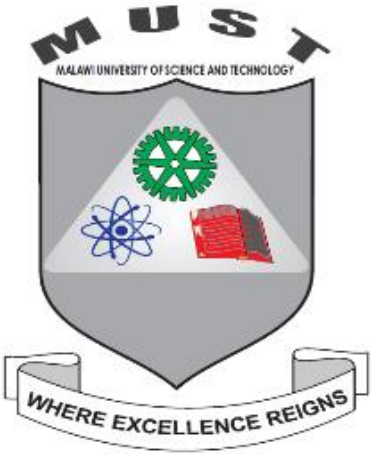


CHARACTERISATION OF GROUNDWATER QUALITY IN AREAS AROUND THE LAKE CHILWA BASIN, ZOMBA

BY

Jannet Thokozani Nzondiwa

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Thyolo, Malawi

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DISSERTATION APPROVED BY: MUSTREC

SUPERVISOR:

MR. HARLOD YAPUWA Signature: _____

ASSESSOR: Signature: _____

DECLARATION

I Jannet Thokozani Nzondiwa declare that "CHARACTERISTION OF GROUNDWATER QUALITY IN AREAS AROUND THE LAKE CHILWA BASIN" is my work and that the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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ABSTRACT

Groundwater quality is affected by human activities in the region and therefore the issue of groundwater contamination is common worldwide. High coliform above 50 CFU/100ml levels in drinking water can rise waterborne diseases like cholera, typhoid, and diarrhea and this problem has been reported in many sorts of research around Malawi and other countries. Other studies related to coliform contamination of groundwater are limited in the study area. The purpose of the study was to investigate the microbiological quality of groundwater in boreholes around the Chilwa Lake basin and the origin of contaminants. To complete the study, at each site, two water samples were collected from six sampling sites at Jali Police Station, Jali Epicentre, Jali Anglican, Chande, Dzinja, and Pilimiti. The physical parameters were measured using the multiparameter water quality probe except for pH, and the temperature was measured by pH meter and turbidity by photometric method, all the chemical parameters were measured using a photometric method by a photometer, and all the microbiological parameters were measured using membrane filtration method by membrane lauryl sulfate broth. Statistical analysis like One-way Analysis of Variance (ANOVA), and Pearson correlation were performed to assess the connection between the water quality parameters, regression analysis to predict dependent variables, and the Water Quality Index (WQI) was calculated to look at the status of water conditions. The results for Physico-chemical showed that temperature surpassed the permissible limit of national for untreated borehole waters while pH, EC, TSS, Turbidity, and TDS values were within the maximum permissible limit of MBS and MoIWD for untreated borehole water. Total coliforms counts were low at BH1 and for BH2, BH3, BH4, BH5, BH6 the values were above the maximum permissible limit and for fecal coliform zero concentrations at BH1 and BH5 while BH3, BH4, and BH6 the values surpassed the maximum limit for untreated borehole water. Furthermore, Pearson's correlation analysis showed a significant positive correlation between, EC and TSS and turbidity, nitrate and ammonia, faecal coliforms, TSS, ammonia, and total coliforms. The ANOVA showed that there were no statistically significant differences ($p>0.05$) in all water quality parameters measured within the six boreholes sampled at Mwambo T/A. The regression found

that the fecal coliform dependent variable can be predicted with independent variables. The WQI found that the groundwater quality of T/A Mwambo is very poor and not suitable for human consumption. The study reflects a very bad quality of groundwater in the in T/A Mwambo. It was concluded that some indicators put into indication mostly microbial pollution because most of the boreholes were found to have high Coliforms as compared to maximum permissible limits for MoIWD and MBS. It was also concluded that the WQI method is a highly efficient tool for determining the quality of potentially polluted water bodies. Therefore, civic education is a need in these communities to reduce water-related diseases by telling people to disinfect water with either chlorine or heat before drinking as well as frequent monitoring activities using the water quality index approach so that the legislative makers can take appropriate action on the polluted water points.

Keywords: Water quality index, physical-chemical parameters, microbiological parameter, water quality.

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ACRONYMS/ABBREVIATIONS

ANOVA	Analysis of Variance
APHA	American Public Health Association
BH	Borehole
CFU	Colony Forming Unit
EC	Electrical Conductivity
GV	Guideline Value
MBS	Malawi bureau of standards
Mg/l	Milligrams per litre
NTU	Nephelometric Turbidity Units
μS/cm	Siemens per meter
°C	degree Celsius
Ppt	parts per thousand
MLSB	Membrane Lauryl Sulphate Broth
MPL	Maximum Permissible Limits
MoIWD	Ministry of Irrigation and Water Development
MUST	Malawi University of Science and Technology
NTU	Nephelometric Turbidity Units
pH	power of Hydrogen
Qi	Subindex of nth parameter
SADC	Southern Africa Development Committee
TDS	Total Dissolved solids
TSS	Total suspended solids
UN	United Nations
WHO	World Health organization
Wi	Unit weightage
WQI	Water Quality Index

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CHARACTERISATION OF GROUNDWATER QUALITY IN AREAS AROUND THE LAKE CHILWA BASIN, ZOMBA

1. INTRODUCTION

1.1. Background of the Study

Groundwater refers to all or any water that is below the surface of the ground in the saturation zone and direct contact with the ground or subsoil (E U, 2005). Groundwater in Malawi is estimated to provide about 3 million people in rural areas, making out about 29% of the rural domestic water supplies (SADC, 2002). Groundwater quality is influenced by geogenic as well as anthropogenic activities, due to these activities' many of the chemicals and pathogens may be encountered in the water depending on the type of activities happening around the area. When indigenous people draw water from improved boreholes, they assume that the water is 'safe' for human consumption. However, this is not true.

To determine the wholesomeness of water supplies two water quality assessment tools are used which are water quality monitoring and water quality modeling (Chapra, 1997). Water can be monitored using Physico-chemical, biomonitoring, and Ecotoxicology approaches. Physico-chemical water quality assessment is comprised of a microbiological and Physico-chemical assessment of water(Chapman, 1996). Water is assessed by collecting water samples in studying areas and measure the water samples against a range of health and non-health-based Physico-chemical standards and bacteriological indicators of fecal and total pollution. The standards are based on the international guidelines of WHO Health Guidelines Values and the Malawi standard of Malawi Bureau of Standards (MBS, 2005) as well as the Ministry of Irrigation and Water Development (MoIWD, 2003).

Referring to the Malawi standard from the Malawi Bureau of Standards (MBS) and World Health Organization (WHO) drinking water quality guidelines, water must be safe from waterborne or any associated disease, free from toxic chemicals, and be aesthetically acceptable to the consumer (MBS, 2005). According to Pritchard(2008), 65% of the total population of Malawi has access to safe drinking water and 50%

of all illnesses are due to water-related diseases(Pritchard et al., 2008). Water is a medium of thousands of microorganisms, some of which are disease-causing organisms. In 2002, the mortality rate due to cholera was over 50% of the water-related deaths (Sajidu et. Al., 2007). Monitoring activities of drinking-water quality are usually only undertaken by legal water suppliers of drinking water in towns and cities(Grimason et al., 2013). Aiming at expanding the monitoring activities in both the urban water supplies and the rural water supplies can be important to ensure that every person in the country has access to good and safe water.

Previous investigations of the quality of groundwater in areas around Lake Chilwa Basin focused on determining the Physico-chemical as well as isotopic properties and their conformance with WHO guidelines and Malawi Bureau of Standards (MBS) borehole and shallow well standards(Missi & Atekwana, 2018; Hellens, 2013). There are no documented studies that these current studies are aware of on water quality assessment of microbiological indicators plus the use of the water quality index (WQI) approach to understanding the suitability of groundwater in the Lake Chilwa Basin. Although borehole supplies are used by a significant percentage of the population in Malawi information on the microbiological quality using the water quality index approach is nonexistent.

The most appropriate way to express the quality of water resources for consumption is the use of the Water Quality Index (WQI). The WQI can reduce the bulk of the information into a single value to express the data in an easy and reasonable form and demonstrate annual cycles, spatial and temporal variation trends in water quality at low concentrations(Madalina & Gabriela, 2014; Tyagi et al., 2013).

An index is a useful tool for communicating water quality information to the large public and legislative decision-makers; it is not a complex predictive model for technical and scientific application (Kumar & Mp, 2014; Yogendra & Puttaiah, 2008). There are two approaches for water quality index analysis which are factorial correspondence analysis and weight arithmetic analysis. The factorial correspondence analysis uses the multivariance approach to analyse data based on the principle of

correspondence factor analysis(Silva et al., 2008) and the weight arithmetic analysis uses the weight of each parameter to analyse data. The weight arithmetic water index method classified the water quality according to the degree of purity, using the most commonly measured water quality variables. In this study, however, the WQI has been used as a tool to determine the impacts of human activities on the water quality of boreholes by defining the overall status of each sampled borehole in T/A Mwambo.

1.2. Problem statement

Pathogens, along with life-threatening chemicals, contaminate the groundwater system through leaching(Kördel & Klein, 2006). Potential sources of water pollutants and contaminants are domestic waste, industrial waste, agricultural waste, and human waste(Chapman, 1996; Chapra, 1997). Water quality pollutants affect the physical, chemical, and microbiological quality of water. Some of these pollutants especially bacterial, viral, and protozoans' pathogens may cause waterborne diseases like cholera, typhoid, and hepatitis A or E. According to Khonje (2012) and Heyerdal (2018) communities around Lake Chilwa have experienced recurrent cholera outbreaks since 1980 which has a high impact on the communities like deaths (Heyerdahl et al., 2018; Khonje et al., 2012). Although communities experience cholera outbreaks almost annually, no research has documented the microbiological quality of groundwater in the area. Only Physico-chemical and isotopic groundwater quality were assessed in two documented studies in 2013 and 2018 (Hellens, 2013; Missi & Atekwana, 2018). There is no current information on microbiological quality in groundwater yet people living around the Lake Chilwa basin rely on the groundwater for their water supply (Hellens, 2013). Therefore, groundwater microbiological quality assessment has been conducted to see if the Cholera outbreaks in the area of study are linked to the groundwater quality.

1.3. Main Objective

To determine the microbiological groundwater quality of T/A Mwambo boreholes using the Water Quality Index approach.

1.3.1. Specific objectives

- To determine the physic o-chemical quality of groundwater based on the randomly selected boreholes.
- To determine the microbiological quality of groundwater based on randomly selected boreholes.
- To relate water quality to human activities in the area.
- To develop an index of groundwater quality for the area.

1.4. Research Questions

The main questions dealt with in this research area:

- Is there a relationship between physic o-chemical variables and microbiologic parameters?
- What are the causes of elevated coliform levels in groundwater around the Chilwa Lake basin?
- What is the state of the borehole water in T/A Mwambo?

1.4.1. Research Hypotheses

1. There is no significant differences between the means of water quality parameters for all the boreholes in the area of study.
2. Contamination by pit latrines is the primary cause of high levels of coliforms in boreholes.

1.5. Significance of the study

Water is a vital component for the endurance of life on earth, it contains minerals, essential for man and living aquatic organisms. It is a right for every person to access safe water that meets the MBS standard and WHO guidelines for drinking water. Many people in this country suffer from waterborne diseases like cholera, typhoid, and diarrhoea every year. The main aim of the study was to determine the microbiological quality of water and its causes. The physicochemical variables were measured since they correlate with the microbiological variables. Therefore, the results of this study have established some key issues of groundwater quality in the

area that can be helpful to design the water management plan for all the areas around the Lake Chilwa Basin thereby controlling contamination. Also, an established water quality dataset is the appropriate starting point to set up the water resources, supply, and management by the government and other organizations in the area.

