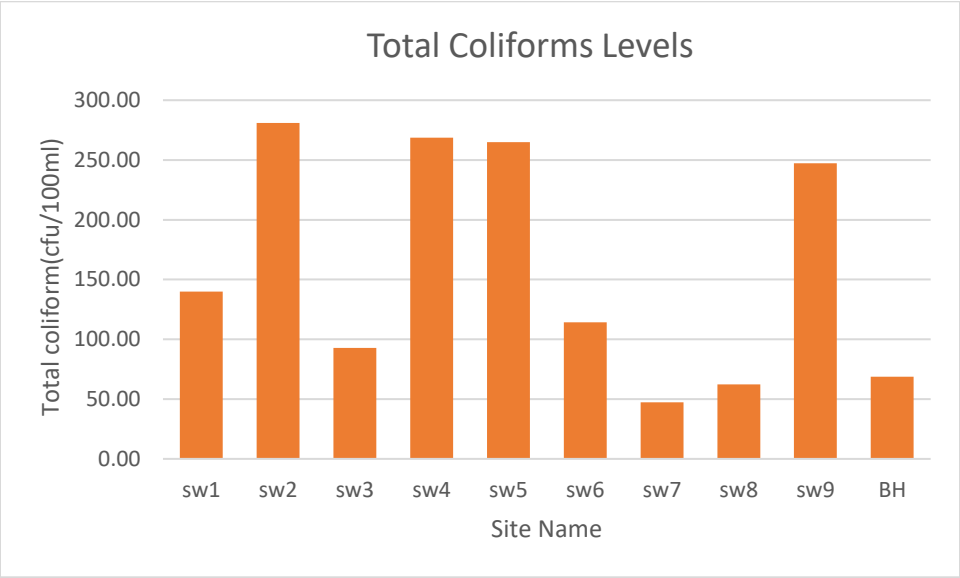


Figure 9*:* Total Coliform counts for groundwater in Gumbi area

4.2. DETERMINATION OF PHYSICAL PARAMETERS

4.2.1. pH

Results in Figure 10 indicate that there were significant differences (P<0.05) in the mean values of pH among the 10 samples. The mean pH values ranged from 6.56±0.01 to 7.78±0.01 with a total mean of 7.06±0.04. The highest pH value was observed at SW2(7.78) while the lowest was observed at SW3 (6.56).

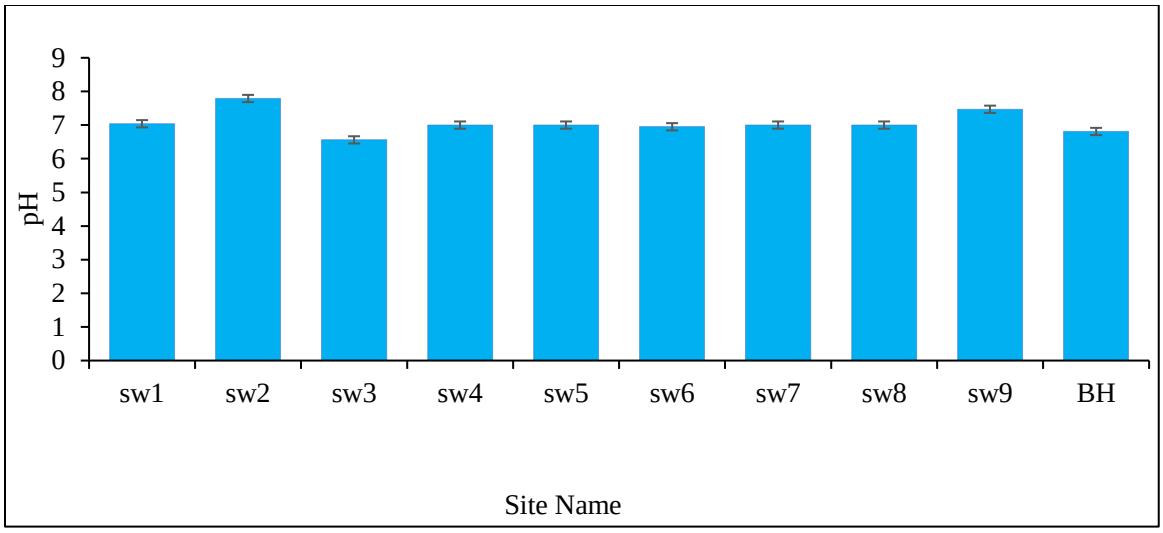


Figure 10: pH levels for groundwater in Gumbi area

4.2.2. Turbidity

Results in figure 11 indicated that there were significant differences ($P<0.05$) in the mean values of turbidity among the 10 samples in Gumbi area. Mean turbidity values ranged from 1.29±0.06 NTU to 28.63±2.39 NTU with a total mean value of 4.76±0.76 NTU. The largest turbidity level was detected at *SW9* (28.63) while the lowest was at *SW3* (1.29).

