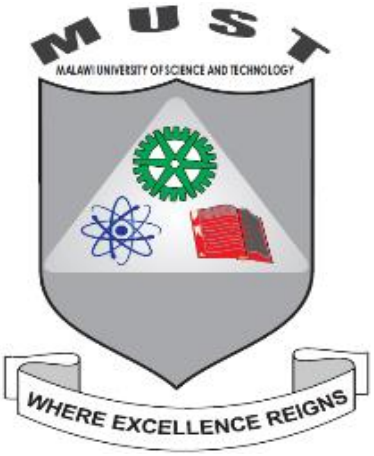


AN ANALYSIS OF GROUNDWATER QUALITY IN BOREHOLES AND SHALLOW WELLS OF MPASU VILLAGE, THYOLO MALAWI

NYIRENDA EMMANUEL

WQM-025-18

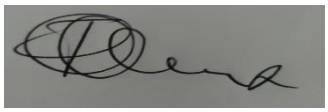
Thyolo, Malawi

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

October, 2022

DISSERTATION APPROVED BY:

SUPERVISOR:

Mr F. CHAULUKA Signature: 

ASSESSOR:

Title, Initials, Name Signature: _____

DECLARATION

I Emmanuel Nyirenda that this research project represents my own 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 : 19/10/2022

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 acknowledgement.

ABSTRACT

People in villages depend on groundwater sources like boreholes and wells. However, due to the cost of conducting water tests most of these boreholes and wells are not tested to determine the quality of water. This study analysed groundwater quality in boreholes and shallows wells under the jurisdiction of Group Village Head Mpasu. The study involved an experimental design. A total of five boreholes and two shallow wells were purposively selected because they were used for drinking and domestic use. The samples were collected during the dry season. Samples were collected using grab method in sample bottles pre-treated with sodium thiosulphate and transported using a cooler box with ice packs. The samples were analysed for Temperature, pH, total dissolved solids (TDS), electrical conductivity (EC), Nitrate (NO3-), Chloride (Cl-), Fluoride (F-), Total Hardness and Faecal Coliforms (FC). All physico-chemical parameters were within acceptable standard limits but elevated levels of coliforms were observed for wells and one borehole. Water quality was determined by using groundwater quality index. Pearson's r correlation was calculated to assess the strength of linear correlation among parameters and between parameters and average distance from pit latrines. Four boreholes had excellent water quality with water quality indices ranging from 4.8 to 21.4. One borehole and two shallow wells had poor water quality with index values ranging from 51.4 to 55.1. Strong positive correlation was observed between EC and Hardness, EC and TDS and TDS and hardness. The r values were 0.84, 0.93 and 0.86 respectively. However, distance from toilets and faecal coliform count showed contradiction to previous studies. Four boreholes failed to meet the minimum acceptable distance from pit latrines as per Malawi Government Standards. This study recommends sensitisation of community members to treat water before drinking because the water may contain harmful microbes from faecal matter. There should also be sensitization on proper siting of toilets to avoid contamination of groundwater sources.

ACKNOWLEDGEMENTS

I would like to thank my wife and parents for their financial and spiritual support throughout the course of my research. Special thanks to my supervisor Mr F. Chauluka and all my lecturers for assisting me during all stages of my research.

TABLE OF CONTENTS

1. CHAPTER 1: INTRODUCTION 1
   1.1. Background 1
   1.2. Problem Statement 2
   1.3. Research Objectives 3
   1.4. Specific Objectives 3
   1.5. Research Questions 3
   1.6. Scientific Significance 3
2. CHAPTER 2: LITERATURE REVIEW 5
   2.1. Water Quality 5
   2.2. Geology of the Area 5
   2.3. Groundwater Quality of Malawi 5
   2.4. Determination of Water Quality Parameters 8
   2.5. Water Quality Assessment 8
3. CHAPTER 3: METHODOLOGY 11
   3.1. Study Area 11
   3.2. Research Design 11
   3.3. Materials and Methods 12
   3.4. Methods 12
   3.4.1. Sampling 12
   3.5. Physico-chemical and microbial Water Quality Analysis 13
   3.5.2. Determination of pH 14
   3.5.3. Determination of TDS 14
   3.5.4. Determination of Hardness 14
   3.5.5. Determination of Nitrates 15
   3.5.6. Determination of Fluoride 15
   3.5.7. Determination of Chloride 16
   3.5.8. Determination of faecal coliforms 16
   3.5.9. Determination Distance between Water Points and Pit latrines 17
   3.6. Quality Control 17
   3.7. Data Analysis 17
4. CHAPTER 4: RESULTS AND DISCUSSION 19
   4.1. Physico-chemical Parameters 19
   4.2. Biological Parameters 27
   4.3. Water Quality Index 27
   4.4. Correlation Analysis 29
   4.5. Distance Between Pit latrines and Water Points. 30
5. CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS 33
   5.1. Conclusion 33
   5.2. Recommendations 33
6. REFERENCES 34
7. APPENDICES 45

ACRONYMS AND ABBREVIATIONS

APHA	American Public Health Association
BH	Borehole
CFU	Colony Forming Units
EC	Electrical Conductivity
FC	Faecal Coliform
GoM	Government of Malawi
GVH	Group Village Head
MBS	Malawi Bureau of Standards
NTU	Nephelometric Turbidity Units
SW	Shallow Well
TDS	Total Dissolved Solids
WHO	World Health Organization
WQI	Water Quality Index

LIST OF FIGURES

Figure 1. Map of the Study Area. 11
Figure 2. Flow Chart of for the Research Design. 12
Figure 3. Sampling Using a Weighted Bottle and Rope. 13
Figure 4. GARMIN GPSMAP64 17
Figure 5. Temperature Variations of Water Ponits Compared to Standard Values. 19
Figure 6. pH Variations of Water Points Compared to Standard Values. 20
Figure 7. EC Variations of Water Points Compared to Standard Values. 21
Figure 8. TDS Variations of Water points Compared to Standard Values. 22
Figure 9. Total Hardness Variations of Water Points Compared to Standard Values. 23
Figure 10. Nitrates Variations of Water points Compared to Standard Values. 24
Figure 11. Chloride Variations of Water Ponits Compared to Standard Values. 25
Figure 12. Fluoride Variations of Water Pointts Compared to Standard Values. 26
Figure 13. Feacal Coliforms Variations of Water Points Compared to Standard Values. 27
Figure 14. Spatial Distribution of Water Quality Index for the Study Area. 28
Figure 15. Location of Pit Latrines in Relation to Recommended Buffer Zones. 31
Figure 16. Groundwater Flow for the Study Area. 32

LIST OF TABLES

Table 1. Water Quality Index Classification 18
Table 2. Summary of Results for Measured Parameters of Boreholes and Shallow Wells Compared to MBS and WHO Standards. 19
Table 3. Calculated Water Quality Indices for the Study Area. 28
Table 4. Correlation Matrix for Water Parameters and Distance. 29
Table 5. Average Distance to Pit latrines. 30

1. CHAPTER 1: INTRODUCTION

1.1. Background

Globally, groundwater remains one of the most important water sources. The ease and low cost of extraction makes groundwater preferred to other means of drinking water supply like dams. However, increase in the rate of pollution worldwide has led to concerns over water quality by different scholars in the world (Gharibi et al., 2012). Primary focus of many regional studies in Africa has been on water quantity and availability (Bonsor et al., 2018). However, water quality puts a lot of countries in the developing world under stress due to its associated problems of waterborne diseases (Li & Wu, 2019). People in the Sub-Saharan Africa and other parts of the world like Asia depend on groundwater from shallow wells, boreholes and springs as a major source of domestic water (Lutterodt et al, 2018). Groundwater in rural areas is mainly abstracted from aquifers using boreholes fitted with handpumps (JMP, 2019). Groundwater may be naturally contaminated from chemicals and inorganic particles due to interaction with rocks or may be contaminated through human activities. Anthropogenic activities like farming and industrial activities are known to cause more water quality deterioration. However, not much has been done to examine the water quality for hand pump boreholes in Africa (Lapworth et al., 2020). This has led to lack of information on groundwater quality.

In Malawi, 91% of people living in rural areas depend on groundwater sources like boreholes, wells, and open sources (National Statistical Office, 2017). Clearly groundwater is the most convenient water source in the country. Groundwater quality studies in Malawi, show that some boreholes fitted with handpumps may have physical, chemical and microbiological contamination (Mtewa, K. T, Chauluka, Mtewa A, Banda & Kalindekafe, 2018; Matsimbe, 2020). According to the Water Barometer (2021), 2.6 million people die every year due to water-related diseases and unsanitary living conditions. Malawi currently has a high rise in cholera cases.

In the southern region, 78 cases of cholera were reported in April 2022 (WHO, 2022). According to NSO (2019), 85% of households in Thyolo district do not have proper or improved toilets and 52.7% of the households do not have proper rubbish disposal facilities. Lack of safely managed sanitation facilities can exacerbate groundwater quality problems especially poorly sited latrines and rubbish pits. Natural and anthropogenic chemical contaminants like fluoride and nitrates may also affect groundwater quality. Fluoride has serious health impacts on people in higher concentrations. In Mpaso, no study has been conducted to find out the quality of groundwater that people use for drinking and sanitation.

1.2. Problem Statement

According to Kanyerere et al (2012) people in rural areas mainly depend on untreated groundwater supplies as sources of safe drinking water. Groundwater is found in aquifers and is mainly abstracted using wells and boreholes. In Mombasa Kenya, Munga et al (2004) found that aquifers were contaminated from on-site sewage disposal systems like pit latrines and septic tanks. Macdonald & Davis (2020) observed that shallow wells in Malawi are usually less than 20m deep and located in unconfined aquifers. Despite having boreholes, some people in rural areas still rely on shallow wells located in better yielding aquifers due to problems of draw down associated with some boreholes.

According to NSO (2019), 85 percent of households in Thyolo district did not have proper or improved toilets as of 2019. Improper pit latrines affect the microbiological quality of water up to 25m lateral distance if not properly sited (Dzwairo et al, 2006). However, excreta disposed on site contain high levels of nitrates and chloride which can affect water quality in shallow wells (British Geological Survey, 2002). Unprotected shallow wells are vulnerable to contamination than deeper boreholes (Ayantobo, 2012). According to Oluwasanya et al (2011) any well that does not have a pump, is not lined with concrete and platform (or apron), has no head wall, no cover or no drainage channel is considered unprotected. In rural areas most wells are characterised by one or more of these criteria. According to cumulative data retrieved from DHIS 2 (2021), TA Chimaliro had 1,733 diarrhoea cases in the year 2021.

However, water quality is an important feature of domestic supplies that influences public health (Howard & Bartram, 2003). Currently no study has been conducted to find out the quality of water from boreholes and shallow wells in Mpasu village, one of the areas in Thyolo district. Hence the study will be conducted to determine if the quality of drinking water points in the area is not compromised. The findings will support the achievement of the SDG 6. The information will also help stakeholders to come up with right interventions to deal with waterborne diseases, prevent problems of diarrhoea, fluorosis, cholera and other waterborne diseases.

1.3. Research Objectives

- The main objective of this study is to analyze groundwater quality in boreholes and shallow wells of Group Village Head Mpasu.

1.4. Specific Objectives

- To examine the physico-chemical parameters of groundwater quality.
- To assess the microbiological quality of groundwater.
- To appraise the water quality of boreholes and wells using a water quality index.
- To determine the effect of distance between pit latrines and water points on water quality.

1.5. Research Questions

- Which parameters exceed standard WHO or MBS groundwater quality standards?
- Which boreholes or wells provide excellent, good, moderate, poor or very poor groundwater quality?
- How many boreholes currently provide water of acceptable quality.

1.6. Scientific Significance

The study will help fill the information gap that exists on water quality of boreholes and wells in Group Village Mpasu Traditional Authority Chimaliro. A better understanding of the water quality will help government and other stakeholders to

come up with effective interventions for preventing and dealing with water related health problems in the area like diarrhoea and fluorosis. The study will also provide information for implementation of water safety plans, a water quality management approach which is being adopted by many countries in the developing world. Finally, the study will help the government in the overall achievement of SDG 3 of having good health and well-being as well as SDG 6 of having access to clean water and sanitation for all.

2. CHAPTER 2: LITERATURE REVIEW

2.1. Water Quality

Water quality is a relative term that enshrines several components of drinking water as well as water for irrigation that arise as a result of both natural processes and anthropogenic activities (Napacho & Manyele, 2010). The quality of source water is one of the most significant determinants of drinking water quality in rural areas where water is usually consumed without any treatment (Scheili et al, 2016). Hence assessment of water quality at a source can provide vital information for water quality to scientists and managers. Pollution from domestic waste, industrial waste, agricultural waste and waste from business places lead to deteriorating water quality (Mtewa et al, 2018). Water quality is said to be compromised only when one or more of the water components is outside the desired water quality standard according to the intended use. For instance, a standard that may be considered as poor for drinking water quality may be acceptable for irrigation water.