2. LITERATURE REVIEW

2.1. Introduction

The review of literature is related to the objective of the study, i.e., the determination of microbiological groundwater quality of boreholes in areas around lake Chilwa basin using the water quality index approach to provide information to the public and decision-makers for easy decision making on the borehole waters and their statistical analysis. Water resources have been the most demoralized natural systems since humans came into existence. This could be as a result of increasing industrialization, urbanization, civilization, and other developmental activities that our natural water system has been polluted by different sources such as leaks & spills at factories, improper hazardous waste disposal, improper use & disposal of pesticides, leachate from landfills, septic systems, saline intrusion, fertilizers, animal wastes, leaking underground storage tanks, pipeline breaks, etc.(Chavula & Mulwafu, 2007; Mkwate et al., 2017; Pritchard et al., 2008). The pollutants coming as a waste of water resources are changing the physical appearance, odor, taste, quality and render the water harmful for utility. So, there is a need for the rapid and frequent monitoring of the quality of water resources. The rapid increase of industrialization, urbanization, and population in the last few decades has caused a dramatic increase in the demand for groundwater, as boreholes as significant deteriorations in water quality all over the world.

2.2. Water resources in Malawi

Malawi when related to other countries in southern Africa it has abundant freshwater resources, it has five lakes and many rivers which contain water throughout the year. Even if the surface water is abundant in Malawi many studies concluded that surface water is easily contaminated by the pollutants from human activities(Kanyerere et al., 2012; Nkrumah, 2011; Silva et al., 2008). On the other hand, the groundwater is less prone to contamination than surface water leading to the increasing demand

for its exploitation, especially in rural areas(MacDonald et al., 2005). The Government of Malawi and several Non-Governmental Organizations(NGOs) have provided many boreholes and protected shallow boreholes(Kanyerere et al., 2012) all over Malawi because it has the responsibility to ensure that the basic needs are met (quantity and quality). In approximation, Malawi had 71% of groundwater coverage in rural areas as water supplies (Baumann & Danert, 2008; Kanyerere et al., 2012). But, almost 31% of improved water points in rural Malawi were not working, dropping the effective coverage to 55%(Baumann & Danert, 2008; Kanyerere et al., 2012).

2.2.1. Groundwater

Groundwater refers to water that is easily extractable from saturated, highly permeable strata known as aquifers(Pritchard et al., 2008). For saturated environments, a distinction between local, intermediate, and regional flow systems, related to the topography of recharge and discharge areas has been long recognized by many hydrologists throughout the world. Therefore groundwater can be defined as a source of potable water in the world which can be classified as shallow aquifers, intermediate and deep aquifers (Morita, 1997; Nkrumah, 2011).

Shallow aquifers are categorized by active flow strongly influenced by local precipitation events. Aquifers that initiate 300 m below the surface of the soil are separated from shallow aquifers by confining layers; they have much slower flow rates, of the order of meters per year. Deep aquifers are also confined, but more than 300 m deep the subsurface soil, and they are characterized by very slow flow rates, (Obuobie & Barry, 2010). Groundwater quality has two aspects which are the natural quality of groundwater which is a result of the minerals the groundwater was in contact within the saturated and unsaturated zones, the hydro-chemical and biochemical conditions (pH, Temperature, pressure, presence of bacteria, etc.), and temporal aspects (flow/infiltration velocity, residence time), and the anthropogenic groundwater quality influenced by human activities that add components to the groundwater or change natural equilibria (Nkrumah, 2011).

In Malawi, many studied have shown that it is obvious that anthropogenic influences, in particular, contamination with pathogens play a very important role. It is however not meant to delegate such local effects or relate them to natural aquifer characteristics(Mkandawire, 2008; Mkwate et al., 2017; Pritchard et al., 2008).
Groundwater is an important water resource all over the world. Many major towns and cities in the world depend on groundwater for their water supplies, mainly because of its abundance, stable quality, and also because groundwater is cheaper to exploit (Morris et al., 2003). In many developing nations, the use of shallow groundwater sources for drinking and other domestic purposes is a common feature of many low-income communities (Howard et al., 1999).

2.3. Borehole Water Standard

Metals such as Lead, copper, Zinc, Selenium, Arsenic, Chromium, Cyanide, Cadmium, and Barium present in water beyond some specific maximum allowable concentrations are considered toxic for human consumption. The table in appendix 2 gives the maximum permissible limits of some untreated borehole water by the Ministry of Irrigation and Water Development (MoIWD, 2003) and Malawi Bureau of Standards (MBS, 2005).

Additionally, many other substances may be injurious to health under certain conditions if present in high concentrations. Not all substances are bad for health other substances are important constituents of drinking water, and when present in too low concentrations may have adverse effects on health. Some of these substances are fluorides and nitrates(Pritchard et al., 2008). When nitrate is available in the highest concentration it causes gastro cancer, hypertension, goiter, and blue baby syndrome in infants and it also causes blue baby syndrome(Abera et al., 2017; Ferral et al., 2014).

2.4. Water Quality

2.4.1. Physicochemical water quality

2.4.1.1. Global groundwater quality

Sulochana examined samples from the bore borehole of Remote village near Tirunelveli in Tamil Nadu. The result showed that the declining groundwater level increases the concentration of inorganic ions due to the predominant influence of subsoil rocks (Sulochana, 1998). Suk and Lee studied the characteristics of a groundwater hydro-chemical system using multivariate analysis, which involved clustering of groundwater zones in Incheon, Korea. According to the study, the site was governed by two distinct hydro-chemical regimes. Somashkar *et. al.,* (2000) collected water from ten different locations in Channapatna taluk Bangalore, Karnataka on which he measured the parameters pH, total alkalinity, total hardness, chloride, fluoride, total dissolved solids, calcium, magnesium, nitrates, and conductivity. They observed low fluoride content in this area.

Gupta assessed the physicochemical parameters of groundwater of the selected area of Kaithal City, Haryana (India). From this study, results revealed that most of the parameters were within the permissible limit prescribed by WHO except few parameters like dissolved oxygen, few samples were reported with lower dissolved oxygen than the permissible level, but this value does not have any impact on the water to use for drinking purpose(Gupta et al., 2009). Mitharwal et. al., (2009) assessed groundwater suitability from localities of Pilani in the Jhunjhunu district during the pre-monsoon and post-monsoon season. According to the results it was found that except nitrate all others parameters were within the maximum permissible limits. A higher nitrate concentration might be attributed to the chemical fertilizers applied in the agricultural field.

Omofonmwan assessed the quality of underground water in Benin metropolis, Nigeria, he aimed at examining the effects of solid waste on the water (Omofonmwan, 2009). He analysed the Physico-chemical, and microbiological parameters of raw water from eight different boreholes, the water samples were

collected around the metropolis close to refuse dumps show that these wastes produce leachates and gases when they are decomposing and are washed by percolating and infiltration rainwater into groundwater. The results showed that most of the water parameters tested to fall within WHO guidelines, while some are not safe.

Reza assessed Physico-chemical analysis of groundwater in the Angul Talcher region of Orissa, India during pre-and post-monsoon seasons. Results revealed that the samples collected in post-monsoon seasons were more polluted than pre-monsoon season samples(Reza et al., 2009). A correlation matrix was prepared within the studied parameters in pre-monsoon and post-monsoon seasons. Total dissolved solids and electrical conductivity can be used to describe each other. Conductivity was related to the dissolved solids; total hardness was positively correlated with chloride, calcium, and magnesium ions(Reza et al., 2009). The correlation between parameters of both seasons showed the analogous trends of seasonal variation, it might be due to the weathering and heavy rainfall in the study area during the monsoon (Obuobie & Barry, 2010).

Ullah examined contamination of groundwater in an industrial city, Sialkot, Pakistan. According to the research, it was found that the groundwater of the study area not be considered suitable for consumption as it was highly turbid with a high level of Zn, Fe, and Pb, which surpassed the WHO, Maximum permissible limits(Ullah et al., 2009). Vikas assessed the groundwater quality of Ajmer city. The results indicated that iron concentrations in all the samples were above the maximum permissible limit (Vikas, 2009). Yadav studied geochemical observation of fluoride in groundwater in Tonk district Rajasthan, India. According to the research, it was found that groundwater of the study area was contaminated with fluoride concentration by a natural fluoride-rich rock salt system (Yadav, 2009).

2.4.1.2. Local groundwater Quality

Chidya *et. al.,* (2016) assessed water samples from boreholes in Mzimba rural areas of northern Malawi. He found that the borehole had high levels of nitrates. The

presence of nitrates in water was attributed to the use of nitrogen-based fertilizers and animal waste in fields by farmers as observed during the study(Chidya et al., 2016). Also, some boreholes were seen to be sited less than 100 m from pit latrines. This might have contributed to contamination of aquifer systems with nitrate due to leaching at some sites (Kördel & Klein, 2006), hence relatively elevated nitrate levels in the borehole water.

Hellen et al., (2013) determined the fluoride and nitrate of the groundwater in the Zomba-Phalombe plain. The values of fluoride were generally of non-measurable concentrations, but some elevated values were obtained. The results showed that the fluoride, concentrations of 1.5 – 4.5 mg/L, were measured in Chande, Jali police station, Jali epicenter, and Jali Anglican which are above the maximum permissible limits; these sample sites were all in the same area situated around the rural village of Jali. On average, most nitrate values were of low or non-measurable concentrations in the area. However, around the area of the village Nine miles, high values of nitrate, 48.5 and 14.5 mg/L, were obtained (Hellens, 2013). He said that the nitrates are attributed the row crop agriculture, irrigated agriculture, natural sources, and waste material like sludge and badly sited pit latrines (Hellens, 2013). There was no information on microbiological indicators of water quality. `

Miss and Atekwana (2018) assessed the groundwater quality of the Lake Chilwa basin, in his study, he measured the physical, chemical, and isotopic properties of groundwater. He analysed 16 boreholes for temperature, pH, electrical conductivity, total dissolved solids (TDS), major ions, and stable isotopes of hydrogen and oxygen. It was found that Groundwater had higher ionic concentrations (e.g., HCO3-, Na+, Ca2+, Mg2+). Concentrations of the TDS, HCO3- and Cl- in many sampling sites were above the maximum permissible limit prescribed for drinking water by the World Health Organization (WHO). The results of this study indicated that poor water quality is due to natural water-rock interactions (Missi & Atekwana, 2018). There was no information on microbiological water quality properties.

2.4.2. Microbiological Quality of Drinking Water

2.4.2.1. Fecal Coliform Organisms

Fecal coliforms are one of the most important water quality parameters to consider when assessing the suitability of drinking water because of the infectious disease risk (WHO, 2002). Fecal Coliforms indicate contamination of water animal waste as well as Human waste and signify the possible occurrence of pathogenic bacteria and viruses which are responsible for water-related diseases such as cholera, typhoid, and other diarrheal-related illnesses(Blackwell, 2011). One gram of faeces is reported to contain 10,000,000 viruses; 1,000,000 bacteria; 1000 parasite cysts; and 100 parasite eggs(Nkrumah, 2011). According to MBS (2005), zero CFU/100 ml of fecal coliform in drinking water represents uncontaminated water (MBS, 2005); 50 fecal CFU/100 ml in borehole waters is regarded as suitable by MoIWD for untreated water (MoIWD, 2003).