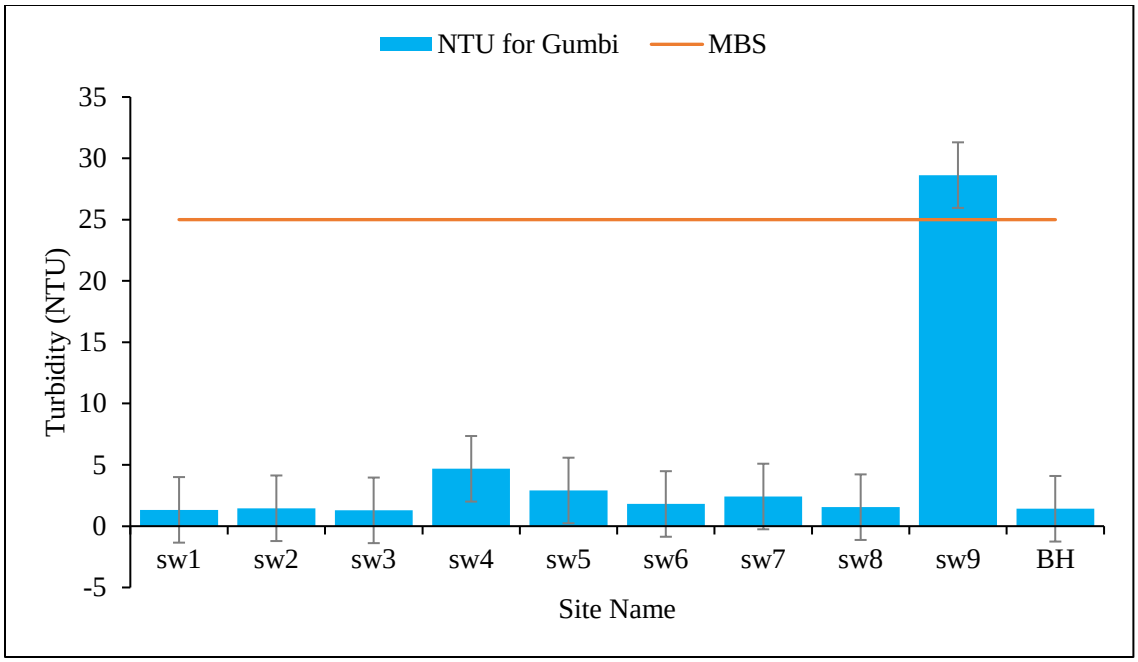


Figure 11*:* Variation of NTU levels for groundwater area in comparison with WHO

4.2.3. Conductivity (EC) and TDS

Results in figure 12 show that there were significant differences (P=<0.05) in the values of Electrical Conductivity (EC) and Total Dissolved Solids (TDS) among the 10 samples in Gumbi area. The mean values of EC ranged from 452.33±8.14 *µS*/cm to 1727±34.1 *µS*/cm with mean a value of 1045.34±1858 *µS*/cm while for TDS ranged between 294±5.20 mg/L to 1122.3±22.1 mg/L with a mean value of 762.07±12.50. SW6 registered the highest levels of both EC and TDS (1727 and 1122.3 respectively) while SW5 registered the lowest values for both EC and TDS (452.33 and 294 respectively).

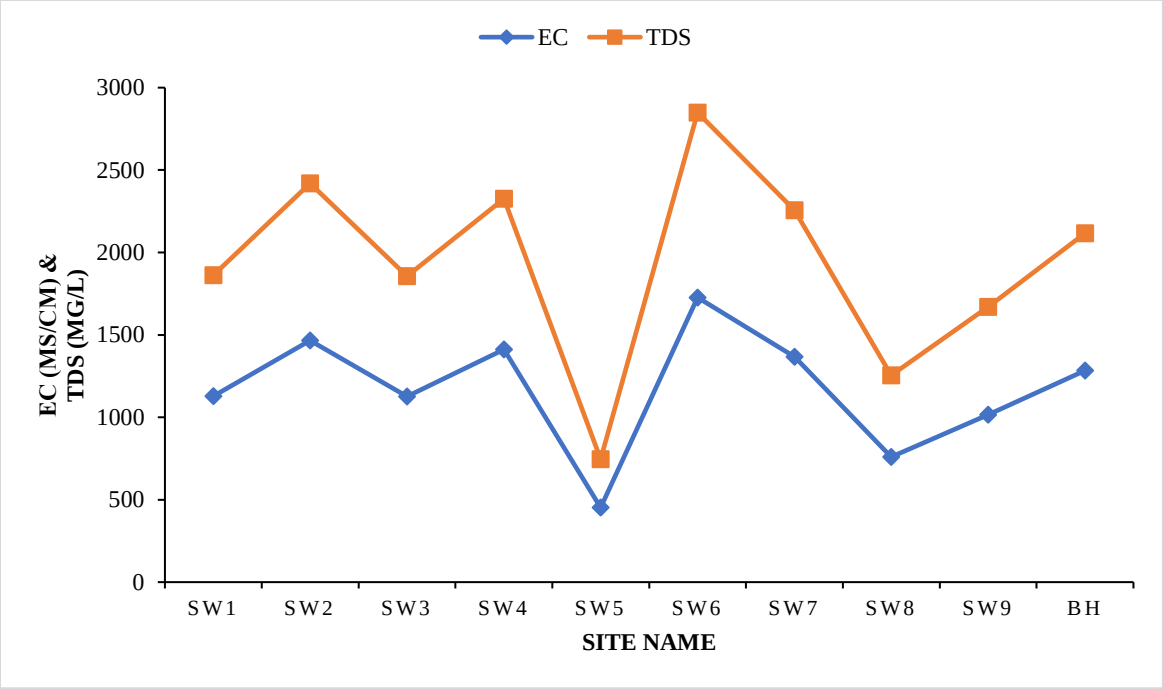


Figure 12: EC and TDS levels for groundwater in Gumbi area.