2.2. Geology of the Area

Thyolo district has a surface elevation ranging from 53m at Chiromo to 1462m above sea level at the summit of Thyolo mountain (Habgood et al, 1973). It has three physiographic zones namely; the Shire valley, Thyolo fault scarp zone and the Thyolo highlands. The study area is located in the Thyolo highlands. There great surface variations in the area (Habgood et al, 1973). The boreholes are sited in fracture zones, in zones of weathered gneiss and in the unconsolidated deposits of the Shire Valley. They give yields of up to 2000 gallons per hour (Habgood et al, 1973).

2.3. Groundwater Quality of Malawi

In Malawi, groundwater quality is affected by both anthropogenic and natural activities. A study conducted in the lower Shire by Grimason et al (2013) in Chikhwawa focussed on physico-chemical parameters. Sodium, iron ad nitrates were exceeded the Malawi Bureua of Standards limits. A study on boreholes in Malawi as a whole also found that only 19.1% of boreholes out of 27,913 complied with WHO standards for fluorides, nitrates, iron and chlorides (Chimphamba & Phiri, 2014).

Many boreholes and wells in Malawi fail to meet the recommended WHO and MBS standards for physicochemical parameters. Some studies also show that groundwater is prone to microbial contamination in Malawi (Pritchard et al, 2008; Mkwate et al, 2017). However, routing water testing or water quality monitoring is rarely conducted due to high costs associated with water testing.

2.3.1. Physico-Chemical Parameters

The Ministry of Water and Sanitation in Malawi recommends measurement of physico-chemical parameters before handing over new boreholes to communities (Grimason et al, 2013). Some of the physico-chemical parameters of concern in drinking water include pH, total dissolved solids, electrical conductivity, iron, turbidity, nitrates. Among studies conducted in Malawi to assess drinking water quality different combination of these variables were measured (Thokozani, K, T., 2013; Kaonga et al, 2013; Wanda, Lewis & Gift, 2012; Matsimbe, 2020). These parameters are not used exclusively to assess drinking water quality. They are used to complement other variables like faecal coliforms and total coliforms units.

pH is essentially the measure of the concentration of hydrogen ions in water ranked on a scale of 1.0 – 14.0. Naturally water has constituents like minerals, gases, non-electrolytes and electrolytes that contribute to pH. However, industrial effluent also has the potential to change pH affecting the test of drinking water (Yadav, Mishra, K., Chaudhary, & Mishra, P., 2015). Apart from affecting test of drinking water, pH determines the water power or ability to cause corrosion (WHO, 2007). Corrosion of plumbing systems may lead to accumulation of heavy metals in drinking water. The efficiency of water treatment is also affected by pH when using chlorine. It is therefore important for the government to engage in more water quality monitoring programs in addition to assessment because water quality is likely to be compromised overtime in water sources that were previously considered safe.

Total dissolved solids and electrical conductivity indicate amounts of solids in drinking water. Electric conductivity is the ability of a water sample to conduct

electric current. A study conducted by Lapworth et al (2020) revealed high levels of total dissolved solids in borehole water collected in Malawi compared to Uganda.

Casado et al (2015) cited in Yadav et al (2015) describes turbidity as the cloudiness of water caused by clay, organic matters, microscopic organisms and other particulate matters. Turbidity is one of the most regulated parameters for drinking water because it affects the acceptability of drinking water by consumers. According to Mtewa, T. K, et al (2018) turbid water is not conducive for drinking.

Iron is one of the trace elements essential for bodily functions in humans (Mtewa et al, 2018) and is regulated in drinking water as a chemical parameter. When taken in excess, iron can cause substantial damage to the human body.

The use of inorganic fertilizer like UREA and NPK contribute to pollution of water from another chemical constituents called nitrate. The conversion of nitrate (NO_3^-) to nitrite (NO_2^-) in the stomach can cause illness or sometimes death in infants under six months of age (Napacho & Manyele, 2010). It combines with haemoglobin to form methanohaemoglobin which deprives tissues of oxygen leading to a condition called blue-baby syndrome. In surface waters, nitrates affect aquatic life by causing eutrophication which reduces dissolved oxygen in water.

2.3.2. Biological Parameters

Coliforms are mainly used for biological assessment of drinking water. Faecal coliforms have previously been used in Malawi by different researchers to assess the quality of drinking water (Pritchard, Mkandawire & O'Neill, 2007; Pritchard, Mkandawire & O'Neill, 2008; Kaonga et al, 2013; Mkwate, Chidya & Wanda, 2016; Mtewa, T. K. et al, 2018). Coliforms indicate faecal contamination from both human and animal waste (Kaonga et al, 2013). Unlike physico-chemical parameters, biological parameters provide information on potential contamination from pathogens. They have been widely used as indicators for drinking water quality and in the past, they led to development of public health protection concept (Nikaeen et al., 2009).

2.4. Determination of Water Quality Parameters

As a result of technological advancement, a broad range of instruments exist for assessing water quality. Physico-chemical parameters like pH, turbidity, total dissolved solids, electrical conductivity, dissolved oxygen, and many more are easily measured using hand held pH meters and multiprobe meters. Temperature is measured using a portable thermometer. Biochemical oxygen demand on the other hand is measured by using respirometric tests. This method also employs the use of an instrument called BOD meter. A spectrophotometer is used to measure a range of variables like phosphorus, nitrates, turbidity and many others.

Biological parameters like faecal coliforms are collected by membrane filtration and incubated at 35°C for 24 hours as standard WHO procedure. After incubation, the colonies are then physically counted using naked eyes, magnifying glass, or microscope and reported as colony forming units. Faecal coliform counts are also determined by using the most probable number method.

2.5. Water Quality Assessment

Water quality assessment is the overall process of evaluating the physical, chemical and biological nature of water WHO and UNEP cited in Chapman (1996). The aim of assessing water quality is to know if it is suitable for the intended use. The conventional approach in water quality assessment involves comparison of observed physico-chemical parameters and biological parameters to predetermined water quality standards like WHO standards (Debel et al, 2005) cited in Poonam, Tanushree & Sukalyan (2013). The government of Malawi uses two water quality standards MS 214:2013 for urban and semi-urban area piped water providers, and MS 733:2005 for groundwater from borehole and shallow wells used for drinking. In assessment of drinking water quality for rural areas the latter is used. Physico-chemical parameters and biological parameters are first determined by using different tools and the results are compared to the standard values. Statistical measures like minimum, maximum, average, median, standard deviation, analysis of variance and correlation statistics just to mention a few, are used to analyse the observed results.

A more common approach in water quality assessment is the use of a water quality index (WQI). According to Wanda et al (2012), WQI is amongst the most effective

tools of assessing water quality. A general water quality index was first developed in 1978 by Brown to provide an overall quality of water using a single value (Poonam et al, 2013). Since then, scientists have modified the WQI to fit different water sources and purposes. However, globally there is no generally accepted composite index of water quality (Tyagi, Sharma, & Singh Dobhal, 2013). Researchers choose different water quality indices depending on the use of the water resources under study or purpose of the water quality index. Water quality indices can be broadly categorized into public, specific consumption indices, designing or planning indices and statistical indices. According to Poonam et al (2013) public indices ignore the use of water and provide a general water quality index while specific consumption indices account for the purpose of water like drinking, industrial and ecosystem preservation etc. Examples of public and specific consumption indices are National Sanitation Foundation Water Quality Index (NSFWQI) and Oregon indices respectively. Designing or planning indices are used for planning water management projects as the name suggests. Statistical indices use statistical approaches to evaluate data, hence they are objective. Water quality index is an example of a statistical index. The first three, use different weights for same variables depending on expert opinions making them subjective and are called expert opinion approach.

3. CHAPTER 3: METHODOLOGY

3.1. Study Area

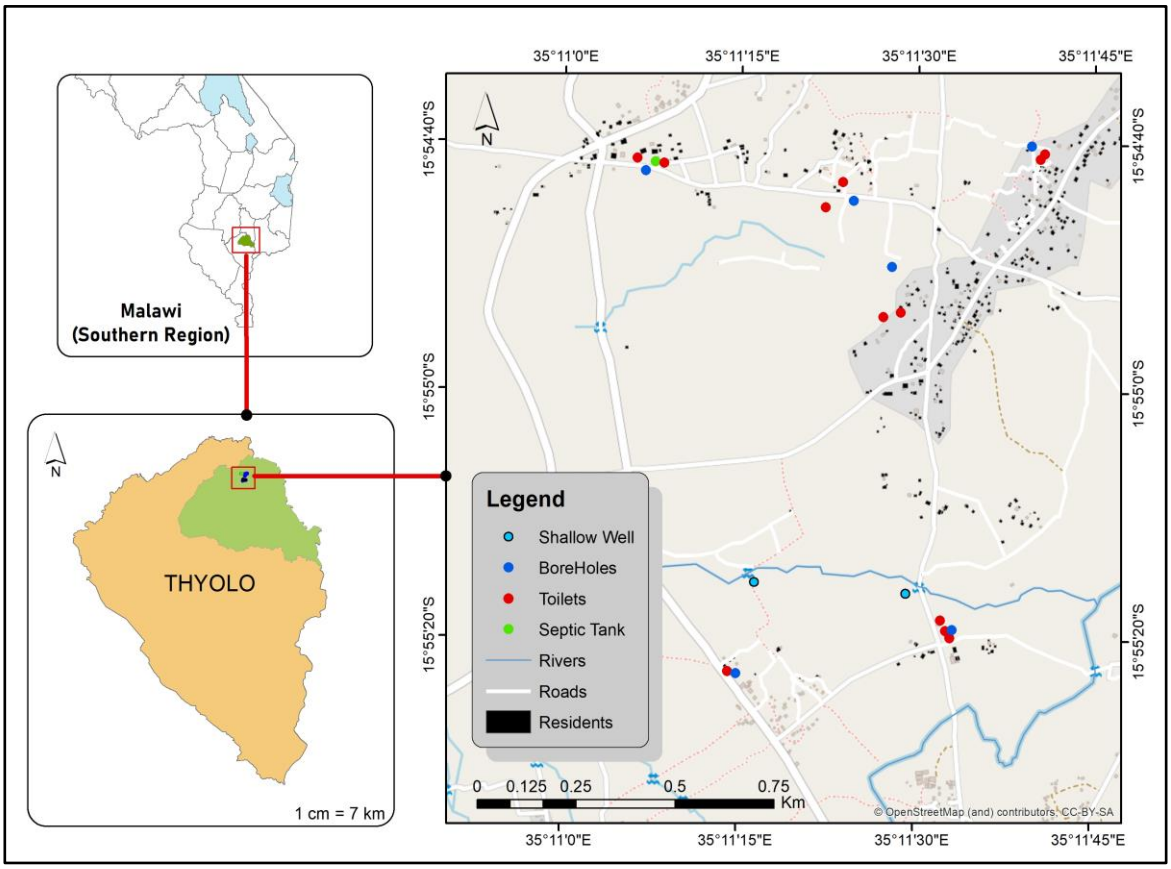


Figure 1. Map of the Study Area.

3.2. Research Design

This research involved a purposive quantitative design. Samples were collected from six water points assessed in the study area because they were main water sources for domestic use. Water quality parameters were measured both in-situ and in the laboratory as outlined in figure 2. Drinking water pH, temperature and EC were measured in-situ using handheld meters while electrical conductivity, coliforms, nitrate, chloride and total hardness were determined through laboratory methods. Depth of shallow wells and distance between water points and pit latrines were also determined.