2.4.2.2. Total Coliforms

The Coliforms are mostly measured because they pose the effects at a very short period as compared to heavy metals which take time to pose their effects on human beings. The bacteria like Gram-negative are cytochrome oxidate negative, non-spore-forming, and ferment lactose at a temperature of 35 °C – 37 °C, within 24 – 48 hours (Morita, 1997). This kind of behavior defines total coliforms. The group is as varied as the habits from which they originate. Thus, the total coliform group should not be regarded as an indicator of organisms exclusively from fecal origins, especially in hot countries where Coliforms of non-fecal origins are common. In water that has high organic material as well as suitable conditions, coliforms multiply. Measurement of fecal coliforms is a better indicator of general contamination of fecal origin. Fecal coliforms differ from the other members of the total coliform groups because they tolerate and grow at higher temperatures of 44 -45 °C(Nkrumah, 2011).

2.4.3. Potential sources of groundwater contamination

2.4.3.1. Pit latrines

Siting a pit latrine close to the wells and boreholes contributes to the pollution of the groundwater system (Kanyerere et al., 2012). According to Nkrumah (2011) when a pit latrine is located at a distance less than 50 m away from wells and boreholes, the water from such wells will be polluted (Nkrumah, 2011). The transportation of these coliforms could be horizontal movement of contaminants from pollution sources such as waste dumps, animal houses, and pit latrines which are sometimes located upstream and close to the water points(Gray, 2010).

2.4.3.2. Agriculture and other sources

The sources of pollutants like nitrate in groundwater are categorized into natural sources, row crop agriculture, and irrigated agriculture. Row crop agriculture and irrigated agriculture are associated with the application of nitrogen fertilizers(Peña et al., 2019). Nitrogen from chemical fertilizers is typically inorganic and applied in the form of ammonium and nitrate ions. The leaching of fertilizers varies with the timing and method used application of fertilizers, vegetative cover, soil porosity, amount of fertilizer added, and rate of irrigation. Nitrogen from human waste or treated wastewater is applied in organic form or as ammonium as well as urea (Hellens, 2013).

2.5. Water Quality Index (WQI)

A water quality index refers to a weighted average of selected concentrations of measured pollutants like chemicals, physical and microbiological parameters, usually related to water quality classes. It can be used as a means to describe, synthesize and summarize water quality analytical data for easy and rapid interpretation. It can also be used as an indicator for a water body's given situation, in which several parameters were used for evaluating the quality and expressed as numeric results. Consumers of this information can range anywhere from knowing nothing about water quality to be closely connected to the resource. The water quality index can be useful by the government officers and managers to regulate the water quality with more ease and provide understandable information to the public.

Sharma estimated the water quality index for river Yamuna to examine the consequences of the projects implemented during Yamuna action plan one and two. The investigation was focused on the use of WQI to define the level of pollution in the river for a period of 10 years (2000–2009). The critical pollutants affecting the river water quality during its course through the city were also identified during the study (Sharma, 2011). Tyagi assessed the water quality in terms of the water quality index. WQI defines the composite influence of different water quality constituencies and communicates water quality information to the public and legislative decision-makers. In spite of the absence of a worldly accepted composite index of water quality; some countries have used and are using combined water quality data in the development of water quality indices(Tyagi et al., 2013).

Bharti et al., (2011) compared various water quality indices for assessing surface water quality. As different national and international interventions involved in water quality assessment and pollution control define water quality criteria for different uses of water, considering different indicator parameters. Consequently, there are many WQI specific to any region or area. An attempt to cover all different water quality indices developed worldwide, their background, and their application area has been made. Kumar studied hydro-geochemistry and the use of the water quality index for groundwater quality assessment in areas of Anna Nagar, Chennai city, Tamil Nadu, India. According to the study, many water samples were falling under the excellent to good classes and were suitable for human consumption like drinking water purposes based on WQI (Kumar & Mp, 2014). The Piper trilinear diagram shows that groundwater in the study area was Na+, Cl- and mixed Ca2+, Mg2+, Cl- type(Kumar & Mp, 2014).

Mouna studied the application of the water quality index as well the use of geographical information systems to determine groundwater quality in the Khairat deep aquifer, Enfidha, Tunisian. According to the study, the results of the spatial distribution map indicated that a majority of the groundwater samples falls in the very hard class, and from the water quality index (WQI) assessment, water samples

fall within the poor and very poor classes, suggesting that groundwater is unsuitable for drinking purposes(Mouna et al., 2011).

Water quality, water quality standard for different groundwater is reviewed in the literature. According to the pieces of literature that have been reviewed it was it can be said the most of the groundwaters worldwide are being contaminated with both physicochemical and microbiological pollutants. Water quality indexes are evaluated to identify pollution levels and some pollutants affecting water quality in groundwater. From the literature, it was observed the water quality indexing will identify the critical pollutants affecting the groundwater by comparing the weight that parameter is carrying.

3. MATERIALS AND METHODS

3.1. Introduction

This chapter discusses the author's materials and methods adopted for the study. It gives a detailed account of the data collection processes employed to obtain data. The main objective was to determine the microbiological groundwater quality of boreholes in areas around the Lake Chilwa Basin. This was done by taking water samples from boreholes sited close to pit latrines as well agricultural lands. This chapter elucidates the research designs, sampling frequency, sample treatment for laboratory analysis, and sampling instruments used in the research. Both primary and secondary data were collected and presented graphically and in tables. Microsoft Excel version 2016 tool, as well as Minitab 17 tool, were used for quantitative data analysis. Background information was collected through field visits by observations, taking images, and measuring physicochemical and microbiological parameters. Secondary data were obtained from Google Scholar through the investigation of case studies and related research in Africa and the whole world.

3.2. General description of the Study Area

Lake Chilwa wetland is situated at a latitude of 15º 20'S and longitude 35º 40'E in southern Malawi and the east of Zomba plateau. It experiences a warm tropical climate, which is characterized by rainy and dry seasons. The rainy and dry seasons occur from November to April and May to October, respectively. The study area is relatively hot and humid due to low lying altitude 0f 2050 to 2200 (Hellens, 2013). The mean annual temperature is 24°C. The highest temperature of 29°C and the lowest temperature of 20°C are experienced in October and June, respectively (Missi & Atekwana, 2018). Rainfall variability has a significant impact on water availability and the discharge of particular catchments (Hellens, 2013). However, processes other than rainfall play a significant role in the hydrologic processes of any catchment (Hellens, 2013). The study was mainly conducted in T/A Mwambo specifically in the villages of Jali, Dzinja and Chande, which were all around Lake Chilwa basin. The area relies on boreholes for water supply on which most of them are located close

to the pit latrines and agricultural lands. Below map showing the all the sampling points.

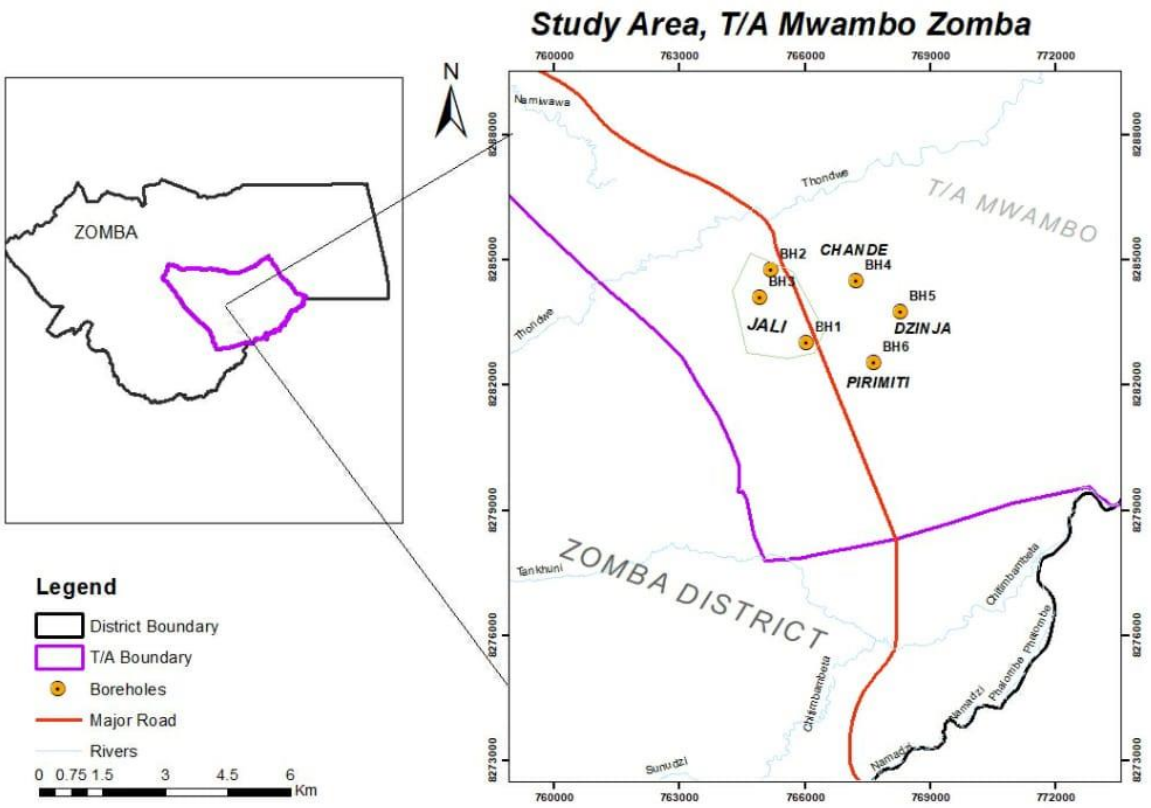


Figure 3. 1 above is the map showing the sampling locations. The purple part on the map of Zomba is the location of the study area.

3.3. Sampling

This study was specifically conducted in group village heads of T/A Mwambo in Zomba District (Figure 3.1). This Traditional Authority was purposively selected because it experiences an outbreak of Cholera almost every year and also many boreholes were close to pit latrines, hence the need for evaluation of the water quality of the boreholes. To assess the quality of boreholes in the area for domestic consumption water samples were collected from six boreholes, using the single grab or catch method according to Standard Methods for Examination of Water and Wastewater standard sampling procedures(APHA, 1998). The simple random sampling technique was used to select sample water points from the whole

population in June 2021. Samples for fecal and total coliforms were collected in the borosilicate glass bottles and for physicochemical parameters, samples were collected in plastic bottles from the following boreholes: Jali Police Station, Dzinja, Jali Anglican, Jali epicenter, Chande, and Pilimiti.

Water samples were collected from randomly selected boreholes(n=6) in boreholes sited close to pit latrines, animal houses, and agricultural lands, and at each site, two samples were taken and measured in duplicate to ensure precision and accuracy of the results. The sampling frequency was twice within a day. Some samples were taken in the morning while the other samples were in the evening. All the laboratory and field equipment were washed thoroughly with distilled water and handled carefully as prescribed in the standard operating procedures to avoid cross-contamination and alteration of the samples (APHA, 1998). Furthermore, to ensure quality assurance during sampling, bottles for water sample collection were washed thrice with distilled water and then with the sampled water. Fixed volume purging of the boreholes was performed before water sampling to ensure the collection of true "representative" groundwater in the surrounding aquifer (APHA, 1998). Water was collected directly into the bottle from the tube to avoid contamination of the bottle from hands or a transfer vessel such as a cup. To ensure the code of ethics and professional conduct of the study, ethical principles and clearance were observed during sampling by seeking consent from relevant authorities in the study area with valid supporting documents from Malawi University of Science and Technology (MUST).