4.3. ANALYSIS OF CHEMICAL PARAMETERS

4.3.1. Total Alkalinity (Carbonates and Bicarbonates)

The findings in figure 13 indicate that there were significant differences ($P<0.05$) in the levels of both carbonates and bicarbonates in all 10 samples from Gumbi area. It was discovered that 90% of the sites had no carbonates in their ground waters. The mean carbonate levels ranged from 0.00 mg/L to 14.40±2.40 mg/L with a total mean value of 1.44±0.76 mg/L. Carbonates were detected only at SW3 (14.40 mg/L). On the other hand, mean bicarbonate levels ranged from 140.71±2.82 mg/L to 326.96±4.23 mg/L with a total mean value of 252.62±2.82 mg/L. The highest bicarbonate level was detected at SW7 (326.96 mg/L) followed by SW2 (309.07 mg/L) and the lowest value was detected at SW3 (140.71 mg/L).

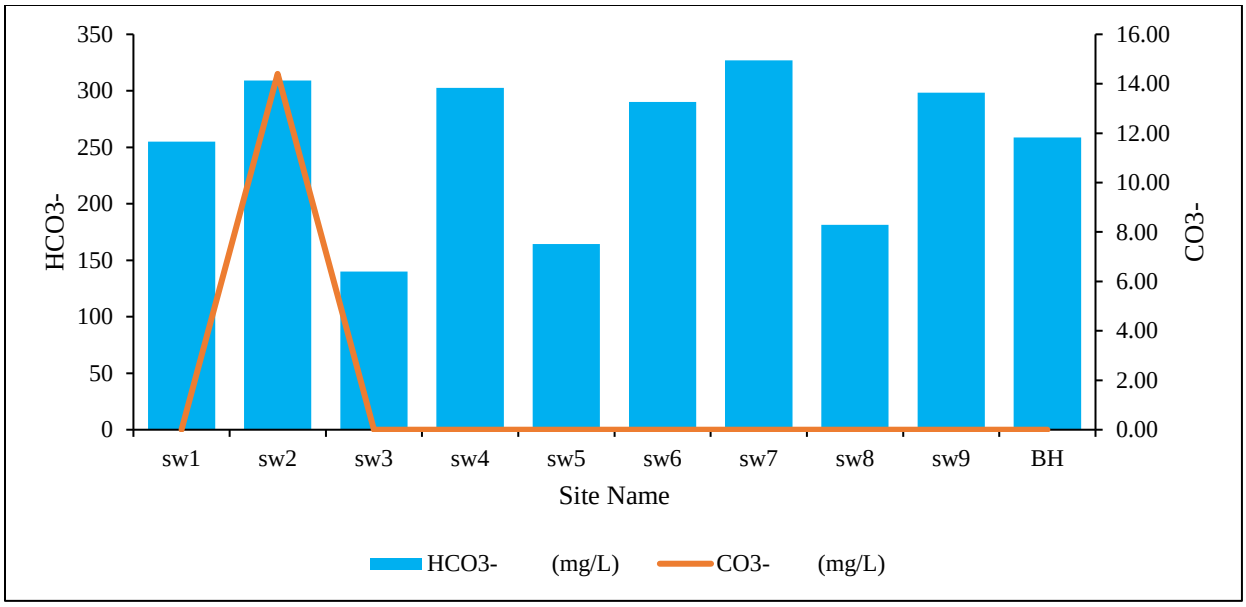


Figure13: Carbonate and Bicarbonate values for groundwater in Gumbi area.

4.3.2. Hardness

The results in figure 14 reveal that there were significant differences ($P<0.05$) in the levels of T/Hardness, C/Hardness and M/Hardness among all 10 samples for groundwater in Gumbi area. Mean values ranged from 41.33±1.16 mg/L to 310.67±11.02 mg/L with a total mean of 186.74±4.84 for T/Hardness. Mean values for C/Hardness ranged from 20.67±1.15 mg/L to 129.33±1.15 mg/L with the lowest mean value at SW1 and the highest at SW7 and a total mean value of 83.93±3.08 mg/L. For M/Hardness the mean values ranged from 20.70±1.15 mg/L to 186±12.49 mg/L with a total mean value of 102.80±6.33 mg/L.