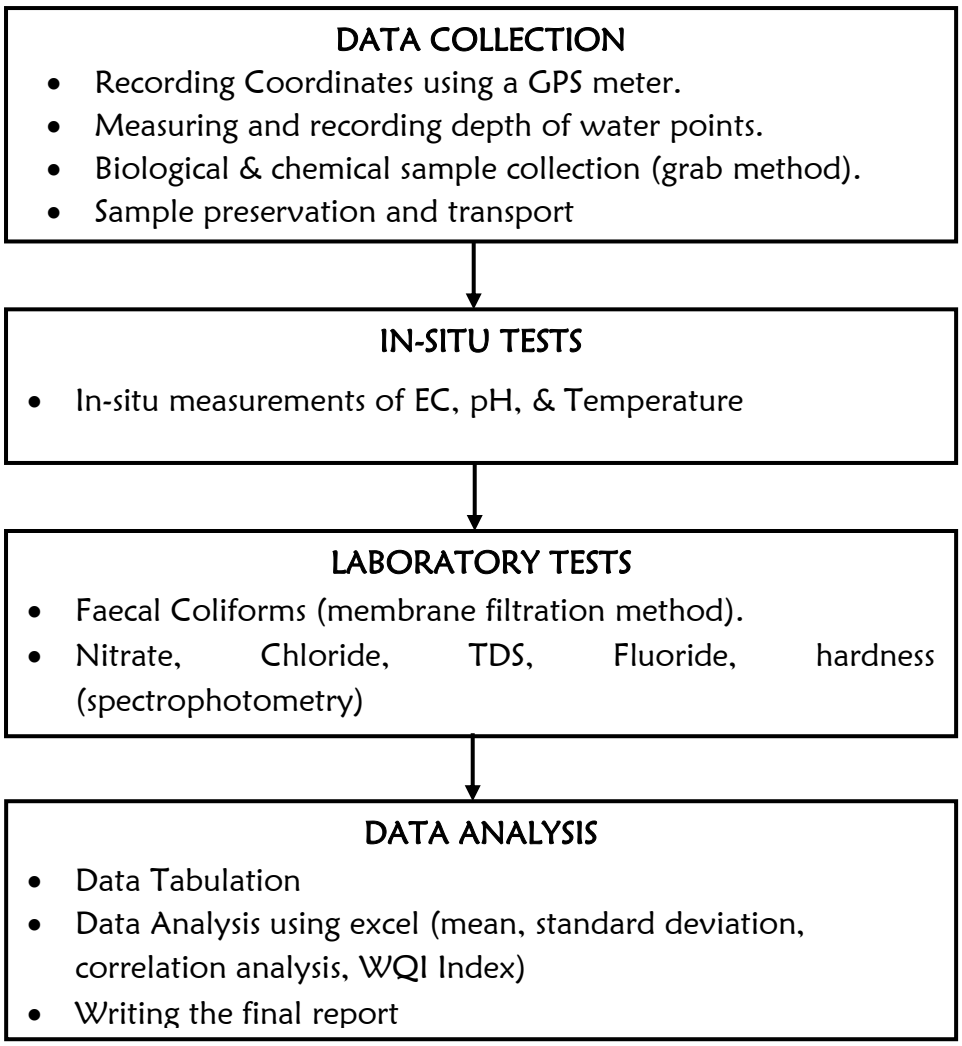


Figure 2. Flow Chart of for the Research Design.

3.3. Materials and Methods

3.3.1. Materials

The study employed different instruments such as Portable GPS meter, multi probe aquameter, hydrotest HT1000 photometer, sterile BOD bottles, markers, writing pads, torch, string, Lauryl Sulphate broth, petri plates, absorbent pads, membrane filters, 70% alcohol, wool, sodium thiosulphate, reagents.

3.4. Methods

3.4.1. Sampling

A total of seven water samples were collected from all the functional boreholes and shallow wells in the area using grab method as prescribed in ALPHA(2001). All

samples were collected in the morning before 12:00 pm to allow biological analysis to be conducted within 24 hours of collection. Since the water points were in use, they were not purged prior to sample collection. Samples for biological analysis were collected before conducting in-situ analysis of physico-chemical parameters to avoid contamination of the water samples. Biological samples were collected in sample bottles pre-treated by auto craving and addition of sodium thiosulphate to prevent the effect of residual chlorine. The samples were collected after sterilizing the sprout by flaming for 2 minutes using a burner in case of borehole water samples to avoid contamination. Soon after collection, sample bottles were covered with sterile bottle tops, labelled, entered into log sheets and then placed in a cooler box with ice packs below 4°C to avoid further biochemical reactions. The cooler box was then closed and transported to Malawi University of Science and Technology laboratory within 4 hours after collection to start biological analysis. After that in situ physico-chemical analysis of water was conducted. Samples for analysis of physical parameters were collected through grab sampling using sterile bottles as outlined by ALPHA (20).



Figure 3. Sampling Using a Weighted Bottle and Rope.

3.5. Physico-chemical and microbial Water Quality Analysis

Physical chemical parameters were measured both insitu and exsitu.

3.5.1. Determination of Temperature and EC

A pre-calibrated multi-probe meter was used to measure temperature and electrical conductivity. The probe was dipped in the sample water soon after collection and

swirled gently for 2 minutes until the readings stabilized. The readings for temperature and EC were then recorded on a log sheet together with the sample stations and sample identification numbers.

3.5.2. Determination of pH

In order to determine pH of the water samples, a handheld meter was used. The pH meter was first calibrated using distilled water and three standard buffer tablets of pH 4.0, 10. 0 and 7.0 respectively as provided by the manufacturer. The tablets were first clashed and placed in individual beakers and labelled. A volume of 10 ml distilled water was then added to each beaker following which the contents were mixed thoroughly using a stirrer. The meter was then switched on. After that the button calibrate was pressed and then it was dipped in the first solution where it stayed for about two minutes. The meter then displayed 4.0 pH as accepted. The steps were repeated for the other two buffer solutions respectively. The pH meter was then used to measure pH in the field by dipping the probe in the water samples and swirling after which pH values were recorded after they stabilized.

3.5.3. Determination of TDS

Total dissolved solids were also measured using the HydroTest photometer HT1000. The procedure was the same as in determination of hardness. The only difference was that distilled water was used as a blank sample in testing total dissolved solids. The results were recorded in the table.

3.5.4. Determination of Hardness

Total hardness was measured using a HydroTest photometer HT1000. The hardness test was selected by holding shift and entering a corresponding number for the test as presented in the AquaSafe SLS50 Pro User manual. After that the meter was in hardness test mode and prompted to prepare a zero solution. The meter was calibrated for each test. The 10ml vial bottle was rinsed with distilled water and filled with the water sample for each test as zero solution. It was then placed on the photometer chamber by aligning the mark on the bottle and the mark on the photometer. After that the enter button was selected and the meter displayed zero

accepted after a few seconds. The vial was then removed and one Hardness Test tablet was added to the vial and stirred. The vial was then realigned in the photometer chamber. Lastly, the test button was pressed and the entered button was double clicked to display results. The results were recorded in the table as mg/L CaCO3.

3.5.5. Determination of Nitrates

Determination of nitrates was conducted by firstly zeroing the photometer. A clean vial was filled with the sample water and closed. After that, the vial was set in the sample chamber by aligning the mark on the vial and the mark in the chamber. The zero key was pressed to calibrate the photometer before analysing the collected samples. The vial was removed and emptied after displaying zero accepted. About 20 ml of the water sample was then measured using a test tube and one level full teaspoon of nitrate test powder was added. The contents were then shaken for about two minutes to allow quick dilution. The mixture was left to stabilize for 2 minutes. Using a clean vial, a volume of 10 ml was taken after 2 minutes to be used for analysis. A tablet of Nitrite LR was then crashed on a paper foil and added to the 10 ml water mixture. After that the mixture was stirred and placed in the photometer chamber. Finally, the test button was pressed after which results were recorded after allowing 10 minutes for the reaction to take place. The procedure was repeated for the rest of the samples.

3.5.6. Determination of Fluoride

Fluoride was determined using the HydroTest HT1000 photometer. The photometer was calibrated using Fluoride standard solution 1 mg/L, distilled water and a water sample. Two drops of SPADNS reagent solution were added to each of the solutions, shaken and left for a minute to react. After that, calibration was done by placing the solution containing distilled water in the photometer chamber and placing zero. The meter then displayed 0.00mg/L as accepted. The vial was then replaced with a 1 mg/l fluoride standard solution and then pressed the enter button. The meter displayed 1mg/l fluoride as accepted and lastly the sample water bottle was also run for calibration to give results. After calibration fluoride was measured by taking 10ml of

the sample and mixing with 2 drops of SPADNS reagent. The vial bottled was then placed in the hydrotest photometer aligning the marks. After that, the test button was entered and results were recorded after a countdown of about 6 minutes as mg/L. The procedure was repeated for the rest of the samples without recalibrating.

3.5.7. Determination of Chloride

Chloride was determined using the HydroTest HT1000 photometer. The photometer was calibrated for Chloride detection by adding 10 ml of the sample water into a clean vial. After that the vial was covered tightly and aligned in the photometer chamber. The test button was then pressed and the vial was removed after the photometer displayed zero accepted, prepare test and press test. Chloride 1 and chloride 2 test tablets were then added to the sample water sample straight from the foil. The tablets were then crushed using a clean stirring rod. The cap was closed and the contents were swirled to speed up dissolution. The vial was then set in the chamber and the test button was pressed. The meter then counted down 2 minutes. After that the measurement started and the results were displayed in mg/L total Chloride. The procedure was repeated for the rest of the samples and the results were recorded in a table. Test setup has been displayed in appendix.

3.5.8. Determination of faecal coliforms

Faecal coliforms testing was done on a sterile station. Petri plates were prepared for incubation of samples by flaming using alcohol. Aqua Safe Membrane Lauryl sulphate broth was prepared by diluting a 7.62g pack in 100 ml of distilled water. The broth was then filled in absorbent pads using a syringe. The petri dishes were covered to avoid contamination from air and labelled. A sample diluted to 100ml using distilled water was then passed through a membrane filter to trap bacteria. After that, the filter was transferred to the prepared broth in petri dishes using a pair of sterile forceps. The procedure was repeated for the rest of the samples. The prepared samples for total coliforms and faecal coliforms were then incubated at 44°C for 18 hours. The yellow spots for faecal coliforms were lastly counted using a handheld magnifying grass and recorded in a table.

3.5.9. Determination Distance between Water Points and Pit latrines

Coordinates for the location of water points and pit latrines were recorded and saved using a GPS meter in figure 4. The results were then entered into an excel spread sheet and saved as a cvs file. The file was exported to Arch GIS where a map was generated. Lastly, distances were calculated and tabulated in excel.



Figure 4. GARMIN GPSMAP64

3.6. Quality Control

A total of two blank samples were prepared in the field using distilled water. The samples were analyzed for biological parameters to verify if there was no contamination during sample transportation and preservation. In order to minimize systematic errors all equipment were calibrated before use and the oven used for incubation of faecal coliforms was preheated.

3.7. Data Analysis

3.7.1. Descriptive and Inferential Statistics

The obtained data was tabulated in excel where descriptive statistics like minimum, median, maximum, mean and standard deviation were calculated. Graphs for mean values were also generated in excel. A correlation analysis was also conducted in excel for all the water parameters including distance between pit latrines and water points. This was done to verify the significance of results by comparing the obtained correlation with the known correlation from previous studies. It was also conducted to understand if distance between pit latrines and water points had any effect on the water quality parameters.

3.7.2. Water Quality Index

The drinking water quality index was determined as in Ram et al (2020) using excel. The water quality index was calculated as below.

$$WQI = \sum_{i=1}^{n} W_i Q_i \; / \; \sum_{i=1}^{n} w_i \quad (1)$$

Where; W_i = Unit for the *i* th parameter, Qi = quality rating sub-index of the i th parameter and n = number of parameters.

$$W_i = K/Sn \quad (2)$$

Where; W_i = unit weight for the *i* th parameter, Sn = standard value for *i* th parameters, K = proportional constant. The value of K has been considered '1' here and is calculated using the mentioned equation below;

$$K = 1/\sum(1/S_n) \quad (3)$$

Qi was then calculated as;

$$Qi = [(V_0 - V_i)/(S_n - V_i)] * 100 \quad (4)$$

where V_0 = observed value of *i* th parameter at a given sampling site, V_i = ideal value of *i* th parameter in pure water, Sn = standard permissible value of *i* th parameter.

Qi for pH was calculated as;

$$Q_{pH} = [(V_{pH} - 7.0)/(8.5-7.0)] \quad (5)$$

Qi equal to zero implies complete absence of contaminants while Qi greater than 0 less than 100 implies that, the contaminants are within acceptable limits.

Index Value	Water Quality
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very Poor
>100	Unsuitable

Table 1. Water Quality Index Classification .

4. CHAPTER 4: RESULTS AND DISCUSSION

4.1. Physico-chemical Parameters

The physico-chemical and microbial results of drinking water points in GVH Mpaso have been summarised in table 1 below. The results were compared to Malawi Standards Board and WHO standard values for borehole and shallow well water quality (MS 733: 2005).

Parameter	Temp (°C)	pH	EC (mS/cm)	TDS	Hardness (CaCO3)	NO3 (mg/L)	CL (mg/L)	F (mg/L)	FC
BH 1	24.8	6.9	509	300	204	3.04	21.7	0.08	4
BH 2	24.6	7.14	481	262	144	0.25	6.2	0.15	20
BH 3	24.7	6.88	279	105	114	2.1	10.9	0.05	320
BH 4	24.8	7.37	475	199	64	0.89	23.3	0.08	120
BH 5	24.2	7.21	862	398	312	0.87	28.3	0.09	10
SW 1	22.6	7.23	323	134	108	0.87	13.1	0.1	350
SW 2	22.9	7.02	325	200	132	2.67	14.9	0.14	400
MBS	25	6.0-9.5	3500	2000	800	45	750	6	50
WHO	25	6.5-8.5	2500	1000	500	45	600	1.5	

Table 2. Summary of Results for Measured Parameters of Boreholes and Shallow Wells Compared to MBS and WHO Standards.