3.3.1. Research Design

The study employed using the experimental study design which uses quantitative research methods to collect relevant data (Creswell, 2009). The statistical analysis of data was done using two different software tools the Minitab 17 and Microsoft excel tool. The accurate measurements were taken to ensure the precision of the results.

The sampling and the sample analysis were done in June 2021 while the data analysis was conducted in July 2021. The boreholes in the study area were sampled to assess the microbiological quality of groundwater using the water quality index approach.

The area was assumed to have poorly sited pit latrines as well as agricultural fields which can affect water quality.

3.4. Treatment of samples for laboratory analysis

All samples were treated according to regalements from Standard Methods for Examination of Water and Wastewater(APHA, 1998). From the field, the samples were kept cool in the cooler box at 4°C and delivered to the laboratory within 24 hours for the analysis thus, according to Standard Methods for Examination of Water and Wastewater (APHA, 1998). The hands were thoroughly washed with soap and water before starting the analysis to avoid the risk of contamination (APHA, 1998). In the laboratory, samples for nitrate and ammonia were filtered with 0.45μg fiber filters.

3.5. Measurements and sample analysis

All samples were analysed for basic physicochemical and microbiological quality variables using standard methods as per Standard Methods for Examination of Water and Wastewater (APHA, 1998).

3.5.1. Microbiological determination

Materials required were; sample bottles, dilution bottles, pipets, graduated cylinder, a container for culture media, hand vacuum pump, Petri dishes, filtration units, membrane filter absorbent pads, methanol, forceps, incubator, membrane lauryl sulfate broth, Colony Counter, and light source.

Total and fecal coliforms were determined using the membrane filtration method. Sterile conditions were obtained by using an autoclave machine which was used to sterilize the sampling bottles for 15 minutes while the membrane filtration unit, the forceps, the traces from the incubator, and the Petri dishes were sterilized using the 95% ethanol and the lighter whereby all the mentioned instrument were rubbed with ethanol and then the lighter was pressed to frame all the instruments rubbed with the ethanol and left for a period of 2- 3minutes. A measured volume (100ml) of water as guided by Standard Methods for Examination of Water and Wastewater

standard sampling procedures (APHA, 1998) was filtered through a membrane. After the standard recovery period of one hour, membranes were then incubated on Membrane Lauryl Sulphate Broth (MLSB) at 37 °C and 44.5 °C for total and fecal coliforms respectively for 24 and 18 hours for total and fecal. Each test was done once due to limited reagents, measuring the samples in duplicates essentially reduces any errors related to measurement. All the Bacteria that were present in the water get trapped on the filter membranes and grew into visible colonies after incubation. The viable colonies were counted using a colony counter and converted to represent a count per 100 mg/l.

3.5.2. Physico-chemical Determination

3.5.2.1. pH and Temperature

In situ measurement was used to determine unstable parameters like temperature and pH at each borehole during purging using a potable Multi probe aqua meter. A pH meter was used to determine the pH and temperature of samples after calibrating with three different buffer solutions (4.0, 7.0, and 14 pH values). The probe of the meter was dipped in the collecting basin receiving the pumped water so that the water-covered sensitized electrode and readings were taken after stabilization (APHA, 1998).

3.5.2.2. Conductivity, Total Suspended Solids, Total Dissolved Solids, and Salinity

The parameters like electrical conductivity (EC), Salinity, Total suspended solids (TSS), and Total dissolved solids (TDS) were measured using a portable Multi probe aqua meter (Aquaread AP-700 & AP-800) in the laboratory using standard methods (APHA, 1998). The probe was dipped in the 500ml beakers filled with water and the readings were taken after stabilization (www.aquaread.com). A probe has specifications as indicated in the table below and the other table in appendix 1.

protection class	IP68(permanent immersion)
Immersion Depth	Min 75mm. Max 50m*
Operating Temperature	-5˚C - +70˚C

Dimensions (L x Día)	290mm x 42mm
Weight	700g

3.5.2.3. Turbidity

The HT1000 Photometer uses the interaction of infrared light with the samples to measure different water quality parameters. All the collected samples from each site were measured for turbidity. A 10 ml sample of water was poured into the viral without adding reagents and without filtering. The viral was placed into the HT1000 photometer instrument making sure that it was in good alignment with the mark in the photometer. The test button was then pressed on to test the content and 10 minutes later the timer on the photometer clocked in seconds then the turbidity value was displayed on the photometer screen was manually recorded on hard copy.

3.5.2.4. Nitrate

Materials and reagents used were the HT1000 photometer, nitrate test tube,10ml vial, stirring rod, nitrate test powder, nitrate test tablets, and a wristwatch.

Nitrate was measured by using the Nitrate(P260) method by an HT1000 photometer instrument in (T20-AN-P260). The nitrate was tested by taken a 20ml filtered sample into a test tube in it the one level nitrate test powder was poured and shaken for 1 minute and then the one nitrate test tablet was crushed and added into the test tube and shaken vigorous for 2 minutes, and then the 10ml from the test tube was poured into the viral and then one nitrite test tablet was crushed and added straight from the foil into the viral and then shaken vigorous until no large pieces were visible. Then viral was pressed in the photometer chamber while making sure that the arrow of the viral was aligned with the arrow of the photometer reading then the test key was pressed, after 10 minutes the reading was recorded(www.aquaread.com).

3.5.2.5. Ammonia

Materials and reagents used were the HT1000 photometer, test tube, 10ml vial, stirring rod, wristwatch, ammonia no 1 & 2 tablets.

Ammonia was measured by using Ammonia(P60) method by an HT1000 photometer instrument in (T20-AN-P60). Ammonia a 10ml sample was poured into a 10ml viral in which ammonia number one test tablet was first crushed using a stirring rod and put in the viral and then the viral was closed tightly with the cup and then the viral was shaken vigorously until all the tablet dissolved, this was followed by the ammonia number two test tablet after all the tablet dissolved the viral was pressed in the photometer chamber while making sure that the arrow of the viral was aligned with the arrow of the photometer reading then the test key was pressed, after 10 minutes the reading was recorded(www.aquaread.com).

3.5.3. Creating a Water Quality Index (WQI)

The weight arithmetic water index method has been used to categorize the water quality according to the degree of purity, using all the measured water quality variables. This method has been largely used by many researchers (House & Ellis, 1987). The water quality data from each sampling site were recorded and a numerical value of WQI was found by using the equation below:

$WQI = \sum_{i=1}^{n} WnQn$

Where,

Wn = sub-index for n^{th} water quality parameter;

Qn = weight associated with n^{th} water quality parameter;

n = number of water quality parameters

The water quality index was calculated to determine the suitability of water for different purposes (Kankal et al., 2012). The water quality index developed in this study consist of four steps:

- Selection of parameters for measurement of water quality. The selection was based on the drinking water quality, the parameters selected were: microbial (total coliform, fecal coliform), physicochemical parameters (temperature, pH, conductivity, salinity, turbidity, total suspended solids, and Total Dissolved Solids (TDS)), Nutrients (nitrates, ammonia).

- Estimation of the unit weight of each indicator parameter was done by considering the weightage of each parameter by the formula which was $Wn = K/Sn$.

Where wn was unit weight K was a proportionality constant which was found by $K = 1/\sum(1/Sn)$ and the Sn was recommended standard value for an nth parameter.

- Determining the sub-index value, they were determined by the formula $Qn = 100 \times \{Vn/Sn\}$.

Where,

Qn was the sub-index of the nth parameter

Vn was monitored value of the nth parameter

Sn was recommended standard value for the nth parameter.

- Aggregating the sub-indices to obtain the overall Water Quality Index (WQI), WQI was found by the formula which was $WQI = \sum(Wn \times Qn)$. By analyzing the values of the index in the table, it is possible to identify the areas of more sensitivity to the anthropogenic impact.

3.6. Statistical analysis

Parametric statistics were used to make inferences about population parameters. This was achieved by taking sample statistics to make estimates of population parameters(Woodbry, 2002). The Microsoft excel 2016 version tool has been used to make tables that present data, correlation analysis to show how the variables were interrelating with one another, trend analysis to make graphs that depict and display results, ANOVA has been used to if the mean of the critical water quality parameter is equal at every borehole, and water quality index analysis to calculate all the measured parameters into a single value which defined water quality status while the Minitab 17 tool has been used for regression analysis to predict dependent variable using independent variables in this research(Mendenhell et al., 2009).

3.7. Data Presentation

To achieve the purpose and objectives of the study, various methods and techniques were applied in data analysis and presentation. The data collected were summarized in tables and graphs.

3.8. Study Limitations

- Due to insufficient reagent, some parameters like fecal and total Coliforms were just analysed once, which led to getting inaccurate results.
- Insufficient samples were collected for the analyses due to limited time for sampling.
- When calculating the Water Quality Index, a great amount of data is handled and a loss of data can occur easily.
- The literature review papers related to this study more especially for the Water Quality Index in Malawi none of the problem areas were considered for the study.
- The samples were only collected in the rainy season, but to get the best results the samples were supposed to be collected in both seasons the rainy and the dry season since during these periods the water quality status differs.

4. RESULTS AND DISCUSSION

The assessment of groundwater quality is important for the protection of human health. Therefore, all the collected water samples were analysed for microbiological concentrations and many other physiochemical parameters concentrations. Tables 4.1 and 4.2 show results from lab analysis of the water samples as well the means and standard deviations of each of the measured parameters.

4.1. Characteristics of the Boreholes

Conditions of the borehole and the surrounding areas have also been described. Observational study results showed clearly that majority of the boreholes and their surroundings are in unhygienic conditions, serve a large population, and are never fenced and maintained. For instance, the four boreholes of the Jali epicenter, Jali Anglican, and Dzinja were found to be without any form of concrete on the top of the boreholes. In all the boreholes the people's hands are used to pump water from the ground. Water from these boreholes can be said to be contaminated with elements from the immediate surroundings. For instance, fertilizer, animal wastes, etc. (see plates in appendix 3).

From the plates in the appendix, it was obvious that all the four boreholes are practically not maintained even though BH1 and BH2 have concrete. In all cases, different users used their hands for pumping the water thereby paving the way for contamination of all sorts from various sources.

Lastly, boreholes from this area were assessed to ascertain their characteristics. The results are tabulated in Table 4.1 and Table 4.2, it can be said that all the boreholes from 50% of sampled boreholes in the area do not have any full concrete on the top of the borehole upon ruined. Therefore, they can be contaminated with elements of any contaminant from the immediate surroundings.

BH3, one of the boreholes from which the people sourced drinking water from is in a disgraceful condition. The borehole is damaged. It is completely not concreted with only the stones on the top of the borehole as shown in appendix 3.

4.2. Physical Characteristics of Water Quality

The results indicate that physical water quality was good. All the values for turbidity Electrical conductivity, Total Dissolved Solids, and total suspended solids (Table 4.1) were below the limiting nation guidelines values except for temperature in all the sampled boreholes which was higher than the allowed limit of 25 °C as set by MoIWD and MBS for untreated water (Appendix 2).

Total Dissolved Solids (mg/l)

TDS indicates the salinity behavior of water. The maximum concentration was found to be 1930mg/l at BH2 and the minimum concentration was 987 mg/l at BH6. All the samples were below the maximum permissible limit of MBS and MoIWD for untreated borehole waters which is 2000mg/l as indicated in appendix 2. The high TDS values in water may change the water taste, and also cause gastrointestinal irritation(Abera et al., 2017).