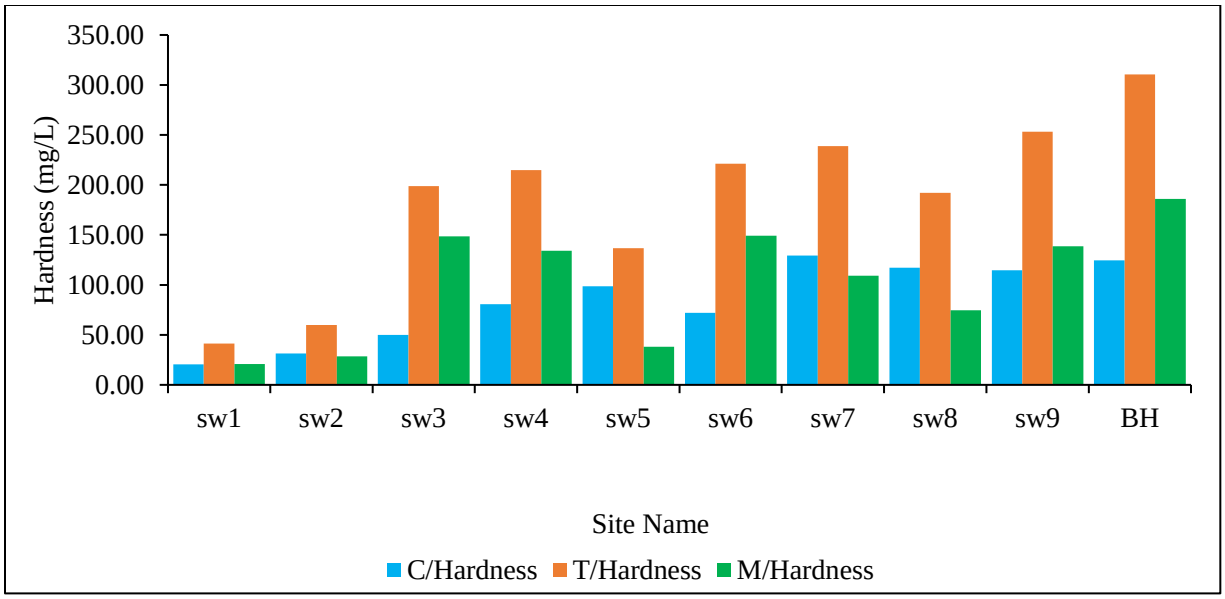


Figure 14: T/Hardness, C/Hardness and values for groundwater in Gumbi area.

4.3.3. Chlorides

Results in figure 15 indicated that there were significant differences ($P<0.05$) in the levels of concentrations of chlorides for groundwater in Gumbi area. The mean values of chloride concentrations ranged from 7.00±1.00 mg/L to 78.00±0.00 mg/L with a total mean value of 45.63±1.62 mg/L. The highest chloride concentration was observed at SW4 (78.00 mg/L) while the lowest value was observed at SW5 (7.00 mg/L).

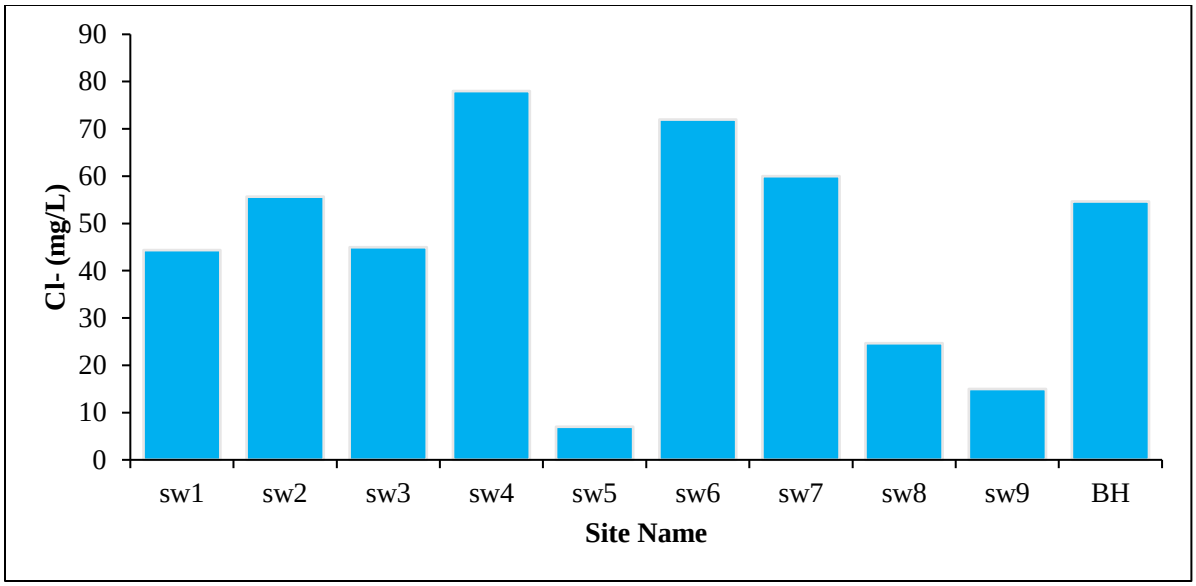


Figure 15: Chloride levels for groundwater in Gumbi area

4.3.4. Fluorides

Results in figure 16 indicates that there were significant differences ($P<0.05$) in the levels of fluoride concentrations among the 10 samples. The mean fluoride concentrations ranged from0.90±0.00 mg/L to 1.35±0.07 mg/L with a total mean value of 1.08±0.08 mg/L. SW1 registered the highest (1.35 mg/L) level of concentration of Fluoride while SW9 registered the lowest levels of Fluoride concentrations (0.9 mg/L).