4.1.1. Temperature

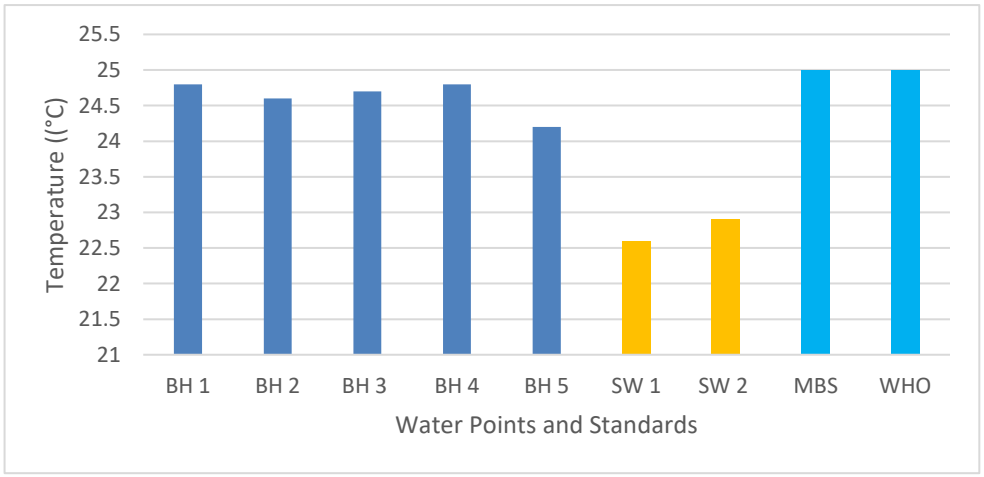


Figure 5. Temperature Variations of Water Ponits Compared to Standard Values.

The mean variations of water temperature have been shown in figure 3 above. Temperature was highest in boreholes ranging from 24.2°C to 24.8°C. Shallow wells had the least temperature values ranging from 22.6°C to 22.9°C in both SW 1 and SW 2. The recommended temperature for drinking water is 25°C as per United Kingdom standards Tebutt (1998) cited in Pritchard et al (2007). WHO and MBS have no guidelines for drinking water temperature. Increase in temperatures leads to increased microbiological activity which may lead to proliferation of bacteria. It also leads to an increase in some chemical reactions.

4.1.2. pH

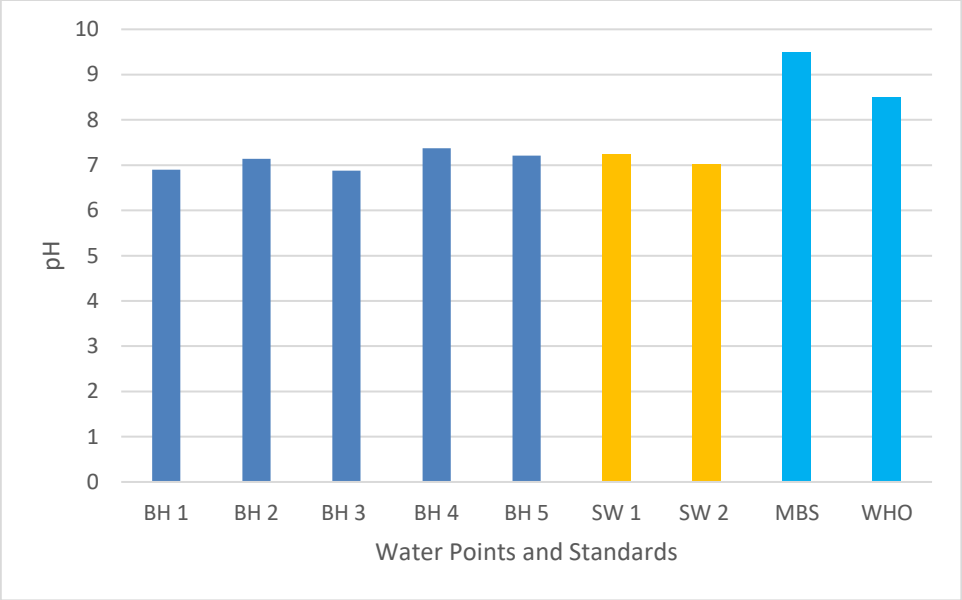


Figure 6. pH Variations of Water Points Compared to Standard Values.

In all the water points, pH of water did not vary much ranging from 6.88 to 7.37 for both shallow wells and boreholes. Borehole 1 and borehole 3 had slightly acidic water while the other boreholes had slightly alkaline water reaching a maximum of 7.37. The pH levels for all the water points were within the acceptable ranges of 6.0 – 9.5 for MBS (2005) and WHO (2008). Water pH below 6.5 is acidic and corrosive to plumbing systems (Ngumbira, 2020). Highly corrosive water increases the risk of contamination from metals in drinking water (Fisher et al, 2015).

4.1.3. Electrical Conductivity

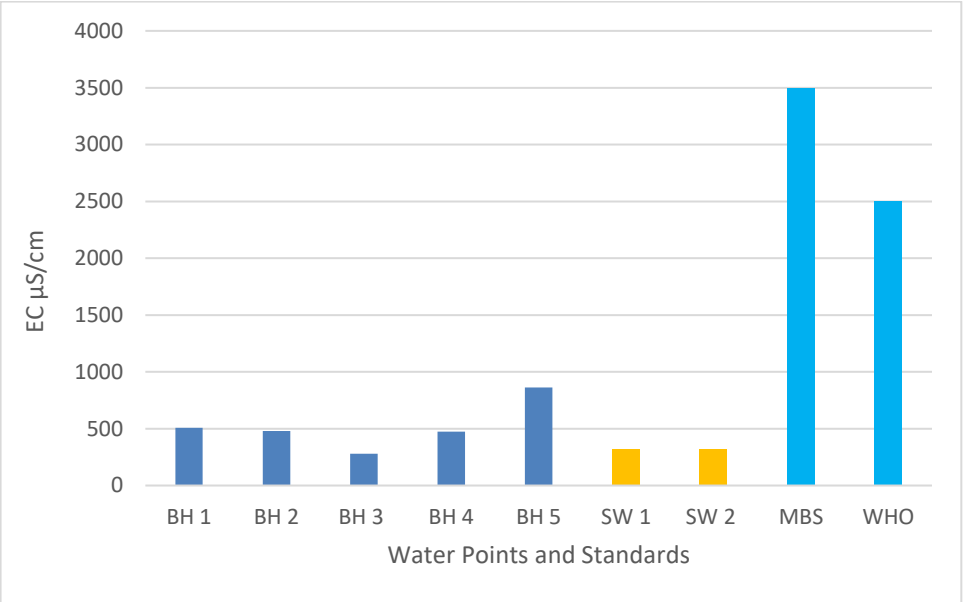


Figure 7. EC Variations of Water Points Compared to Standard Values.

The variations in EC are shown in the figure 7 above. Electrical conductivity was lowest in borehole 3 at 279 *µS*/cm followed by the two shallow wells. Borehole 1, 2 4, and 5 had higher EC values ranging from 475 *µS*/cm to 862 *µS*/cm. However, all the observed electrical conductivity values were below standard values of WHO (2008) and MBS (2005) standards. The amount of electricity conducting ions present determines the amount of EC detected in a particular water sample. It is a proxy for dissolved substances in water. According to the observed EC values, all boreholes but borehole 3 had high concentrations of dissolved substances while shallow wells had less amounts of dissolved substances. EC is a function of aquifer mineralogy, groundwater residence time and speed of groundwater flow (Dobaradaran, 2009). All these factors change with depth because soil profile changes vertically. Hence the difference in EC between boreholes and shallow wells.

4.1.4. Total Dissolved Solids

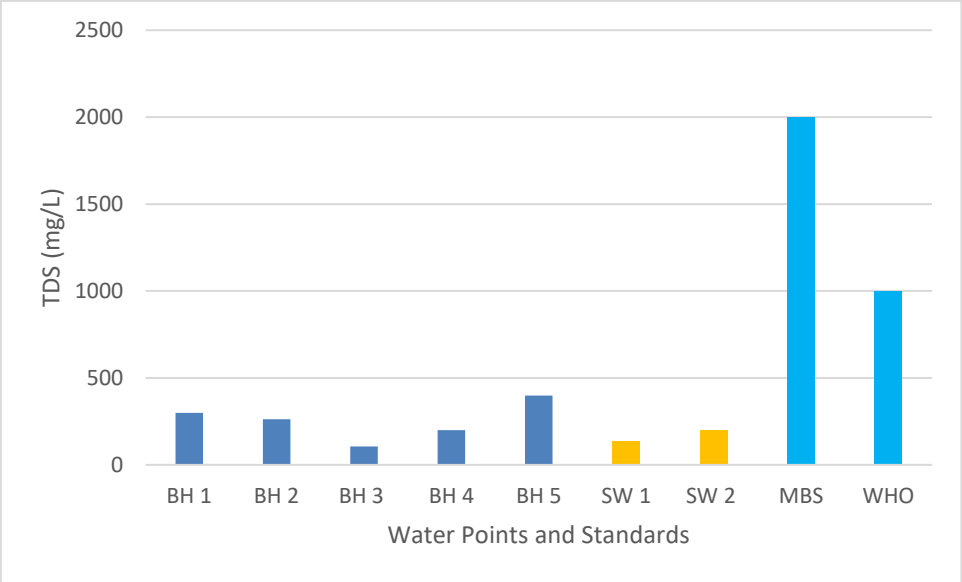


Figure 8. TDS Variations of Water points Compared to Standard Values.

The variations in TDS are shown in the figure 8 above. The highest TDS mean value for boreholes was 2000 mg/L while the lowest TDS mean value observed in shallow well (1) was 134 mg/L. TDS was highest in boreholes as compared to shallow wells except for borehole 3. TDS also increases with depth of wells because just like EC it is influenced by aquifer mineralogy, groundwater residence time and speed of groundwater flow which changes with change in soil depth (Dobaradaran, 2009). However, TDS for all the water points did not exceed the maximum permissible concentrations of 2000 mg/L and 1000 mg/L for MBS (2005) and WHO (2008) respectively. The amount of total dissolved solids influences taste of drinking water (Onweluzo & Akuagbazie, 2011). This may lead to people opting for well water which is prone to microbial contamination.

4.1.5. Total Hardness

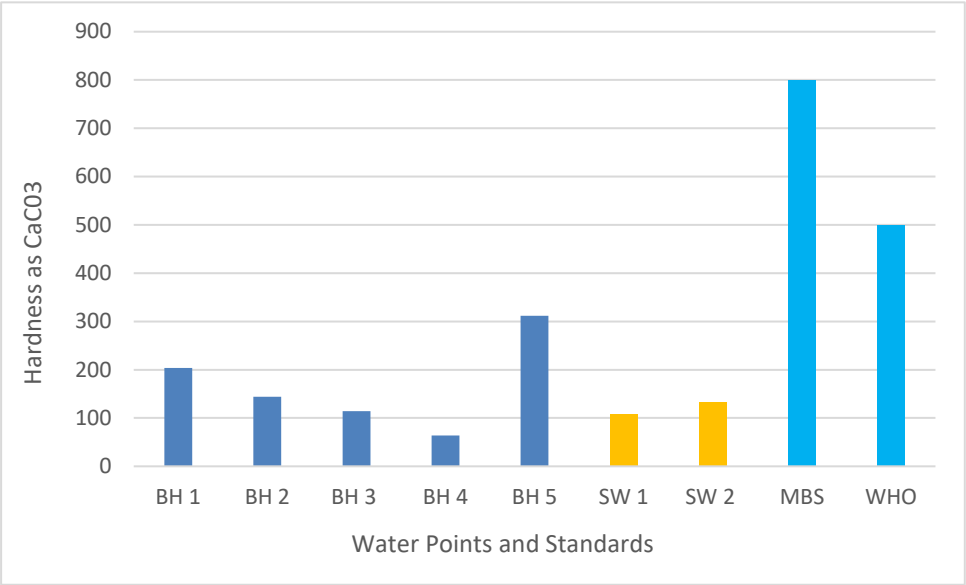


Figure 9. Total Hardness Variations of Water Points Compared to Standard Values.