Total Suspended Solids (mg/l)

TSS indicates turbidity caused due to the presence of silts and organic matter in water(Abera et al., 2017; Gray, 2010). The high value which was found was 12mg/l and the lowest value was 2mg/l. Just like turbidity, TSS may inhibit the functionality of the water disinfectants. All the sampled boreholes had concentrations below the maximum permissible limits of MBS and MoIWD as indicated in appendix 2.

Power Of Hydrogen (pH)

The pH levels of the various borehole ranged between 6.78 to 7.11, with BH1 recording the high value (Table 4.1) and the low value being recorded at BH6. The pH values were almost the same at every point of the study (figure 4.1). The groundwater of the area was neutral since all the sampled boreholes had pH values

close to 7 therefore more susceptible to high microbiological pollutants since many of them survive well under this condition(Morita, 1997). pH is defined as a measure of how acidic or basic the water is (https://www.omega.co.uk). It ranges from 0 t0 14 on which the middle number which is 7 is said to be neutral and 0 more acidic while 14 more basic Long-term exposure beyond the permissible limit ranges of WHO, MBS, and MoIWD affects the mucous membrane of cells. pH is mainly influenced by anthropogenic activities such as sewage disposal and the use of fertilizers in fields. It is also influenced by the sedimentary rocks as a result of weathering of the plagioclase feldspar in sediments(Abera et al., 2017).

Turbidity (NTU)

The mean values of Turbidity ranged between 0. NTU and 4.5 NTU, with BH1, BH4, and BH6 recording the 0 NTU values, and BH2 the highest of 4.5 NTU. The turbidity values showed that the water was not cloudy. It indicates the presence of suspended solids in water and when it is in the highest amount it mostly causes the muddy or turbid appearance of the water body (Owa, 2014). BH2 indicated the slight turbid water, this may be as a result of the presence of inorganic particulate matter and non-soluble metal oxides(Abera et al., 2017). High turbid water may cause health risks as turbid water protect the pathogenic microorganisms from the effects of disinfectants like chlorine(Singh et al., 2007).

Electrical Conductivity (us/cm)

Electrical Conductivity values ranged between 1521.00 μS/cm and 2970 μS/cm. EC indicates the conductivity capacity of water. EC is a measure of TDS i.e.; it is influenced by the ionic strength of the solution. An increase in dissolved solids increases the ionic strength of the solution (Abera et al., 2017). The increase in EC increases the corrosivity of water. This may result in an unusual taste, odor, and feel problem(Gray, 2005).

Temperature (°C)

All the maximum permissible limits for borehole water values for physical water parameters are given in appendix 2. All the sampled boreholes registered the highest temperature. The maximum value of 28.4 °C was registered at BH6 and the least value 0f 26.65°C at BH4. The higher temperatures could be a result of the geothermal gradient (WHITE, 2015).

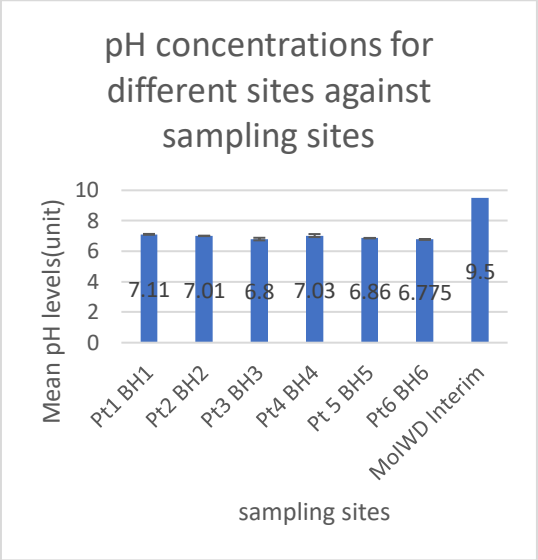
Total Solids (mg/l)

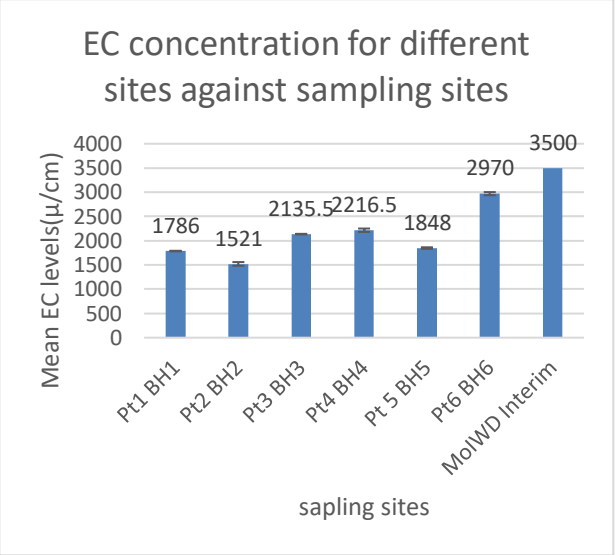
Total solids are dissolved solids plus suspended and settleable solids in water (https://achieve.epa.gov). It has been calculated by adding the TDS and TSS found during the study. The purpose was to know the overall solids that were in the water. Total solids in high amounts affect water clearness by decreasing the passage of light through water.

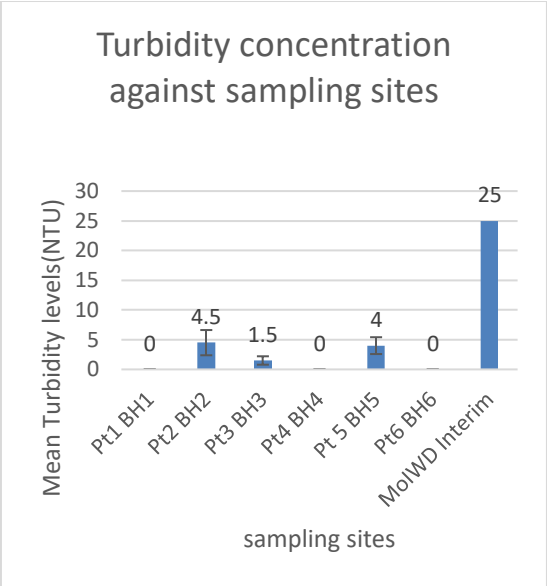
The standard error bar on each bar on the graph shows how the two samples at each sampling point differed in terms of measured values, when the standard error bar is high that means there was an error during measurements or sampling of each sample at that particular sampling site and when the standard error bar is short it means the measurements and sampling were accurate(Woodbry, 2002). According to Table 4.1, the variables with standard deviations less than 5 mean that the measurements were accurate while the standard deviations greater than 5 implies to errors during measurements and sampling(Mendenhell et al., 2009).

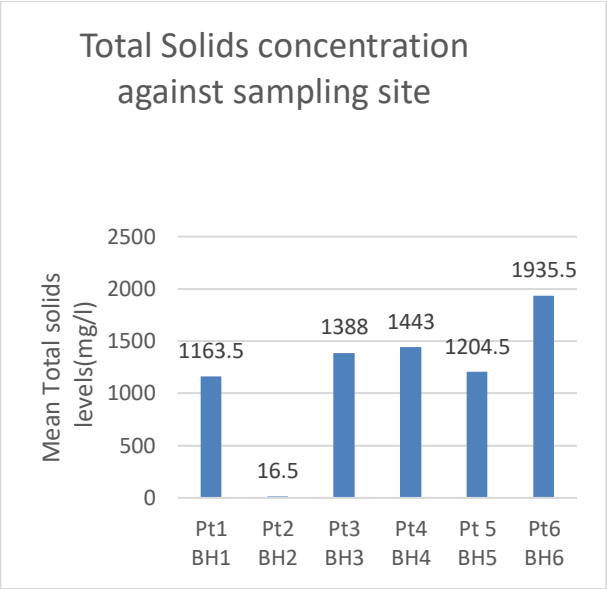
Table 4. 1 Below shows all the measured values, means, and standard deviations of physical water quality variables for various boreholes.

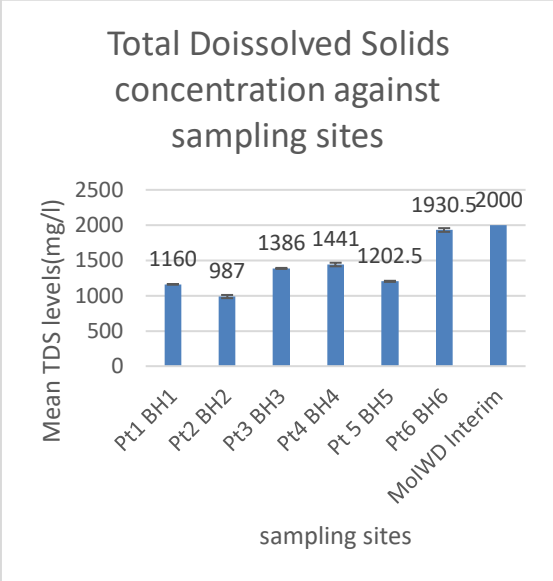
		Temp(oC)	pH	EC (µs/cm)	TSS (mg/l)	TDS (mg/l)	Turbidity (NTU)	Salinity(ppt)
Jali Police Station	Min	27.3	7.09	1782	2	1158	0	0.88
	Max	27.6	7.13	1790	5	1162	0	0.88
	Avg	27.45	7.11	1786	3.5	1160	0	0.88
	SD	0.212132034	0.028284271	5.656854249	2.121320344	2.828427125	0	0
Jali Epicentre	Min	27.3	7	1494	7	971	3	0.69
	Max	27.4	7.02	1548	17	1003	6	0.76
	Avg	27.35	7.01	1521	12	987	4.5	0.725
	SD	0.070710678	0.014142136	38.18376618	7.071067812	22.627417	2.121320344	0.049497475
Dzinja	Min	27.6	6.74	2131	1	1381	1	1.07
	Max	27.7	6.86	2140	3	1391	2	1.08
	Avg	27.65	6.8	2135.5	2	1386	1.5	1.075
	SD	0.070710678	0.084852814	6.363961031	1.414213562	7.071067812	0.707106781	0.007071068
Jali Anglican	Min	26.4	6.96	2192	1	1423	0	1.1
	Max	26.9	7.1	2241	3	1459	0	1.13
	Avg	26.65	7.03	2216.5	2	1441	0	1.115
	SD	0.353553391	0.098994949	34.64823228	1.414213562	25.45584412	0	0.021213203
Chande	Min	27.8	6.85	1837	1	1197	3	1.51
	Max	28	6.87	1859	3	1208	5	1.53
	Avg	27.9	6.86	1848	2	1202.5	4	1.52
	SD	0.141421356	0.014142136	15.55634919	1.414213562	7.778174593	1.414213562	0.014142136
Pilimiti	Min	28.4	6.77	2947	5	1912	0	0.51
	Max	28.4	6.78	2993	5	1949	0	1.53
	Avg	28.4	6.775	2970	5	1930.5	0	1.02
	SD	0	0.007071068	32.52691193	0	26.1629509	0	0.721248917