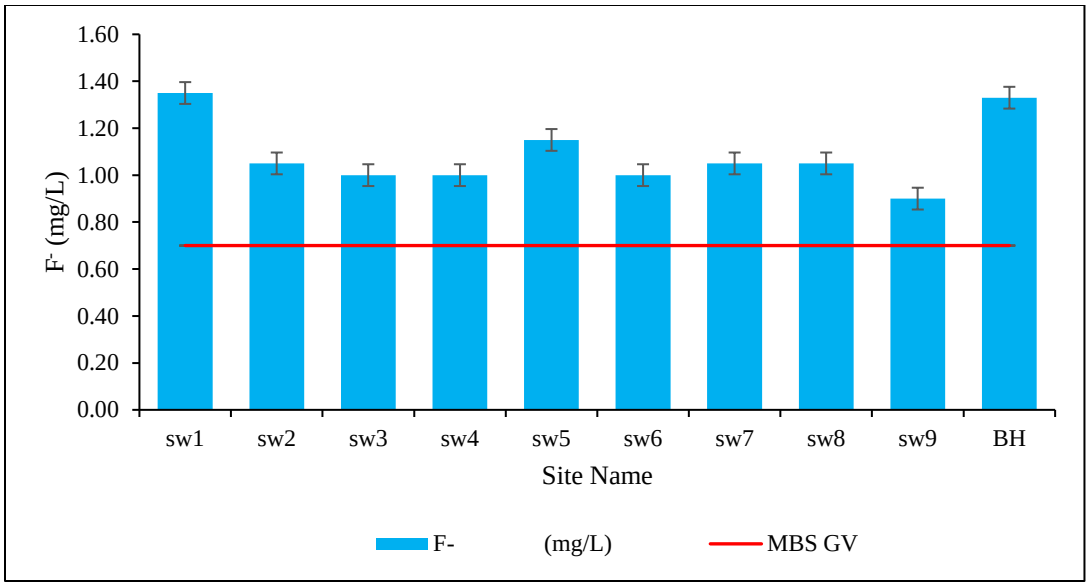


Figure 16: Fluoride levels for groundwater in Gumbi area in comparison to the MBS acceptable Limit.

Table 1: Drinking water guidelines adopted from WHO (2011) and MSB 214:2013, 733:2005)

Parameter	MBS (upper limit and ranges)	WHO	Units
E.coli (95% of sample)	0	5	cfu/100Ml
Total Coliforms (95% of sample	0	0	colonies/100Ml
pH (@ 25oC)	5.0 - 8.0	6.5 - 8.5	
Turbidity	25	5	NTU
EC	3500	1000	µS/cm at 20 ◦C
TDS	2000	***	mg/L

TSS	***	500	mg/L
Bicarbonates	600	***	mg/L
Total Alkalinity	400	***	mg/L
Total Hardness	800	***	mg/L
Chlorides	100	<250	mg/L
Fluorides	0.7	1.5	mg/L

key

**********= Null

5.0. DISCUSSIONS

5.1. PATHOGENIC MICROORGANISMS IN GROUNDWATER

Results from groundwater samples from all wells in Gumbi area indicated Faecal contamination with indicator organism *E.coli* present in all samples from these wells as the values were higher than recommended standards of WHO and MBS. The presence of *E.coli* provides evidence of recent fecal contamination and detection should lead to consideration of further action which could include further sampling and investigation of potential sources of pollution (WHO, 2011). It was that 60% of these shallow wells were located in close proximity to sanitation facilities (latrines). A study conducted in South Lunzu township by Palamuleni indicated that water sources were on average distance of <10m from nearby pit latrines. UNEP (1999) recommends that pit latrines be located at least 40m away from the water source. In addition to this, some wells had stagnant pools of water around them and animal kraals in close proximity (SW2 and SW5). Rubbish pits, stagnant water pool, toilets, animal kraals and refuse dump sites were observed to be the major possible sources of groundwater contamination in a study conducted in Mzuzu city (Wanda et al, 2013). Furthermore, another possible cause of contamination could be the

vessel that is used to collect the water from the well. However no *E.coli* was detected in the borehole in all three replicate samples.

The absence of *E.coli* in this water source could imply that the total coliforms that were detected could be naturally occurring bacteria that do not necessarily reflect fecal contamination of the groundwater (British Columbia Groundwater Association, 2007; Kamanula et al, 2014). Based on the WHO and MBS guidelines in table 3 indicate that all samples tested did not meet the total coliform guideline value.

5.2. PHYSICAL PARAMETER ANALYSIS

5.2.1. pH

Among all the physicochemical parameters analysed, pH is one of the most important parameters which determine the suitazbility of water for various purposes (Wanda et al, 2017). Water pH values ranged from 6.56 to 7.79 with an average of 7.06 indicating occurrence of slightly neutral waters (in between acidic and alkaline). 50% of the water samples had pH values of 7.00. All pH values indicated to be within the acceptable limits of the MBS (MS 214: 2013, 733: 2005) and WHO. The pH of the water was generally conducive for the survival of fecal coliforms because most pathogens will breed properly at a pH range of 5.8 to 8.4 (Kaonga et al, 2013). Waters having pH values below 6.0 are highly acidic and may be corrosive in nature. Such waters are not suitable for direct human consumption (Tebbutt, (1999). Exposure to extreme pH values (<4 and >11) may result in irritation of the eyes, skin and mucus membranes (Hoko, 2008; Kushe, 2008). In addition to this, highly acidic water may result in the corroding parts of borehole pumps, causing the possible release of iron, lead or copper into the water (ODNR, 1997)

5.2.2. Turbidity

Results indicate that 90% of the sample sites were within recommended WHO guideline values however, SW9 exceeded the permissible levels of WHO (5 NTU). The values reported in the study however were far much lower than turbidity values reported by Kamanula (2014) which ranged from 0.01 NTU to 103.0 NTU in a study conducted in Ndirande, Blantyre. Pritchard et al. (2008) reported values ranging from 0-209 NTU for

shallow wells in Balaka, Chikwawa and Zomba for both the dry and wet season. Suspended solids are rarely harmful, yet elimination of turbidity increases the aesthetic quality and acceptability of the water. Pritchard et al. (2007) suggest that the impact of turbidity is that the colloidal particles which cause turbidity can harbor pathogens thereby making disinfection ineffective. Turbid waters demand relatively higher dosage of disinfectants, which is the only treatment method for groundwater in rural areas, is deemed necessary (Hoko, 2008; Kushe, 2008).