The variations in hardness between water points and standard values have been shown in figure 9. Hardness values were highest in boreholes reaching a maximum of 312 mg/L as $CaCo_3$. The lowest value of hardness was observed in borehole 4 at 64 mg/L. Shallow wells had mean hardness of 108 mg/L as $CaCo_3$ for SW 1 and 132 mg/L as $CaCo_3$ for SW 2. Hardness was below the maximum permissible limit for all water points that were sampled in the area. The observed lower values of hardness agree with findings by Pritchard et al (2007), that groundwater hardness is high in the wet season than in the dry season. This is because there is less dissolution of chemicals in water. High levels of water hardness cause high soap usage and metal or soap residues on skin (WHO, 2010). This cause direct skin irritation.

4.1.6. Nitrates

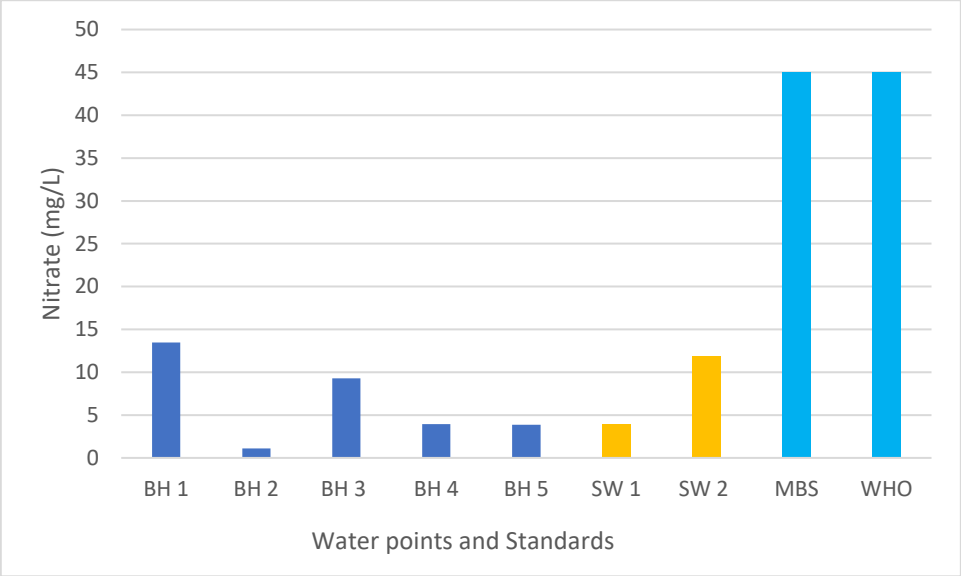


Figure 10. Nitrates Variations of Water points Compared to Standard Values.

The differences in concentration of nitrates for each borehole have been shown in the figure 10 above. The values for nitrate were minimal for borehole 2, borehole 4, borehole 5 and shallow well 1 ranging from 1.11 mg/L to 3.85 mg/L. Borehole 1 had the highest concentration of nitrates at 13.46 mg/L followed by shallow well 2 and borehole 2 at 11.82 mg/L and 9.30 mg/L respectively. However, the concentrations were still within the MBS (2005) and WHO (2008) standards. According to Egereonu and Nwachukwu (2005), nitrate is undesirable in groundwater because it causes methaemoglobin in infants less than 6 months old. The highest concentration of nitrates in BH 1 can be attributed to contamination due to its proximity to a pit latrine. Toilets that are constructed near water points increase the risk of nitrate contamination through inflow and seepage of faecal matter from the pit latrines (Cave & Kolsky, 1999).

4.1.7. Chloride

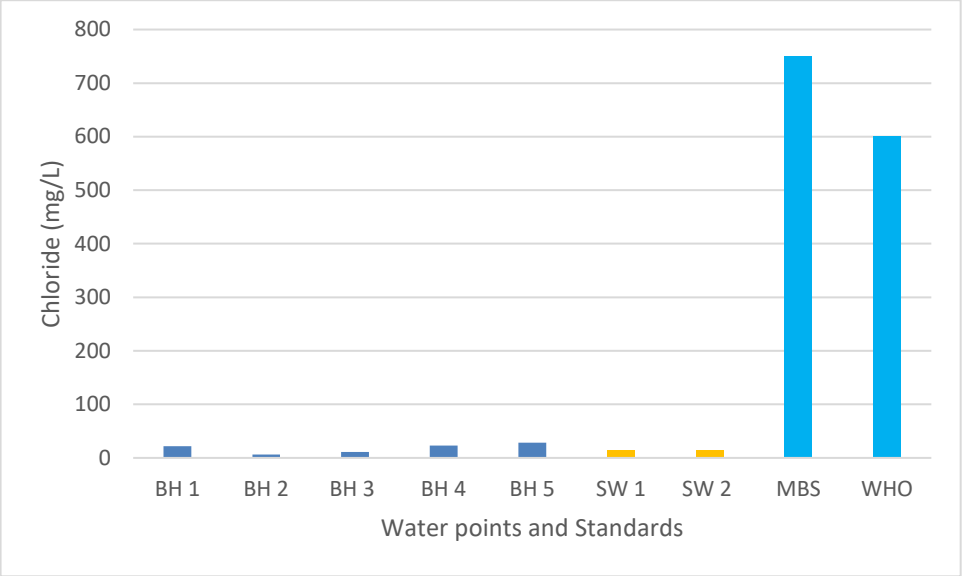


Figure 11. Chloride Variations of Water Ponits Compared to Standard Values.

The concentrations of chloride as compared to the Malawi Standards (2013) and WHO Standards (2011) have been displayed in the figure 11 above. The concentration of nitrates was highest in borehole one, four and five at 21.7mg/L, 23.3 mg/L and 28.3 mg/L respectively. Borehole two had the lowest concentration of chlorides at 6.2 mg/L. Shallow well one and two had concentrations of 13.1 mg/L and 14.9 mg/L respectively. In comparison to the standards the concentration of chloride was within acceptable limits for all water points in the area. According to Kizito (2007), exposure to light can reduce concentration of chloride leading to under reporting of the concentration. The low levels of chloride in the samples can hence be attributed to exposure to light since chemical parameters were measured last in the laboratory. Chloride affects the taste of water to a point that some people abandon boreholes producing salty water for unprotected wells. This puts people at risk of drinking contaminated water.

4.1.8. Fluoride

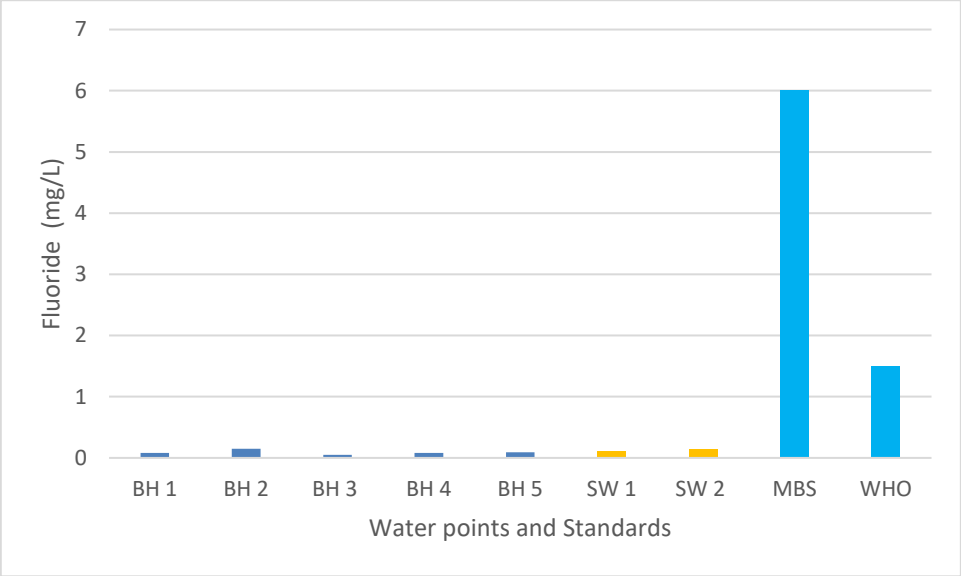


Figure 12. Fluoride Variations of Water Pointts Compared to Standard Values.

The concentration of fluoride in the different sampled points as compared to Malawi standards (2013) and WHO standards (2008) have been displayed in the figure 12 above. All the water points had less than 1 mg/L of fluoride. In a study conducted in Balaka and Chikwawa district, Pritchard et al (2007) found that fluoride concentration was high for samples collected in the wet season than those collected in the dry season. Hence low fluoride levels observed could be a result of seasonality since the samples were collected in the dry season for the present study. Fluoride is essential for teeth development in children up to 1.5 mg/L but concentrations above 1.5 mg/L can cause skeletal fluorosis (Msonda et al, 2007).

4.2. BIOLOGICAL PARAMETERS

4.2.1. Faecal Coliforms

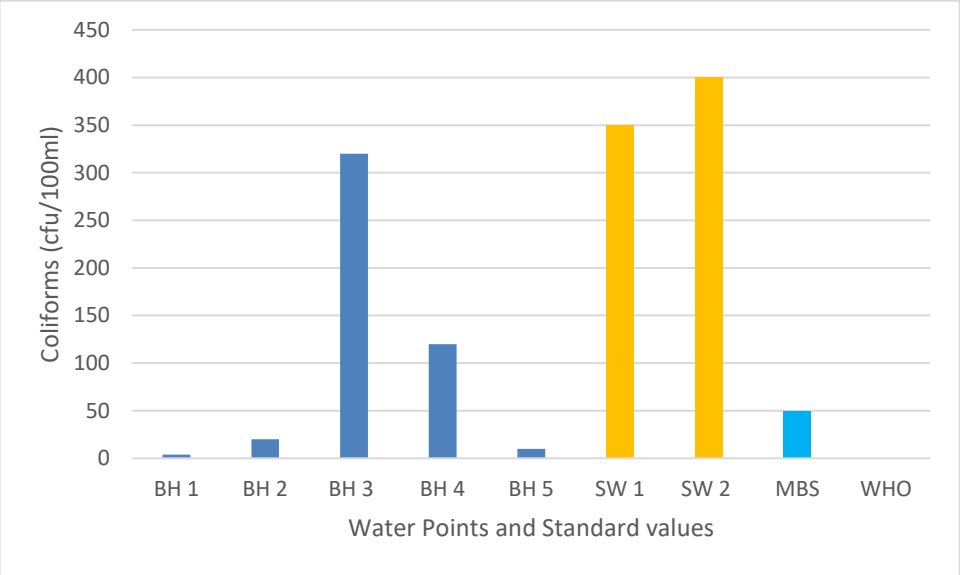


Figure 13. Feacal Coliforms Variations of Water Points Compared to Standard Values.

Faecal coliforms that were found for each point have been showed in the figure 13 above as compared to Malawi standards for untreated water (2005) and WHO standards (2008). The standard values for faecal coliforms in drinking water is zero for both Malawi standards and WHO standards. However, Malawi standards provides an allowance of 50 cfu/100ml for untreated or groundwater before it can be deemed microbiologically contaminated and unsuitable for human consumption (Pritchard et al, 2007). The counts of faecal coliforms for borehole one, two and five were within the allowable limit ranging from 4 cfu/ml to 20 cfu/ml. Elevated levels were observed in borehole three, four and all the shallow wells. Faecal coliforms were highest in shallow wells at 350 cfu /100ml and 400 cfu/ml. According to the observed results, only borehole one, two and five had water that was safe from microbiological contamination. This means that people in the area using borehole three, four, and shallow wells are at risk of faecal oral disease contraction.

4.3. Water Quality Index

Water quality indices were calculated for each of the water points in area. The results have presented in the table 3 below.

Water Point	Water Quality Index Value	Water Quality Status
BH 1	4.78	Excellent
BH2	5.98	Excellent
BH 3	51.42	Poor
BH 4	21.41	Excellent
BH 5	5.65	Excellent
SW 1	52.47	Poor
SW 2	55.08	Poor

Table 3. Calculated Water Quality Indices for the Study Area.