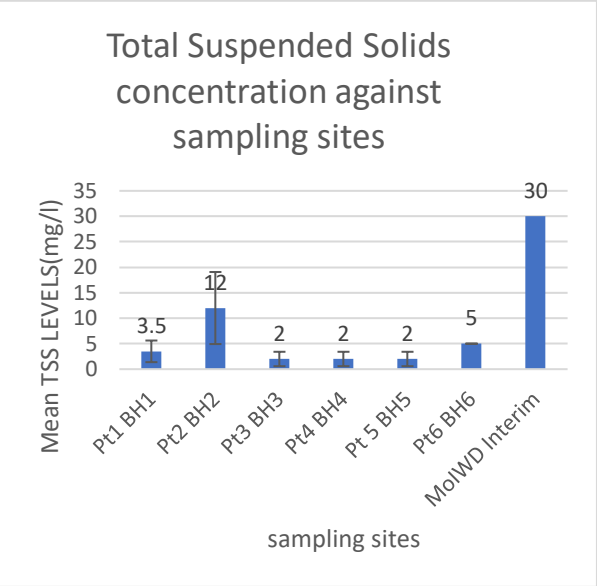





Turbidity concentration against sampling sites
Mean Turbidity levels(NTU)
30
25
20
15
10
5
0
0
4.5
1.5
0
4
0
25
Pt1 BH1
Pt2 BH2
Pt3 BH3
Pt4 BH4
Pt 5 BH5
Pt6 BH6
MoIWD Interim
sampling sites


Total Solids concentration against sampling site
Mean Total solids levels(mg/l)
2500
2000
1500
1000
500
0
1163.5
16.5
1388
1443
1204.5
1935.5
Pt1 BH1
Pt2 BH2
Pt3 BH3
Pt4 BH4
Pt 5 BH5
Pt6 BH6


Total Doissolved Solids concentration against sampling sites
Mean TDS levels(mg/l)
2500
2000
1500
1000
500
0
1160
987
1386
1441
1202.5
1930.5
2000
Pt1 BH1
Pt2 BH2
Pt3 BH3
Pt4 BH4
Pt 5 BH5
Pt6 BH6
MoIWD Interim
sampling sites


Total Suspended Solids concentration against sampling sites
Mean TSS LEVELS(mg/l)
35
30
25
20
15
10
5
0
3.5
12
2
2
2
5
30
Pt1 BH1
Pt2 BH2
Pt3 BH3
Pt4 BH4
Pt 5 BH5
Pt6 BH6
MoIWD Interim
sampling sites

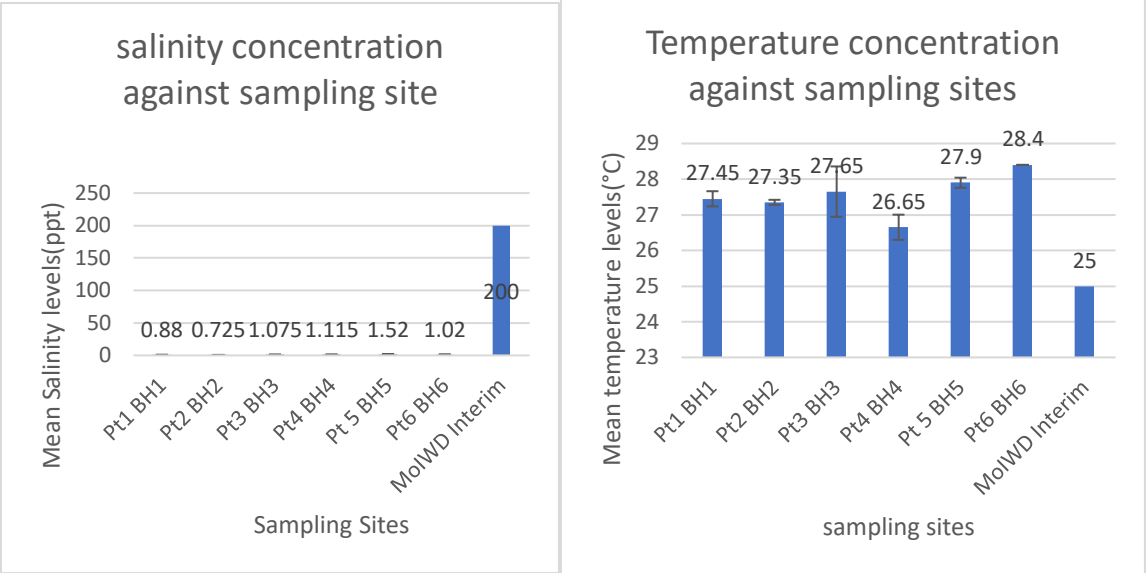


Figure 4. 1 Graphs above are showing Physical groundwater quality parameters for every sample point compared to MoIWD guideline values, showing that the majority of the sample sites had the pH within the acceptable ranges of MoIWD values.

4.3. Chemical characteristics of borehole water

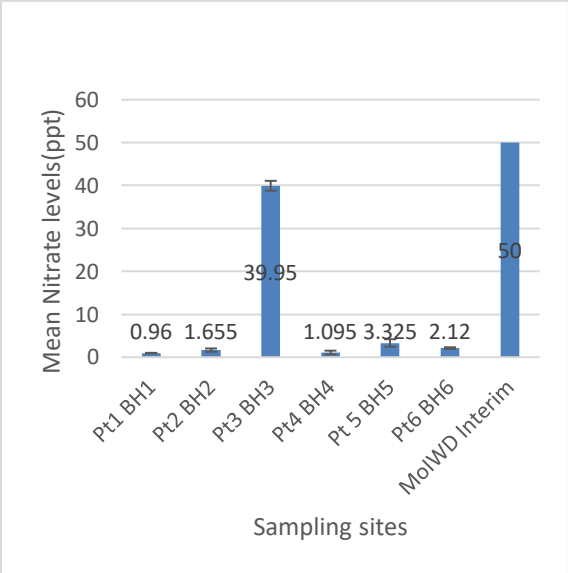
The results indicated that chemically, the quality of water from most of the boreholes was good. Nitrate and ammonia values given in table 4.2 were all below limiting values. For nitrate, the highest nitrate value of 39.995mg/l at the Dzinja borehole was registered but still, it was below the limit value 0f MBS and MoIWD which is 50mg/l. Unlike ammonia, nitrates have effects on human health, when it is available in the highest amount it can cause gastric cancer, can cause blue baby syndrome(Hellens, 2013), birth malformations, goiter, hypertension, and it can also cause cardiac arrest when the nitrate reacts with the medication of heart(Gupta et al., 2009). These results do not state that there is a major health problem in the area, merely that there might be a risk and further examinations would be important. The maximum values for chemical water quality recommended by MoIWD are given in the table in appendix 2.

These elements normally originate from agricultural input e.g., fertilizers and their increase in the water resource could be attributed to the farming activities and the

use of fertilizers in the gardens, which are leached or transported by runoff(Kördel & Klein, 2006). Nitrate levels in groundwater are used to investigate anthropogenic influences on groundwater quality and it correlates with other parameters(Kundu et al., 2008). Some samples close to the agricultural fields showed low nitrate content. From the Pearson correlation in Table 3, the positive correlation of coliforms with nitrate shows that the anthropogenic sources affect microbiological contamination of the area.

Table 4. 2 below is Showing chemical concentrations of different boreholes

		Nitrate(mg/l)	Ammonia(mg/l
Jali Police Station	Min	0.92	0.19
	Max	1	0.24
	Avg	0.96	0.215
	SD	0.056568542	0.035355339
Jali Epicentre	Min	1.38	7
	Max	1.93	14
	Avg	1.655	10.5
	SD	0.38890873	4.949747468
Dzinja	Min	39.18	11
	Max	40.81	14
	Avg	39.995	12.5
	SD	39.995	2.121320344
Jali Anglican	Min	0.79	0.06
	Max	1.4	0.07
	Avg	1.095	0.065
	SD	0.431335137	0.007071068
Chande	Min	2.71	0.17
	Max	3.94	0.21
	Avg	3.325	0.19
	SD	0.869741341	0.028284271
Pilimiti	Min	1.98	9
	Max	2.26	14
	Avg	2.12	11.5
	SD	0.197989899	3.535533906



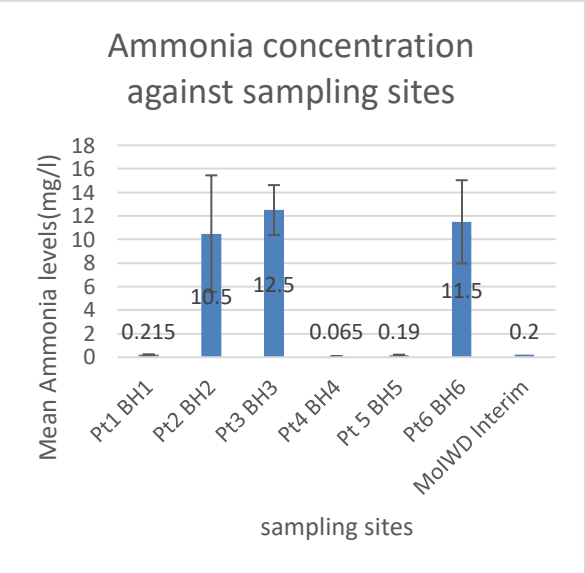


Figure 4. 2 Graphs are showing Nitrate and Ammonia concentration for every sample point as compared to MoIWD guideline values, Nitrate graph is showing that only one sample site was at the risk of high nitrate contamination.

Correlation Matrix of all the Parameters

The interactions between parameters of all the sampled boreholes were verified by Pearson correlation. The values used for correlation analysis ranged from 0 to 1, the zero value means no correlation and one means perfect correlation(Jannat et al., 2019). The negative value means that the relationship between the variables is negative or inverse meaning that when one variable is increasing the other decreases and the positive value means that there is a positive relationship meaning that when one variable is increasing the other variable also increases(Mendenhell et al., 2009). The values ranging from 0 to 0.4 mean there is a weak positive relationship between the variables while the value ranging from 0.5 to 1 implies a strong relationship, but the strength of the relationship differs, the 0.5 value implies a strong relationship while the value of 1 implies the strongest relationship.

Table 4. 3 below is Showing the Pearson correlation matrix for sample parameters using Microsoft excel 2016 version software, it shows how different variables are interrelated to each other.

	pH	EC(µ/cm)	Turbidity(NTU)	TSS(mg/l)	TDS(mg/l)	Temperature(°C)	salinity(ppt)	Nitrate(mg/l)	Ammonia (mg/l)	Total coliform(cfu/100ml)	Fecal Coliform(cfu/100ml)
pH	1										
EC(µ/cm)	0.702221	1									
Turbidity(NTU)	0.966999	0.654905672	1								
TSS(mg/l)	0.940343	0.636146534	0.954431087	1							
TDS(mg/l)	0.568048	0.984558593	0.515715058	0.503495345	1						
Temperature(°C)	-0.91375	-0.516590004	-0.848046695	-0.819548567	-0.37846673	1					
salinity(ppt)	0.991551	0.760110702	0.977489475	0.937502024	0.634647649	-0.87557163	1				
Nitrate(mg/l)	0.693535	0.589861941	0.724960642	0.625156591	0.500260468	-0.617114619	0.742931844	1			
Ammonia (mg/l)	-0.41845	-0.072657416	-0.315959669	-0.181017589	0.005690562	0.51217348	-0.350898402	0.070095398	1		
Total coliform(cfu/100ml)	-0.46763	-0.368180563	-0.410140844	-0.276247596	-0.312880465	0.234697954	-0.468666888	-0.280483184	0.564213185	1	
Fecal Coliform(cfu/100ml)	-0.34399	-0.172305484	-0.263650536	-0.075713734	-0.121684472	0.272351006	-0.317683814	-0.060446652	0.855907152	0.87303886	1

According to the results from table 4.3, it's showing that there's the strongest relationship between an equivalent variable (pH to pH) which is 1. Most of the parameters correlated with several other parameters, there was a big interaction between the parameters within the groundwater. this suggests that the presence of certain pollution indicators will influence the presence of another parameter (Woodbry, 2002). the rise of one parameter indicates the rise or decrease of another parameter. There is a strong positive correlation between pH and EC, EC and TDS, Salinity and pH, turbidity and TSS, Salinity and EC, Salinity and TDS, Faecal and Ammonia, and also there is a strong negative correlation between pH and temperature, Turbidity and temperature, and temperature and salinity. As an example, at higher TDS implies there are more cations than anions in water, and with more ions within the groundwater the groundwater's EC increases. Once we measure EC, we will indirectly determine its TDS concentration. When water's TDS is higher the salinity of the water also becomes higher. Also, the direct correlation of fecal coliforms with Ammonia and temperature from Table 4.3 of correlation of sample parameters indicates the presence of Faecal coliforms.