5.2.3. Conductivity (EC) and TDS

Values obtained for EC and TDS (figure 5) were in the ranges of permissible levels of MSB (3500 μS/cm). However, according to WHO 70% of the samples were above permissible levels (>1000 μS/cm)). A study conducted by Kushe (2008) in Dedza found values ranging from 195 μS/cm to 4156 µS/cm with a mean value of 1242 µS/cm. Grimason et al (2013) observed extremely high conductivity levels of up to 6574 μS/cm for the S/cm in the lower Shire Valley.

Electrical Conductivity is an important indicator for the dissolved minerals that are present in water. Furthermore, Total dissolved Solids (TDS) comprise of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water. TDS in drinking water originates from natural sources, sewage, urban runoff and industrial wastewater (WHO, 2011). Based on this, it was then concluded that conductivity values observed in the study area resulted from the dissolved ions and that values measured were dependent on the concentration of the dissolved ions (Kushe, 2008).

5.3. CHEMICAL ANALYSIS

5.3.1. Total Alkalinity

Only one sample site SW2 had carbonates present in its groundwater during the analysis. No specifications are available from WHO and MBS concerning the permissible or maximum levels of carbonates in ground waters.

A study conducted by Wanda et al (2017) detected bicarbonate levels of up to 746.44mg/L. There are no specifications on the maximum acceptable limits of bicarbonates by WHO. However, these values were below the maximum permissible limits of 600mg/L by the Malawi Standards (MBS 214; 2005 and MBS 733: 2005). Total alkalinity is due to the presence of bicarbonates HCO^{-}_{3}, carbonates CO_3^{2-} and Hydroxide OH^-. Most of the natural alkalinity in waters is due to the high presence of HCO_3^- produced by the action of groundwater on limestone or chalk. Alkalinity is useful in waters because it provides buffering to resist changes in pH (Tebbutt, 1999). Bicarbonates has side effects which include metabolic alkalosis and may have an effect on the acid-base balance (Chilton, 1996). Alkalinity relates to concentration of calcium and carbonate and high alkalinity has a bearing on the hardness of the water. It was concluded that alkalinity of the water in the area was acceptable in all water points.

5.3.2. Total Hardness

Hard water results from of the presence of mainly magnesium and calcium in water. The degree of hardness of drinking-water is important for aesthetic acceptability by consumers and for economic and operational considerations. According to Hem (1991), hardness of water limits its use for both industrial and domestic purposes. Hard water causes scaling of pots, boilers, and irrigation pipes due to deposition of carbonates of mostly calcium and magnesium. Muss (1962) and Monjerezi et al (2012) indicated that hardness of water for domestic purposes causes inhibition of soap action in water and some evidence of its role in heart and circulatory diseases has been reported. BH registered the highest hardness (from both Calcium and Magnesium) value. One of the reasons why this was observed so could be because there is an increase in hardness with distance as it interacts with the geological material and with longer period of interaction (Kushe, 2008) and boreholes are usually deeper than shallow wells.

Hardness was well below the ranges of maximum acceptable limits by MBS (800mg/L) though a hardness in excess of 300mg/L would normally be considered undesirable (Tebbutt, 1999).

5.3.3. Chlorides

Chlorides are one of the most important parameters in assessing the water quality. Munawar (1970) was one of the opinions that higher concentrations of chlorides indicate higher degrees of organic pollution and the unsuitability of that water for domestic use. A water quality assessment study conducted by Yogendra et al (2008) showed that chlorides varied seasonably; higher during summer season and lower during rainy season. A similar observation was also made by Sinha in 1995. The values obtained from the analysis indicated that water samples were in the range of acceptable limits of MBS at 100 mg/L and WHO at 750 mg/L. Most chloride in ground waters originates indirectly from evaporated seawater that enters aquifers as rainfall recharge. Rainfall contains high levels of chloride near the coasts and as a consequence it is found at higher concentrations in groundwater that originate nearer to the coast (Todd, 1980). Chlorides also originate from sediments of igneous rocks, evaporites, pit latrines and animal wastes (Kushe, 2008). High concentrations of chloride give a salty taste to water and beverages. Concentrations in excess of 250 mg/l are increasingly likely to be detected by taste, but some consumers may become accustomed to low levels of chloride-induced taste. However, no health-based guideline value is proposed for chloride in drinking-water (WHO, 2011).