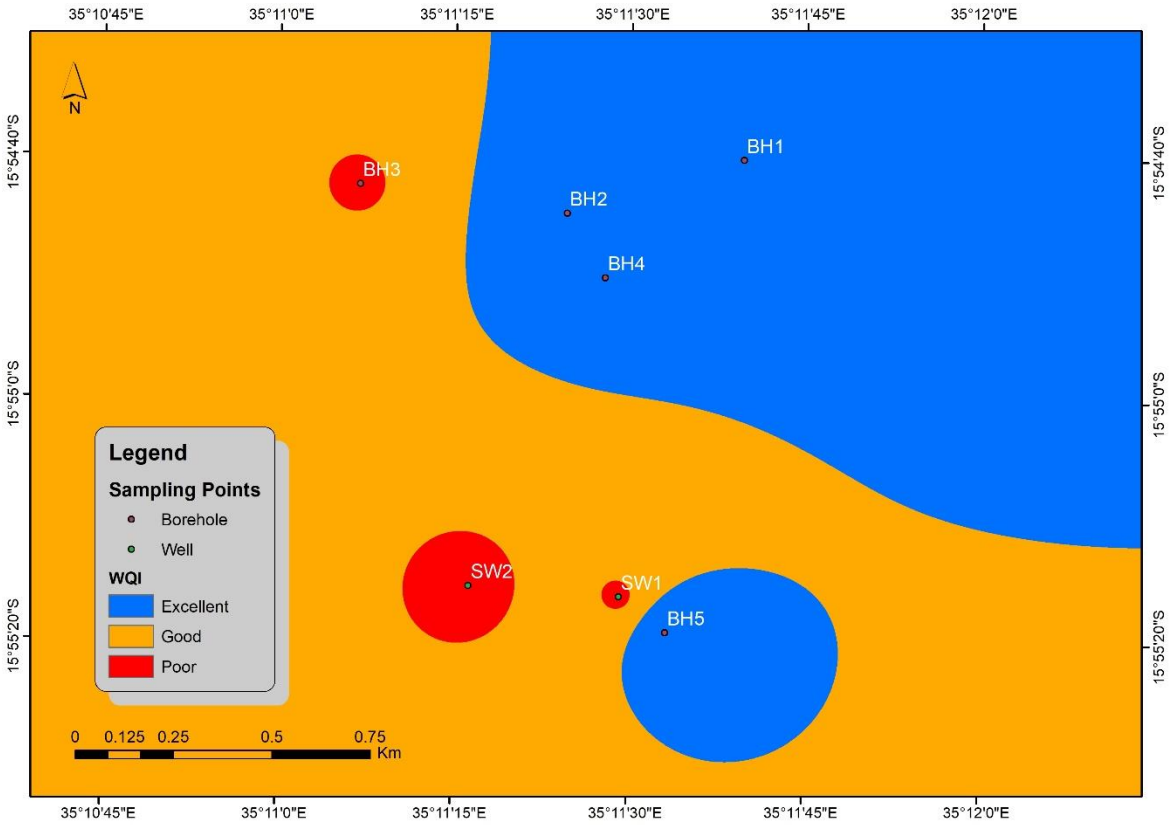


Figure 14. Spatial Distribution of Water Quality Index for the Study Area.

The use of a water quality index helps to aid the understanding of water quality data using a single value. The parameters used in this study were selected due to their association with contamination from on-site sanitation systems. In this study the calculated values for water quality index show that borehole 1, borehole 2, borehole 4 and borehole 5 had excellent water quality. This means that the water from these boreholes can be used for drinking purposes without any further treatment. However, borehole 3 and shallow well 1 and 2 had poor water quality. Water from these points require treatment before use. The poor water quality can be attributed

to lack of sanitary covers for the wells. Even, though four boreholes show that the water quality was excellent, this may be because the study was conducted in the dry season. According to Muzenda et al (2019) temporal variability exists in water quality index due to changes in rainfall patterns. The spatial distribution of water quality has been presented in the figure 12.

4.4. Correlation Analysis

	Temp	*pH*	*EC (mS/cm)*	*TDS*	*HARDNESS (CaCO3)*	*NO3 (mg/L)*	*CL (mg/L)*	*Fluoride (mg/L)*	*FC*	*Distance*
Temp	1									
pH	-0.1469	1								
EC (mS/cm)	0.31884	0.33379	1							
TDS	0.29078	0.13575	0.93035	1						
HARDNESS (CaCO3)	0.11804	-0.1434	0.83735	0.86489	1					
NO3 (mg/L)	-0.0222	-0.7751	-0.31191	-0.1062	0.046208	1				
CL (mg/L)	0.18561	0.30433	0.71207	0.61413	0.53399	0.12323	1			
Fluoride (mg/	-0.4128	0.1915	-0.01317	0.19555	-0.00926	-0.2554	-0.39611	1		
FC	-0.7039	-0.1676	-0.76396	-0.796	-0.5452	0.27349	-0.41168	0.00452	1	
Distance	-0.6398	0.15526	-0.47515	-0.36607	-0.48138	0.22055	-0.15605	0.50464	0.65690	1

Table 4. Correlation Matrix for Water Parameters and Distance.

Pearson's correlation shows the degree of association between variables. A positive correlation exists when an increase in one parameter causes an increase in another parameter and a negative correlation exists when an increase in one parameter causes a decrease in the other parameter (Shroff, et al., 2015). Correlation is represented by a value from -1 to +1. A strong positive correlation has an r value close to 1 while a strong negative correlation has a r value of -1. Table 4 shows the calculated correlation matrix. There was a strong correlation between EC and TDS with an r value of 0.93035. TDS measures concentration of inorganic salts and small amounts of organic substances in water while EC measures the ability of water to conduct electric current. Hence, they are positively correlated. Both TDS and EC indicate possibility of water salinity which affects palatability of water (Rusydi, 2018). There was also a strong correlation between water hardness and TDS. Water hardness is

the measure of divalent cations dissolved in water, therefore related to total dissolved solids. The most common ions are calcium and magnesium. According to the results, problems of water hardness are likely to manifest in the area especially during the rainy season.

4.5. Distance Between Pit latrines and Water Points.

Water Point	Average Distance to Pit latrine (meters)
BH 1	38.9
BH 2	63.1
BH 3	44.1
BH 4	121.5
BH 5	29.6
SW 1	107.4
SW2	231.2

Table 5. Average Distance to Pit latrines.

The average distances between pit latrines and water points have been shown in table 4. The prescribed distance between pit latrines and boreholes for Malawi is 100m and 30m for shallow wells (GoM, 2014). This reduces risk of chemical and microbial contamination. According to the calculated distance between boreholes and pit latrines, only one borehole 4 had a recommended distance from a pit latrine at 121.5 metres. The rest of the boreholes had distances below 100 metres from pit latrines. The results suggest that pit latrines are possible sources of contamination in the study area. However, there is a positive correlation suggesting that there were other contamination sources in the area because a decrease in distance did not cause significant changes in faecal coliform levels. A study conducted in Phalombe also found that microbial contamination was not only from pit latrines (Back et al, 2014). The results contradicted with a previous study by Muruka et al (2012) where there was a strong negative correlation between faecal coliforms. According to Kim et al (2015) Pearson's r coefficient is very sensitive to outliers. In the present study shallow wells had very high values of faecal coliforms. This could be because they were not covered and were very shallow rendering them vulnerable to contamination.

However, both the wells were located near a stream and away from toilets. These values can be categorised as outliers when comparing distance and faecal coliforms. Hence the contradiction with the previous study.

Unlike boreholes, all shallow wells were located at appropriate distances. The results are supported by excellent water quality at borehole 4 as depicted by the water quality index. Figure 14 shows recommended buffer zones for water points according to Malawi government standards and location of pit latrines.

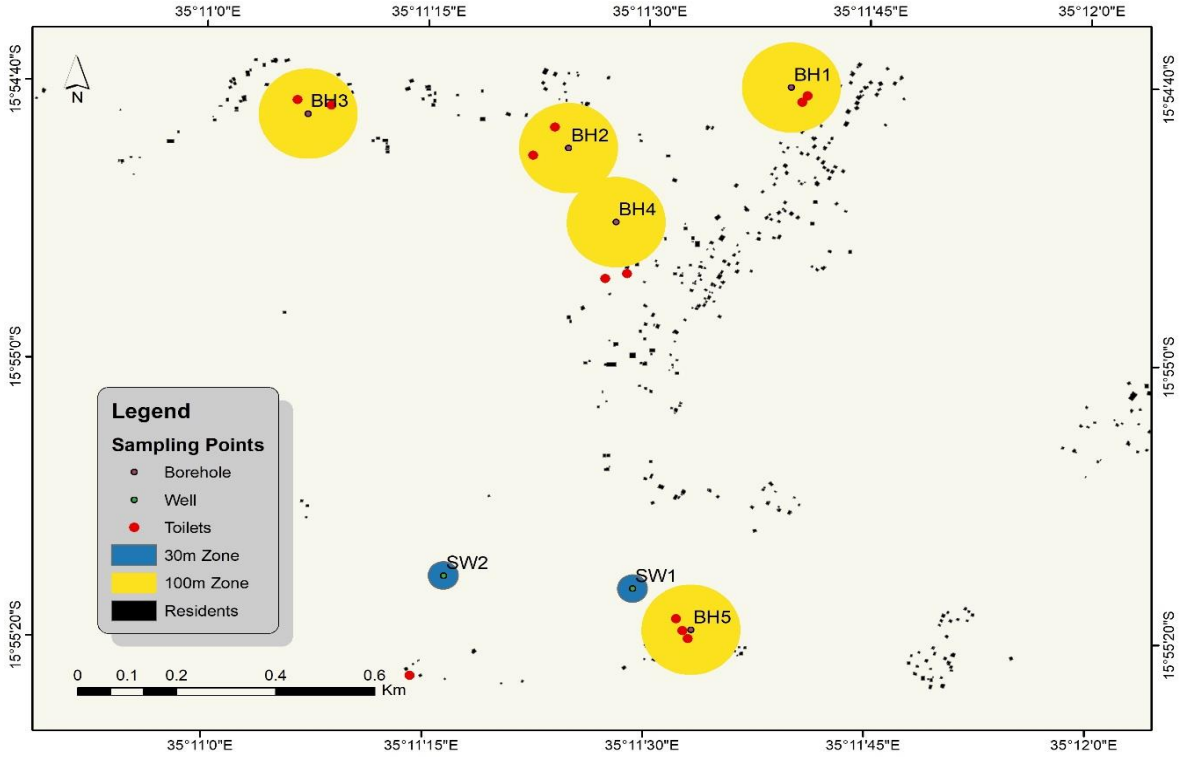


Figure 15. Location of Pit Latrines in Relation to Recommended Buffer Zones.

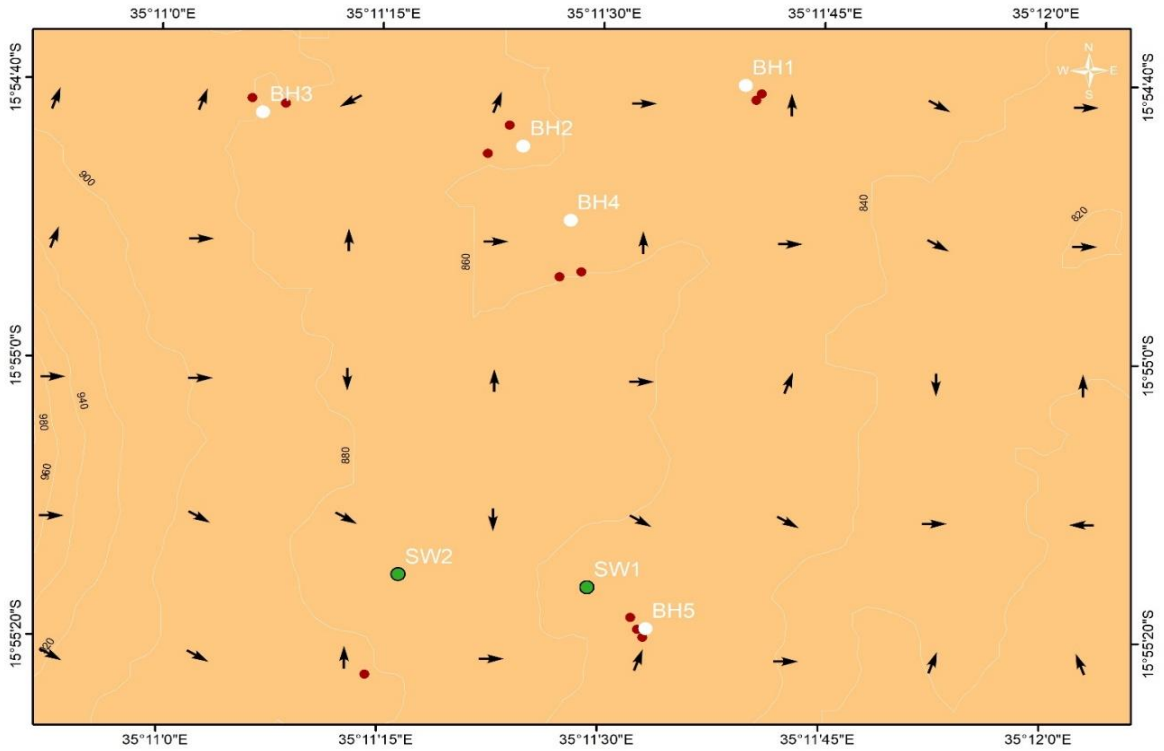


Figure 16. Groundwater Flow for the Study Area.