ANOVA Analysis

One-way Analysis of Variance (ANOVA) was conducted to work out the connection of the means of all the water quality measured at different study points of the area. it had been done supported a significance level of alpha(α) of 0.05. The ANOVA analysis revealed that there was no statistically significant difference ($p>0.05$) altogether in the measured water quality parameters among all the samples boreholes. The null hypothesis one could also be accepted because statistically there's no significant difference among the six different points within the T/A Mwambo since the $p= 0.973068192$ as shown in Table 7.4(Appendix 3).

Regression Analysis

In trying to predict the fecal coliforms within the borehole waters a water model tool was developed using the fit regression analysis by a Minitab 17 tool. All the predictors were chosen by looking at the p-values of each parameter on the model

summary in appendix 1(Table 7.2). On the model summary the regression equation was Fecal Coliform (CFU/100mg/l) = 7302 - 441 pH - 154.0 Temperature (°C) + 17.75 TSS (mg/l). The p-value for each term tests the null hypothesis that the coefficient is equal to zero (no effect). A low p-value (< 0.05) indicates that you can reject the null hypothesis. In other words, a predictor that has a low p-value is likely to be a meaningful addition to your model because changes in the predictor's value are related to changes in the response variable (Mendenhell et al., 2009). Regression coefficients represent the mean change in the response variable for one unit of change in the predictor variable while holding other predictors in the model constant. The sign of a regression coefficient tells you whether there is a positive or negative correlation between each independent variable and the dependent variable(Mendenhell et al., 2009). A positive coefficient indicates that as the value of the independent variable increases, the mean of the dependent variable also tends to increase. This analysis is important because it separates the role of one variable from all of the others in the model (Woodbry, 2002).

Table 4. 4 below is showing the measured values of dependent and independent variables as well as the predicted values of the predictors and response.

Parameter	Measured value	Predicted value
Ammonia (mg/l)	5.83	10
TSS (mg/l)	4.42	8
pH	6.93	9
Temperature (°C)	27.56	20
Faecal coliform (cfu/100ml)	167.33	548.4

From the results, at the time when the concentration of all predictors the ammonia, total suspended solids, pH, and temperature would be 10mg/l, 8 mg/l 9, and 20°C respectively, the concentration of fecal Coliform in water would be 548.4 CFU/100mg/l. Models have the predictive capacity and that they are also a relatively cheap tool as compared to monitoring (Chapra, 1997) since only a few reagents are used to measure the concentrations of the predictors.

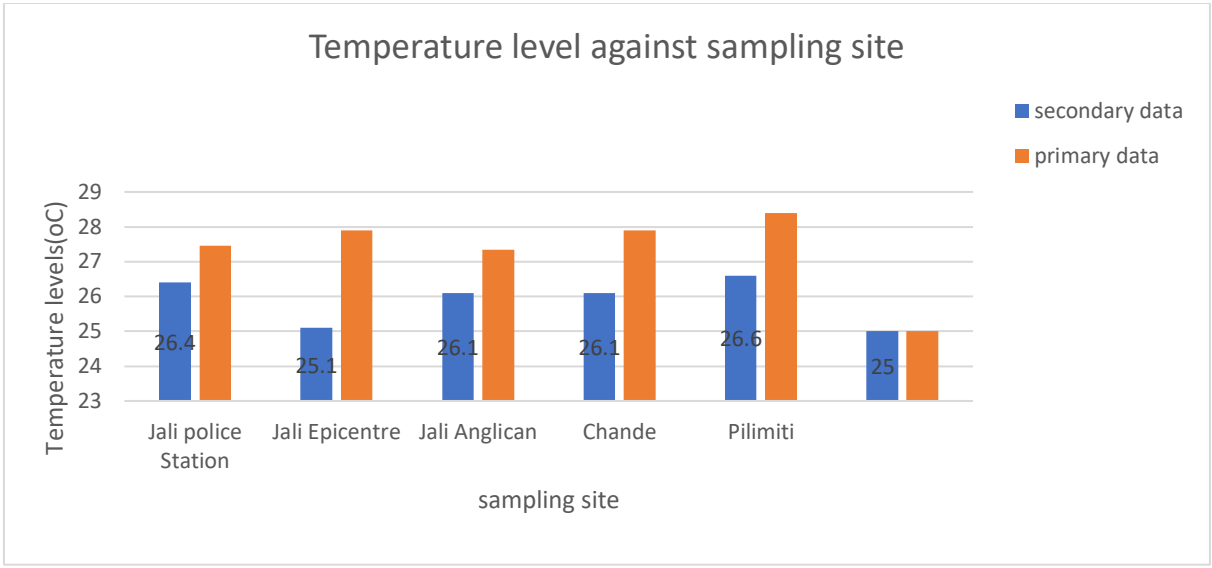
Table 4. 5 Below showing results of Groundwater quality of Malawi – fluoride, and nitrate of the Zomba-Phalombe plain by Anastasia von Hellens done in 2013(Hellens, 2013).

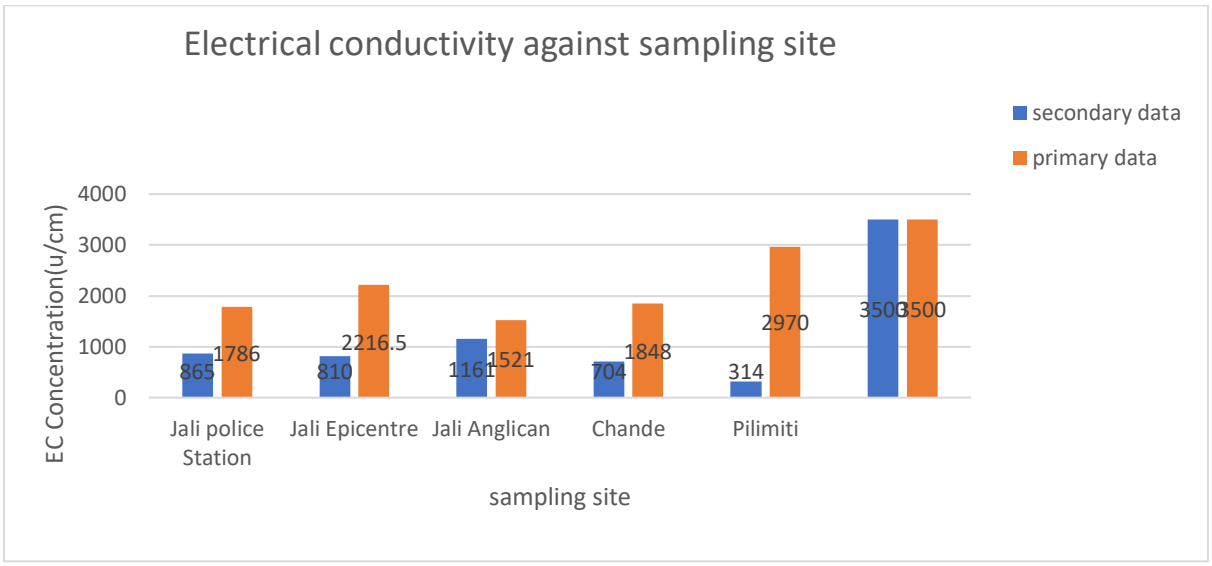
Sample ID	Station ID	pH	Nitrate	EC	Temperature
BH1	Jali Police Station	7.2	3.5	865	26.4
BH2	Jali Epicentre	6.9	2.5	810	25.1
BH4	Jali Anglican	6.9	1.5	1161	26.1
BH5	Chande	7	2	704	26.1
BH6	Pilimiti	6.7	0	314	26.6
MoIWD Interim		9.5	100	3500	25

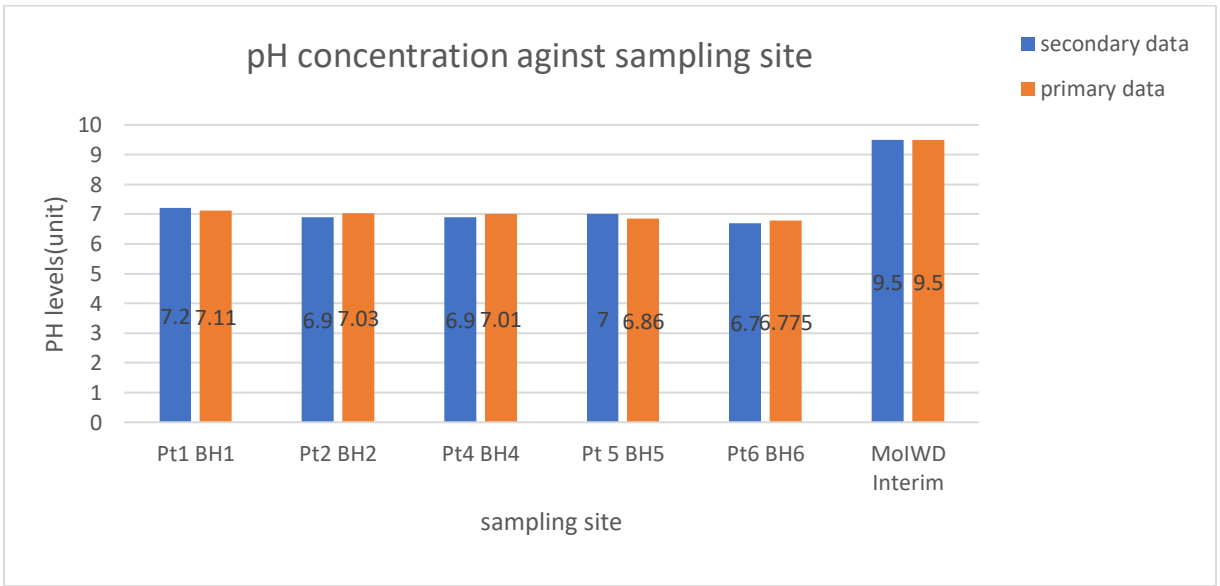
Table 4. 6 below is showing the results of physicochemical water quality obtained in this study.