5.3.4. Fluorides

Fluorides are among some of the substances that may become undesirable in excessive amounts. At levels of fluoride above 1.5 mg/L, there is a possibility of yellow staining of teeth and at much higher levels there is the danger of bone damage through fluorosis (Tebbutt, 1999). Further studies have shown that the effects of fluorides could go beyond the mottling of teeth and cause mental retardation in children (Mullenix et al, 1995; Chimphamba et al, 2014). Pritchard et al. (2008) observed higher values for fluoride in the range of 0.3 mg/L to 11 mg/L for dry season and 0.9 mg/L to 14 mg/L for the wet season for Chikwawa. The high values for the wet season in Chikwawa were found in open and protected shallow wells. Msonda et al. (2007) reported that high fluoride zones are associated with areas of discharge, especially places where shallow groundwater less than 4m occurs. In Gumbi area, 70% of the open shallow wells had groundwater levels

of less than 5m, this was observed during water sample collection. Studies conducted in Nsanje, revealed that only one of six borehole samples complied with the WHO guideline value and five with the MBS maximum permissible levels, and this area is renowned within the country for the sight of dental fluorosis amongst locals (Sajidu, 2008; Grimason et al 2013).

The measurements obtained in the study were within maximum acceptable limits of WHO of 1.5 mg/L. However, according to MBS (2013), the values are beyond the permissible levels which were set at 0.7 mg/L. The current WHO health-based GV is considered to be a threshold where the benefit of resistance to tooth decay is weighed against the risk of developing dental fluorosis (Grimason et al 2013).

Fluoride is an example of a constituent of water which can be beneficial at low concentrations but which becomes harmful at higher concentrations. Such effects are not uncommon with many chemicals found in the diet.

6.0 ETHICAL CONSIDERATIONS

Permission to conduct the collection of samples in the selected sites was sorted from the District Commissioner, Water and Environmental Officers and the Village Headman Gumbi village. For sites that were located on a private property, permission was sorted from the owner of the household. No subject concerned was forced to give permission to collect samples on their household. Throughout the study, no harm was brought to any subject encountered during sample collection. Cultural values were considered, respected and not violated in any way.

6.1 LIMITATIONS

Heavy metals were not determined due to unavailability of resources and finances and due to limited time, I failed to develop water quality index which could have been important key for my research.

6.2 CONCLUSIONS AND RECOMMENDATIONS

The study conducted in Gumbi aimed to determine the microbial and physico-chemical characteristics of drinking water from shallow wells and boreholes. Based on the results that were obtained, and the Malawi Bureau of Standards specifications for drinking water (MS 214: 2013; MS 733:2005), drinking water from all shallow wells contained high levels of *E.coli*, suggesting that the water was heavily polluted by faecal matter and therefore, the water was not suitable for direct human consumption. The water from the borehole however had no presence of faecal contamination and so was fit for direct human consumption.

The concentrations of pH, EC and TDS were all under the and within the maximum permissible limits of Malawi Bureau Standards (MBS 214: 2013; 733:2005) implying that the water sources were free from contamination by these parameters. However, turbidity levels from one source were way beyond the Malawi board specifications and not fit for direct human consumption.

The concentrations of total alkalinity (carbonates and bicarbonates), total hardness (calcium + magnesium) and chlorides were all in the ranges of acceptable limits of the Malawi Bureau of Standards. Fluorides on the other hand were above the specified limits of the Malawi Bureau of Standards. Considering the health effects of fluoride, it is necessary to investigate interim and long-term measures on how to deal with the problem.

The Water Resources Act stipulate in the water pollution control regulations that all water points must be sited 100m upstream of sanitation facilities (e.g. pit latrines) (Lakudzala et al, 2005; Pritchard et al 2007). There is need for the government and water organizations to enforce these standards effectively in order to reduce (if possible, completely eliminate) levels of fecal contamination in drinking water. Provision of safe water is vital for the protection and development of human resources (Ndolo et al).

Further studies on why SW9 had extremely high turbidity levels must be conducted and action must be taken so that water consumed must be safe for consumption by all users. Turbidity may harbor pathogenic microorganisms that may even fail to be treated with chlorine.

There is also need for frequent water quality monitoring mechanisms so that appropriate action is taken for those wells that produce water of unacceptable quality.