An understanding of groundwater flow in groundwater quality studies helps to understand the movement of contaminants in the subsurface. The area for Mpaso is mountainous hence almost all the water points and pit latrines were located on slopes. This means that there is possible contamination of groundwater sources from pit latrines in the area. Figure 14 shows groundwater flow between pit latrines in red and water points. The map shows possibility of groundwater between water points and pit latrines.

5. CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

Boreholes and wells are main sources of water in Mpasu. Hence it is very important to understand the quality of water that people are consuming. The study shows that some parts of Group Village Head Mpasu consume good water while some parts use water contaminated with faeces. The results show that only 57% of the water points provide good water in the area. The results have also exposed that people in the area carelessly locate their pit latrines which may be the cause of elevated levels of coliforms in some boreholes and shallow wells. This information will help stakeholders initiate proper interventions to deal with the practice which increases risk of waterborne diseases.

5.2. Recommendations

Based on the study results, some people consume water that is contaminated from feacal matter in Mpaso. The following recommendations have been made in light of the observations made;

i. Due to elevated levels of feacal coliforms in drinking water, there is need for health workers (HSAs) to pay attention to water related diseases in the area to avoid outbreaks of water borne diseases.
ii. Community members should be encouraged to treat water before consumption.
iii. There is need to monitor water quality in the study area during the rainy season as contamination may be worse than in the dry season.
iv. The community should be sensitized on the importance of appropriate location of pit latrines since only one borehole complied with the Malawi standards.

6.

7. REFERENCES

APHA, AWWA, & WEF. (2001). Standard Methods for the Examination of Water and Wastewater (20th ed.).

Ashraf, M. A., Maah, M. J., Yusoff, I., & Wajid, A. (2011). Sand mining effects , causes and concerns : A case study from Bestari Jaya , Selangor , Peninsular Malaysia. 6(6), 1216–1231. https://doi.org/10.5897/SRE10.690

Ayantobo, O. O., Oluwasanya, G. O., Idowu, O. A., & Eruola, O. A. (2012). Water quality evaluation of hand-dug wells in Ibadan, Oyo State, Nigeria. *Special Publication of the Nigerian Association of Hydrological Sciences*, 231-239.

Back, J. O., Rivett, M. O., Hinz, L. B., Mackay, N., Wanangwa, G. J., Phiri, O. L., Songola, C. E., Thomas, M. A. S., Kumwenda, S., Nhlema, M., Miller, A. V. M., & Kalin, R. M. (2018). Risk assessment to groundwater of pit latrine rural sanitation policy in developing country settings. *Science of the Total Environment*, *613–614*, 592–610. https://doi.org/10.1016/j.scitotenv.2017.09.071

Bartosh, C. D. (2012). Integrating land survey data into measurement-based GIS: An assessment of chalenges and practical solutions for sureyors in Texas. August.

Bartram, J., & Ballance, R. (1996). Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes (J. Bartram & R. Ballance (eds.)).

Boakye, R. (2012). IMPACTS OF WASTE ON URBAN SURFACE WATER RESOURCES: CASE STUDY OF ABOABO STREAM , KUMASI , GHANA .

Bonsor, H., MacDonald, A., Casey, V., Carter, R., & Wilson, P. (2018). The need for a standard approach to assessing the functionality of rural community water supplies. *Hydrogeology Journal*, *26*(2), 367–370. https://doi.org/10.1007/s10040-017-1711-0

Brain, R., Lynch, J., & Kopp, K. (2015). Greywater Systems. Utah State University: Extension Sustainability, January, 1–5.

British Geological Survey. (2002). Assessing Risk to Groundwater from On-site Sanitation: Scientific Review & Case Studies. Keyworth, UK: BGS. DOI:http://r4d.dfid.gov.uk/pdf/outputs/r68692.pdf

Cammack, D. (2012). Peri-urban governance and the delivery of public goods in Malawi, 2009-11. Africa Power and Politics, January, 63.

Cave, B., & Kolsky, P. (1999). *Groundwater, Latrines and Health*. *163*, 30. http://www.lboro.ac.uk/orgs/well/resources/well-studies/full-reports-pdf/task0163.pdf

Cervantes-godoy, D. (2014). Economic Importance of Agriculture for Sustainable Development and Poverty Reduction : Findings from a Case Study of Indonesia. November 2010.

Chapman, D. (1996). Water Quality Assessments - A Guide to Use of Biota , Sediments and Water in Environmental Monitoring (D. Chapman (ed.); 2nd ed.). E&FN Spon, an imprint of Chapman & Hall.

Chimphamba, J. B., & Phiri, O. L. (2014). Borehole Water Pollution and its Implication on health on the Rural Communities of Malawi. *Malawi Journal of Science and Technology*, *10*(1), 32–39. https://www.ajol.info/index.php/mjst/article/view/105867

Clark, I. (2015). Sampling and Analysis. Groundwater Geochemistry and Isotopes, 399–420. https://doi.org/10.1201/b18347-12

Dickens, C., & Graham, P. M. (2002). The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. January 2016. https://doi.org/10.2989/16085914.2002.9626569

District Health Information Software 2.

Dobaradaran, S., Bina, B., Persian, T., Marine, G., Services, H., & Hatamzadeh, M. (2009). The Effect of Well Depth on Water Quality in Neiboring Zone of Zayandehroud. *World Appl. Sc. J. 5, 80-83, 2009,*

Dzwairo, B., Hoko, Z., Love, D., & Guzha, E. (2006). Assessment of the Impacts of Pit Latrines on Groundwater Quality in Rural Areas: A Case Study From

Marondera District, Zimbabwe. *Physics and Chemistry of the Earth, Parts* A/B/C, 31(15-16), 779-788.

Edmunds, W. M., & Smedley, P. L. (2013). Fluoride in Natural Waters. In O. Selinus (Ed.), *Essentials of Medical Geology: Revised Edition* (pp. 311–336). Springer Netherlands. https://doi.org/10.1007/978-94-007-4375-5_13

Egereonu UU, Nwachukwu UL (2005) Evaluation of the surface & groundwater resources of Efuru River Catchment, Mbano, South Eastern. Nigeria J Assoc Adv Model Simulat Tech Enterpr 66:53–71

Fisher, M. B., Williams, A. R., Jalloh, M. F., Saquee, G., Bain, R. E. S., & Bartram, J. K.(2015). Microbiological and Chemical Quality of Packaged Sachet Water and Household Stored Drinking Water in Freetown, Sierra Leone. *PLOS ONE*, *10*(7), e0131772. https://doi.org/10.1371/journal.pone.0131772

Gharibi, H., Mahvi, A. H., Nabizadeh, T., Arabalibeik, H., Yunesian, M., & Sowlat, M. H. (2012). A Novel Approach in Water Quality Assessment Based on Fuzzy Logic. *Journal of Environmental Management*. 112, 87-95, Retrieved from: http://dx.doi.org/10.1016/j.jenvman.2012.07.007

Government of Malawi. (2014). Indicators Concepts & Definitions for Irrigation, Water & Sanitation. Lilongwe.

Govorushko, S. (2007). Effect of human activity on Rivers. 21(2), 40–47.

Grimason, A. M., Beattie, T. K., Morse, T. D., Masangwi, S. J., Jabu, G. C., Taulo, S. C., & Lungu, K. K. (2013). Classification and quality of groundwater supplies in the Lower Shire Valley, Malawi - Part 2: Classification of borehole water supplies in Chikhwawa, Malawi. *Water SA*, *39*(4), 573–582. https://doi.org/10.4314/wsa.v39i4.17

Grimason, A. M., Morse, T. D., Beattie, T. K., Masangwi, S. J., Jabu, G. C., Taulo, S. C., & Lungu, K. K. (2013). Classification & Quality of Groundwater Supplies in the Lower Shire Valley, Malawi –Part 1: Physico-Chemical Quality of Borehole Water Supplies in Chikhwawa, Malawi.39, 4, July 2013. DOI: http://dx.doi.org/10.4314/wsa.v39i4.16

Habgood, F., Holt, D. N., & Walshaw, R. D. (1973). The geology of the Thyolo Area (No. 22). Government Printer.

Hadeed, L., & Thomson, B. (2006). Free-Flowing Rivers: Economic Luxury or Ecological Necessity? Wwf, 1–41.

Hamid, A., Bhat, S. A., Bhat, U., & Jehangir, A. (2016). Environmetric techniques in water quality assessment and monitoring: a case study. Environmental Earth Sciences, February. https://doi.org/10.1007/s12665-015-5139-3

Heywood, I., Carver, S., & Cornelius, S. (2006). AN INTRODUCTION TO GEOGRAPHICAL INFORMATION SYSTEMS (3rd ed.).

Ho, Y. C., Show, K. Y., Guo, X. X., & Norli, I. (2012). Industrial Discharge and Their Effect to the Environment.

JICA. (2020). Sector position paper: Water Sector. May.

Kamba, F., Sangija, F., & Wei, S. (2016). Impact of water pollution on human health in the Central African Republic. Advances in Social Sciences Research Journal, 3(1). https://doi.org/10.14738/assrj.31.1764

Kanu, I., & Achi, O. (2011). INDUSTRIAL EFFLUENTS AND THEIR IMPACT ON WATER QUALITY OF RECEIVING RIVERS IN NIGERIA. January.

Kaonga, C. C., Kambala, C., Mwendera, C., & Mkandawire, T. (2013). Water Quality Assessment in Bangwe Township, Blantyre City, Malawi. *African Journal of Environmental Science & Technology*, 7(5), 259-266. Retrieved from: https://doi.org/10.5897/AJEST12.196

Kefford, B., Papas, P., Crowther, D., & Nugegoda, D. (2002). Are salts toxicants. January.

Khan, R., & Jhariya, D. C. (2017). Groundwater quality assessment for drinking purpose in Raipur city, Chhattisgarh using water quality index and geographic information system. *Journal of the Geological Society of India*, *90*(1), 69–76. https://doi.org/10.1007/s12594-017-0665-0

Kim, Y., Kim, T. H., & Ergün, T. (2015). The instability of the Pearson correlation coefficient in the presence of coincidental outliers. *Finance Research Letters*, *13*, 243-257.

Kuyeli, S. M., Fabiano, E., & Sajidu, S. M. (2009). TEMPORAL AND SPATIAL PHYSICOCHEMICAL WATER QUALITY. 9(1), 5–10.

Lao-Swedish Forestry Program. (1997). Land Survey Methods and Training in Participatory Land Use Planning and Land Allocation. 1–30.

Lapworth, D. J., MacDonald, A. M., Kebede, S., Owor, M., Chavula, G., Fallas, H., Wilson, P., Ward, J. S. T., Lark, M., Okullo, J., Mwathunga, E., Banda, S., Gwengweya, G., Nedaw, D., Jumbo, S., Banks, E., Cook, P., & Casey, V. (2020). Drinking Water Quality from Rural Handpump-boreholes in Africa. *Environmental research letters.* 15, (2020) 064020. Retrieved from: https://doi.org/10.1088/1748-9326/ab8031

Li, P., & Wu, J. (2019). Drinking Water Quality and Public Health. *Exposure and Health*, *11*(2), 73–79. https://doi.org/10.1007/s12403-019-00299-8

Lutterodt, G., Vossenberg, J. Van De, Hoiting, Y., Kamara, A. K., Oduro-kwarteng, S., & Foppen, J. W. A. (n.d.). *Microbial Groundwater Quality Status of Hand-Dug Wells and Boreholes in the Dodowa Area of Ghana*. 1–12. https://doi.org/10.3390/ijerph15040730

Macdonald, A. M. & Davies, J. (2000). A Brief Review of Groundwater For Rural Water Supply in Sub-Saharan Africa. Technical Report WC/00/33. Overseas Geology Series. British Geology Survey and Department for International Development, Nottingham.

Masese, F. O., Raburu, P. O., Mwasi, B. N., & Etiégni, L. (2014). Effects of Deforestation on Water Resources : Integrating Effects of Deforestation on Water Resources : Integrating Science and Community Perspectives in the Sondu-Miriu River Basin , Kenya. November. https://doi.org/10.5772/34373

Matsimbe, J. (2020). Comparative Study of Water Quality from Boreholes & Hand-Dug Wells: Case of Namatapa in Bangwe Township. In: *Engineering a& Technology Quarterly Reviews*, 3, 2, 67-73. Retrieved from: https://www.asianinstituteofresearch.org/

Meng, J., Klauschen, A., Antonelli, F., & Thieme, M. (2011). RIVERS FOR LIFE: The Case for Conservation Priorities in the Face of Water Infrastructure Development.

Mensah, P. K., Palmer, C. G., & Odume, O. N. (2015). Ecotoxicology of Glyphosate and Glyphosate-Based Herbicides — Toxicity to Wildlife and Humans. Toxicity and Hazard of Agrochemicals, July. https://doi.org/10.5772/60767

Mirzaei, M., Solgi, E., & Salman-mahiny, A. (2016). Evaluation of Surface Water Quality by NSFWQI Index and Pollution Risk Assessment , Using WRASTIC Index in 2015. July.

Mkwate, R. C., Chidya, R. C. G., & Wanda, E. M. M. (2017). Assessment of drinking water quality and rural household water treatment in Balaka District, Malawi. *Physics and Chemistry of the Earth*, *100*, 353–362. https://doi.org/10.1016/j.pce.2016.10.006

Mooney, H. A. (2005). Millenium Ecosystem Assessment Synthesis Report (Issue March).

Mtewa, T. K., Chauluka, F., Mtewa, A., Banda, L., & Kalindekafe, L. (2018). Water Quality Assessment of Various Sources in Peri-urban areas of Malawi: A case of Bangwe township in Blantyre. *African Journal of Environmental Science & Technology*, 12(11), pp. 421-428. Retrieved from: https://doi.org/10.5897/AJEST2018.2542

Mumba, P., Moyo, B. H., & Kadewa, W. (2005). Assessment of the Impact of Industrial Effluents on Water Quality of Receiving Rivers in Urban Areas of Malawi. September. https://doi.org/10.1007/BF03325882

Munga, D., Kitheka, J. U., Mwaguni, S. M., Massa, H. S., Mwashote, B. M., Mwangi, S., Ong'anda, H., Muthuka, M. M., Mdoe, F., Chidagaya, S. J., & Opello, G. (2004). Pollution & Vulnerability of Water Supply Aquifers in Mombasa Kenya: Interim Progress Report. Kenya Marine Fisheries and Research Institute. Retrieved from: http://hdl.handle.net/1834/6972

Muruka, C., Adeniyi Fagbamigbe, F., Muruka, A., Njuguna, J., Odhiambo Otieno, D., Onyando, J., Saidi Wanjiku, Z., & Onyango, Z. (2012). The Relationship between Bacteriological Quality of Dug-Wells & Pit Latrine Siting in an Unplanned Peri-Urban Settlement: A Case Study of Langas – Eldoret

Municipality, Western Kenya. *Public Health Research*, *2*(2), 32–36. https://doi.org/10.5923/j.phr.20120202.06

Muzenda, F., Masocha, M., & Misi, S. N. (2019). Groundwater Quality Assessment Using a Water Quality Index and GIS: A Case of Ushewokunze Settlement, Harare, Zimbabwe. *Physics and Chemistry of the Earth*. https://doi.org/10.1016/j.pce.2019.02.011

Napacho, A. Z., & Manyele, V. S. (2010). Quality Assessment of Drinking Water in Temeke District (part II): Characterization of Chemical Parameters. *African Journal of Environmental Science & Technology*. 4(11), pp. 775-789, November 2010. Retrieved from: http://www.academicjournals.org/AJEST

National Statistical O¨ce-NSO/Malawi., & ICF. (2017). Malawi Demographic & Health Survey 2015-16. NSO & ICF, Zomba, Malawi. Retrieved from: https://dhsprogram.com/publications/publication-fr319-dhs-nal-reports.cfm

National Statistical Office. (2019). 2018 Malawi Population & Housing Census Main Report. Retrieved from: http://www.nsomalawi.mw/index.php?option=com_content&view=article&id=226:2018-malawi-population-and-housing-census&catid=8:reports&Itemid=6

NGUMBIRA, K. S. (2020). *An analysis of the physico-chemical and microbial quality of sachet water in Lilongwe, Malawi: Implication on public health and WASH policies* (Master's thesis, PAUWES).

Nikaeen, M., Pejhan, A., & Jalali, M. (2009). Rapid Monitoring of Indicator Coliforms in Drinking Water by an Enzymatic Assay. Iran. *Journal of Environmental Health Science English.* 6(1):7-10

Obarska-pempkowiak, H., Gajewska, M., Wojciechowska, E., & Pempkowiak, J. (2015). Domestic wastewater treatment. In GeoPlanet: Earth and Planetary Sciences (Vol. 23, Issue January). https://doi.org/10.1007/978-3-319-13794-0_4

Odume, O. N. (2017). Ecosystem Approach to Managing Water Quality. Water Quality, January. https://doi.org/10.5772/65707

Olabode, A. D., & Lawrence, A. (2014). ENVIRONMENTAL IMPACT OF INDISCRIMINATE WASTE DISPOSAL ON RIVER CHANNEL IN PART OF AKOKO-REGION , ONDO STATE , NIGERIA. 5(2), 162–168.

Onweluzo, J., & Akuagbazie, C. (2011). Assessment of the quality of bottled and sachet water sold in Nsukka town. *Agro-Science*, *9*(2), 104–110. https://doi.org/10.4314/as.v9i2.64804

Palmer, T., Berold, R., & Muller, N. (2004). Environmental Water Quality in Water Resources Management.

Peters, N. E., Meybeck, M., & Chapman, D. (2006). Effects of Human Activities on Water Quality. April. https://doi.org/10.1002/0470848944.hsa096

Poonam, T., Tanushree, B., & Sukalyan, C. (2013). Water Quality Indices-Important Tools for Water Quality Assessment:A Review. *International Journal of Advances in Chemistry*, 1, 1, November 2013.

Postolache, O., Girão, P. S., & Pereira, J. M. D. (2012). WATER QUALITY MONITORING AND ASSESSMENT: Water Quality Monitoring and Associated Distributed Measurement Systems (K. Voudouris & D. Voutsa (eds.)). InTech.

Pritchard, M., Mkandawire, T., & O'Neill, G. J. (2007). Biological, Chemical & Physical Drinking Water Quality from Shallow Wells in Malawi: Case Study of Blantyre, Chiradzulu & Mulanje. *Physics & Chemistry of the Earth*, *32*, 1167–1177. Retrieved from: https://doi.org/10.1016/j.pce.2007.07.013

Pritchard, M., Mkandawire, T., & O'Neill, J. G. (2008). Assessment of groundwater quality in shallow wells within the southern districts of Malawi. *Physics and Chemistry of the Earth*, *33*(8–13), 812–823. https://doi.org/10.1016/j.pce.2008.06.036

Pullanikkatil, D., Palamuleni, L. G., & Ruhiiga, T. M. (2015). Impact of land use on water quality in the Likangala catchment, southern Malawi. African Journal of Aquatic Science, 40(3), 277–286. https://doi.org/10.2989/16085914.2015.1077777

Rizal, P., & Syah, I. (2018). Land Use and River Degradation Impact of Sand and Gravel Mining. 09034, 2–5.

Rusydi, A. F. (2018). Correlation between conductivity and total dissolved solid in various types of water: A review. *IOP Conference Series: Earth and Environmental Science*, *118*, 012019. https://doi.org/10.1088/1755-1315/118/1/012019

Scheili A, Delpla I, Sadiq R, Rodriguez MJ (2016b) Impact of raw water quality and climate factors on the variability of drinking water quality in small systems. Water Resourse Manage 30:2703– 2718. Retrieved from: https://doi.org/10.1007/s11269-016-1312-z

Science for Environment Policy. (2011). Plastic Waste : Ecological and Human Health Impacts. November.

Seth, mukesh kumar. (2017). Trees and Their Economic Importance. 8101(October 2003). https://doi.org/10.1663/0006-8101(2004)069

Shroff, P., Vashi, R. T., Champaneri, V. A., & Patel, K. K. (2015). Correlation study among water quality parameters of groundwater of Valsad district of south Gujarat (India). *Journal of fundamental & applied sciences*, (3), 340-349.

Stoyanova, Z. D., & Harizanova, H. (2019). Impact of agriculture on water pollution. October. https://doi.org/10.7251/AGRENG1901111S

Tessema, D. A. (2000). Environmental Chemistry.

Tyagi, S., Sharma, B., Singh, P., & Dobhal, R. (2013). Water Quality Assessment in Terms of Water Quality Index.*American Journal of Water Resources, 2013, Vol. 1, No. 3, 34-38*. Retrieved from: http://pubs.sciepub.com/ajwr/1/3/3

Ullberg, M. (2015). Temporal water quality study of the heavily human- impacted Likangala River , Zomba , Malawi.

UN-HABITAT. (2011). Malawi : Blantyre Urban Profile.

United States Enviromental Protection Agency. (2002). Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms Fifth Edition. Environmental Protection, October, 266.

USEPA. (2002). PUEBLO OF ISLETA SURFACE WATER QUALITY STANDARDS: Clean Water Act.

Vellemu, E. (2017). THE ECOLOGICAL RISK OF ACID MINE DRAINAGE IN A SALINISING LANDSCAPE. October.

Vellemu, E. C., Mensah, P. K., Griffin, N., & Odume, O. N. (2018). Derivation of scenario-specific water quality guidelines for acid mine drainage in South Africa , using a risk-based approach. 5914.

Von Sperling, M. (2015). Wastewater Characteristics, Treatment and Disposal. In Water Intelligence Online (Vol. 6, Issue 0). https://doi.org/10.2166/9781780402086

Wanda, E. M. M., Gulula, C. L., & Phiri, G. (2012). Determination of Characteristics & Drinking Water Quality Index in Mzuzu City, Northern Malawi. *Journal of Physics & Chemistry of the Earth.* Pp. 92 – 97. September 2012. Retrieved from: https://daneshyari.com/en/article/6442050/

Weeks, J., Sims, I., Harrison, D., & Lawson, C. (2003). River Mining: assessment of the ecological effects of river mining in the Rio Minho and Yallahs rivers, Jamaica.

Weiner, E. R. (2007). Applications of Environmental Aquatic: A Practical Guide (2nd ed.). CRC Press - Taylor & Francis Group, Boca Raton London New York.

WHO. (2007). pH in Drinking-water. In Revised Background Document for Development of WHO Guidelines for Drinking-water Quality, Geneva: WHO: pp. 1-8

WHO. (2010) Hardness in Drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality. WHO/HSE/WSH/10.01/10/Rev/1. 20 Geneva.

Yadav, S. D. P., Mishra, K., Chaudhary, N. K., & Mishra, P. (2015). Assessing Physico-Chemical Parameters of Potable Water in Dhankuta Municipality of Nepal.

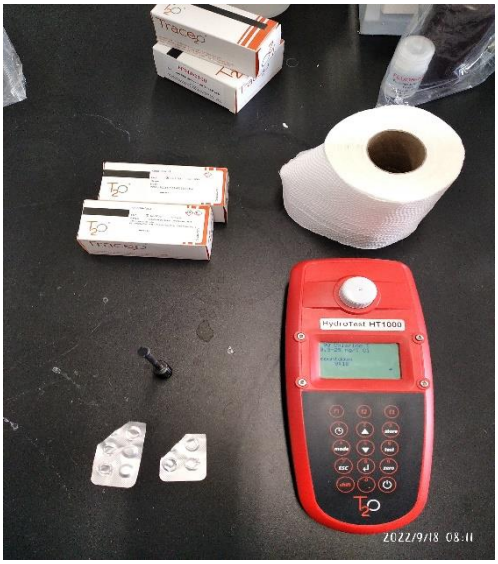
Science Journal of Analytical Chemistry. 3, 2, pp. 17-21. Retrieved from: doi: 10.11648/j.sjac.20150302.11

8. APPENDICES

Appendix 1. Table for Calculating Water Quality Index

Parameter	Vo	Sn	1/Sn	K	Wi = K/Sn	Qi	Wi*Qi	Vi	Vo/Vi
pH	6.9	9.5	0.105263158	3.1494	0.331515	4	1.32606	7	0.04
EC (mS/cm)	509	3500	0.000285714	3.1494	0.0009	14.54286	0.01309	0	0.14543
TDS	300	2000	0.0005	3.1494	0.001575	15	0.02362	0	0.15
HARDNESS	204	800	0.00125	3.1494	0.003937	25.5	0.10039	0	0.255
NO3 (mg/L)	13.4632	45	0.022222222	3.1494	0.069987	29.91832	2.09388	0	0.29918
CL (mg/L)	21.7	750	0.001333333	3.1494	0.004199	2.893333	0.01215	0	0.02893
Fluoride	0.08	6	0.166666667	3.1494	0.5249	1.333333	0.69987	0	0.01333
Faecal	4	50	0.02	3.1494	0.062988	8	0.5039	0	0.08
			0.317521094		1	WQI	4.77296		

Appendix 2. Physico-chemical parameters tests using HydroTest HT1000 Multiparameter Photometer



Appendix 3. Faecal Coliforms after incubation.