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THE APPENDIX


SHOT ON S15
itel DUAL CAMERA

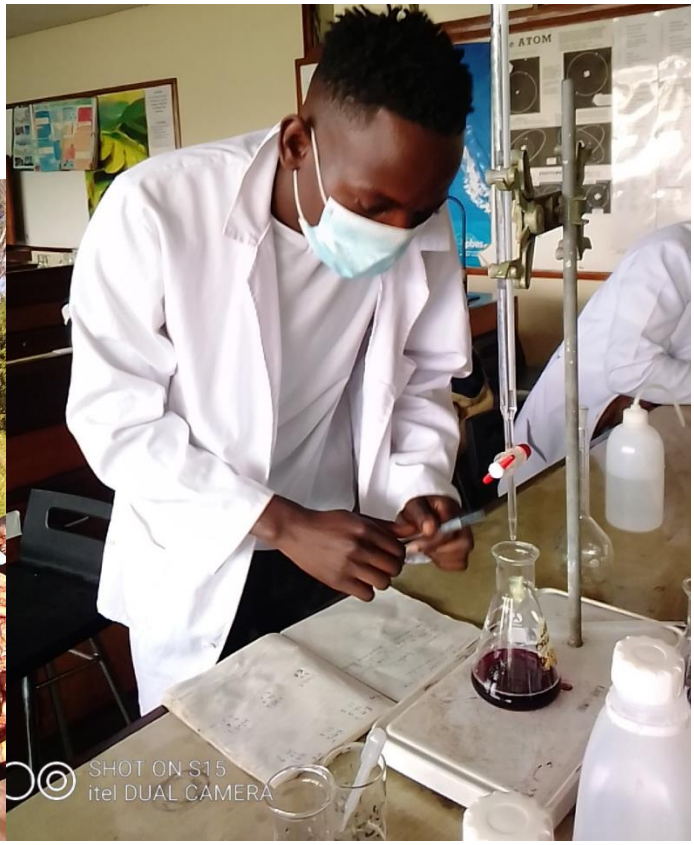

SHOT ON S15
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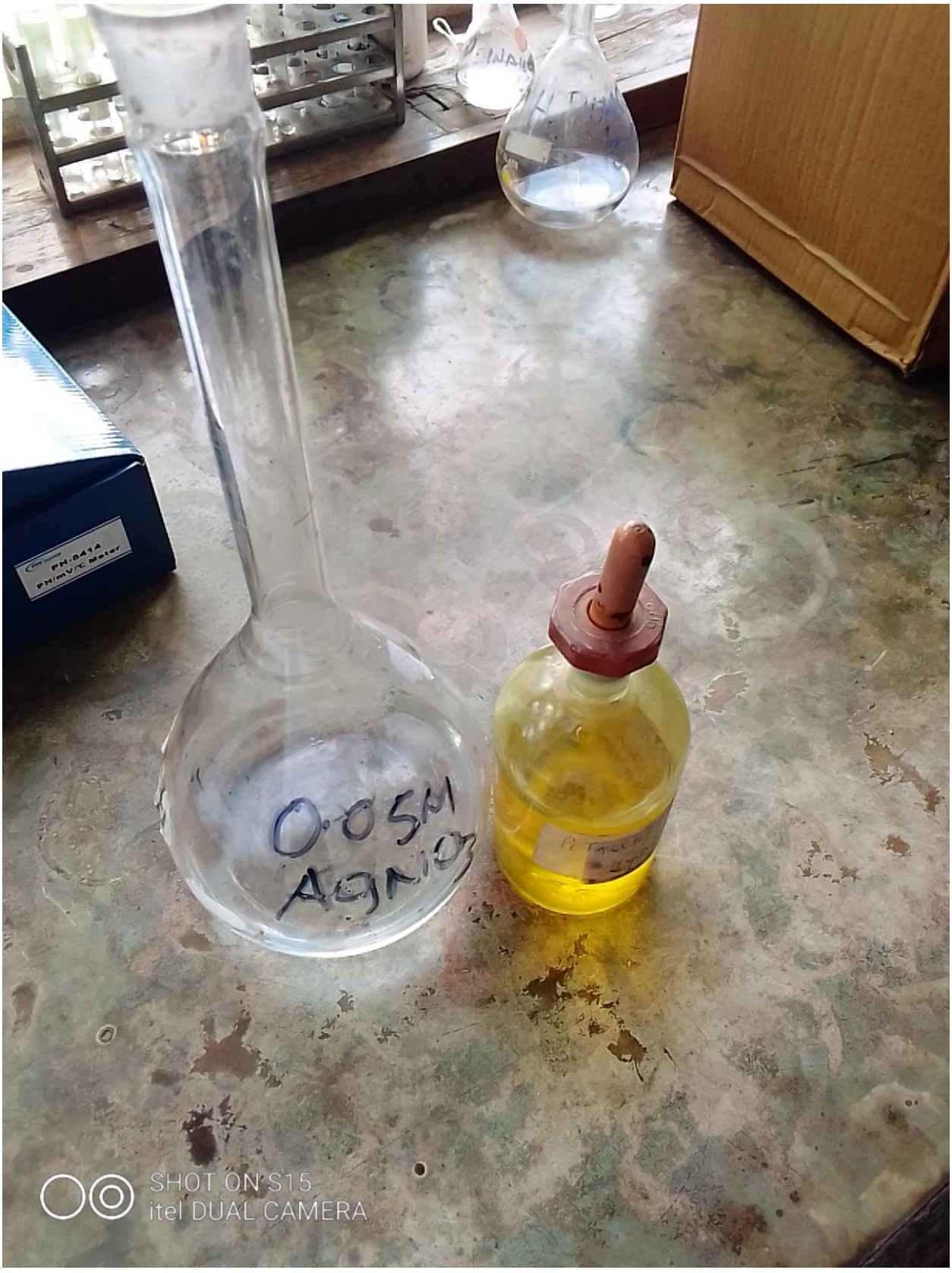
FIGURE 1. SHOW GPS COLLECTION FOR SAMPLED AREA

SITE	NORTHINGS	EASTINGS	ATTITUDE(M)
WELL 1	3422402	147190	808
WELL 2	3422306	147219	805
WELL 3	3422304	147146	899
WELL 4	3422157	147323	804
WELL 5	3422452	147697	805
WELL 6	3422666	147697	810
WELL 7	3422669	147798	812
WELL 8	3423079	147719	816
WELL 9	3422574	147400	803
BOREHOLE	3422670	147603	811

FIGURE 1: TABLE SHOW GPS COLLECTION FOR SAMPLED AREA.




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itel DUAL CAMERA


0.05M
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