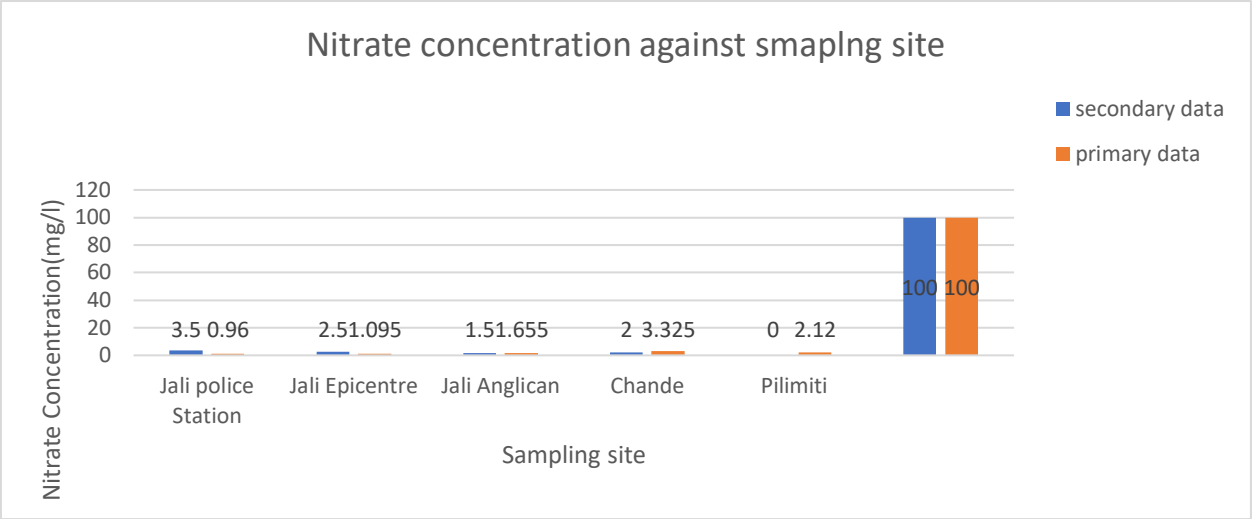
Sample ID	station ID	pH	Nitrate	EC	temperature
BH1	Jali police Station	7.11	0.96	1786	27.45
BH2	Jali Epicentre	7.03	1.095	2216.5	27.9
BH4	Jali Anglican	7.01	1.655	1521	27.35
BH5	Chande	6.86	3.325	1848	27.9
BH6	Pilimiti	6.775	2.12	2970	28.4
MoIWD Interim		9.5	100	3500	25

Figures 4. 4 Graphs Below are showing the variation of the different water variables for two different studies


Temperature level against sampling site
secondary data
primary data
Temperature levels(oC)
29
28
27
26
25
24
23
26.4
25.1
26.1
26.1
26.6
25
Jali police Station
Jali Epicentre
Jali Anglican
Chande
Pilimiti
sampling site


Electrical conductivity against sampling site
secondary data
primary data
EC Concentration(u/cm)
4000
3000
2000
1000
0
865
1786
810
2216.5
1161
1521
704
1848
314
2970
3500
3500
Jali police Station
Jali Epicentre
Jali Anglican
Chande
Pilimiti
sampling site


pH concentration aginst sampling site
secondary data
primary data
PH levels(unit)
10
9
8
7
6
5
4
3
2
1
0
7.2
7.11
6.9
7.03
6.9
7.01
7
6.86
6.7
6.775
9.5
9.5
Pt1 BH1
Pt2 BH2
Pt4 BH4
Pt 5 BH5
Pt6 BH6
MoIWD Interim
sampling site



The results show that there are almost similar pH values at every point in the two studies. The graphs also display that there are some variations in the EC, Nitrate, and temperature variables between the two studies. This means that there are some slight changes in anthropogenic activities taking place around this ar

4.4. Microbiological characteristics of borehole water

To determine the microbiological characteristics of the boreholes understudy, presumptive tests were conducted. The presumptive tests gave the coliform formed per 100 ml of samples.

Table 4. 7 Below gives the number of coliforms formed at various boreholes and the distances of the borehole from the pit latrine.

Station ID	Distance of borehole from pit latrine (m)	Total Coliform concentration (cfu/100ml)	Faecal Coliform concentration (cfu/100ml)
BH1	49.8	12	0
BH2	8.54	1014	364
BH3	15.45	630	252
BH4	10.1	840	154
BH5	27.7	204	0
BH6	26.1	500	234

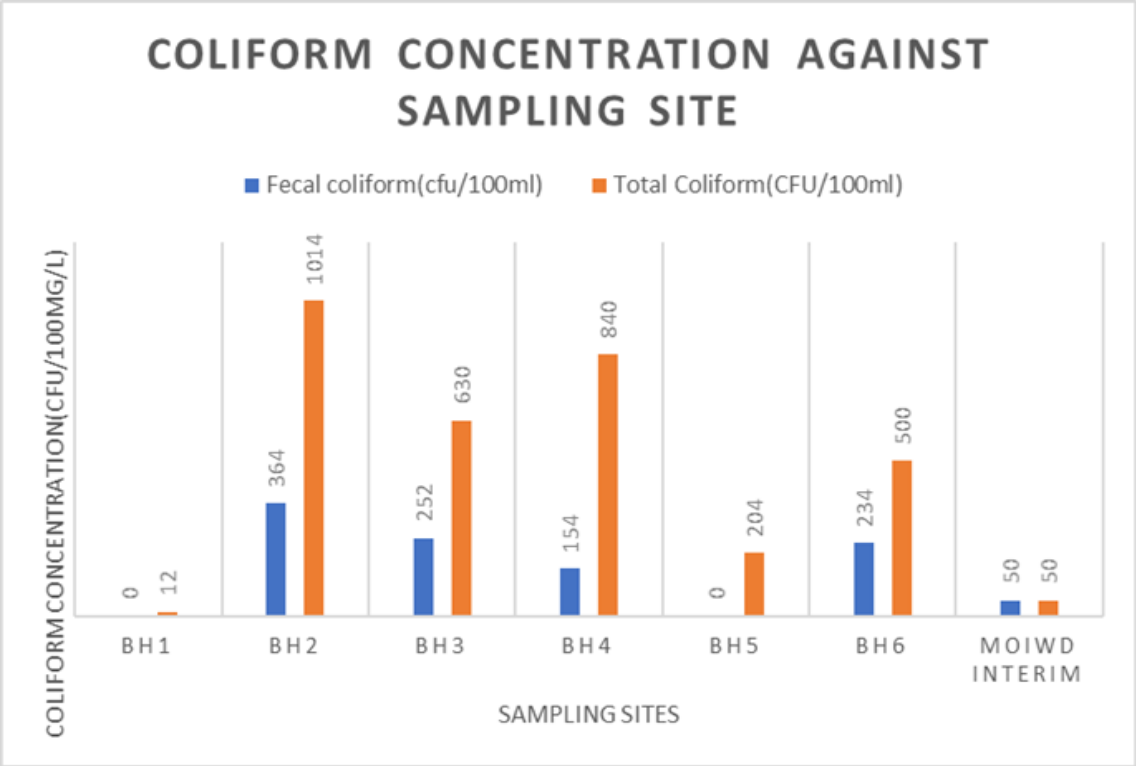


Figure 4. 5 above is showing the variations of fecal coliforms and total coliforms at different boreholes

Results tabulated in Table 4.2 indicate that groundwater water from most boreholes is polluted with both total and fecal matter as the values are much higher than the recommended values as given in a table in appendix 2. The analysis showed 12-1014 CFU/100ml total coliform. The analysis also showed 0 -364 CFU/100ml fecal coliform. Total coliform figures as high as 1014 CFU/100 ml and fecal coliform figures as high as 364 were recorded in boreholes sited close to the toilets (table 4.6). The 0CFU/100ml fecal coliform was found at the Jali police station and Chande boreholes.

All the samples tested for total coliform did not meet the total coliform guideline value of 50 CFU/100ml except for BH1 which had 12cfu/100ml, this means that 83.33% of the sampled boreholes did not meet the guidelines value and only 16% met the guideline values. About 33.33% of the samples tested met the fecal coliform guideline value of 50 CFU/100ml of the untreated water (MoIWD,2003) and 66.667% did not meet. All this suggests that boreholes are more polluted. Total and fecal coliform figures were much higher in boreholes sited at a distance of 8.54m, 10.2m, and 15.45m from onsite sanitation systems, the concentrations of total coliform 1014, 840, and 630 CFU/100mg/l respectively (Table 4.6). The presence of Fecal coliforms in water may indicate the presence of pathogens mainly bacteria, which are responsible for water-related diseases such as cholera, diarrhea, typhoid, and other gastrointestinal disorders(Blackwell, 2011; Mkandawire, 2008).

The high coliform content could be attributed to the movement of pollutants into water bodies by rainwater through groundwater recharge. Also, the high coliform count could be attributed to the horizontal movement of contaminants from pollution sources such as waste dumps, animal houses, and pit latrines which are sometimes located upstream and very close to these water points(Owa, 2014). Almost all the six sampled boreholes were within 50m distance from the pit latrines and animal houses, as it has been documented that when onsite sanitation systems

are located less than 50 m away from the wells and boreholes, the water from such wells will be polluted(Nkrumah, 2011). Therefore, the human activity of locating a pit latrine close to a borehole has contributed to the contamination of the groundwater with the microbiological pollutants in the area of study. And it can be said that the incidences of Cholera that almost each year occur in the area may be as a result of water contamination with the bacteria pathogens in the water.

According to the results found from the table relating the distance and the coliform concentrations, it is showing that at a shorter distance the concentration of coliforms was high while at a bigger distance the concentration of the coliforms was low. Therefore, hypothesis number two can be accepted.

4.5. Water quality index

The main objective of computing of Water Quality Index (WQI) was to change the complex water quality data into information that is easily understandable and usable.

Table 4. 8 . Below shows the Rating of Water Quality for various WQI(Jannat et al., 2019)

WQI	Rating of Water Quality
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
Above 100	Unsuitable for Drinking

Table 4. 9 Below shows The Measured Values of the Water Quality Parameters and MoIWD standards.

SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE6	MoIWD
7.11	7.01	6.8	7.03	6.86	6.775	9.5
1786.00	1521	2135.5	2216.5	1848	2970	3500
0.00	4.5	1.5	0	4	0	25
3.50	12	2	2	2	5	30
1160.00	987	1386	1441	1202.5	1930.5	2000
0.96	1.655	39.9	1.095	3.325	2.12	100
12	1014	630	840	204	500	50
0	364	252	154	0	234	50
0.08	0.725	1.075	1.115	1.52	1.02	200
27.45	27.35	27.65	26.65	27.9	28.7	25

From the table above all the maximum, permissible limits were from MoIWDfor untreated waters except for salinity on which the value is for chloride for drinking water as recommended by MBS (refer to the table in Appendix 2). WQI indicates the quality of water in terms of an index number that represents the overall quality of water for any intended use. The values of the calculated water quality index were 48.08032, 252.8302, 175.502, 189.8941, 77.15343, and 67.59894 for BH1, BH2, BH3, BH4, BH5, and BH6 respectively (Table 4.9) which show that only BH1 was suitable for any human use while the rest was not suitable. The WQI represented 16.67% good water quality,16.67% poor water quality,16.67% very poor water quality, and 50% extremely poor water quality of groundwater in the area.

Table 4. 10 below Shows Calculated water quality index values together with the water quality status as defined by Oni and Fasakin (Oni & Fasakin, 2016).

Sample ID	Station ID	WQI values	Water Quality Status
Pt1 BH1	Jali Police Station	48.08032203	Good
Pt2 BH2	Jali Epicentre	252.8301714	Unsuitable for drinking
Pt3 BH3	Dzinja	175.5019727	Unsuitable for drinking
Pt4 BH4	Jali Anglican	189.8940644	Unsuitable for drinking
Pt 5 BH5	Chande	77.15343053	Very Poor
Pt6 BH6	Pilimiti	67.59893989	Poor

The excellent water quality can be put to uses like drinking, irrigation, and industrial uses. The poor water quality can be used for irrigation and industrial usages. The very poor water quality can only be used for irrigation(Jannat et al., 2019). The

water which had an index value above 100 that water cannot be put to any use without proper treatment since it has a lot of constituencies that can cause harm.

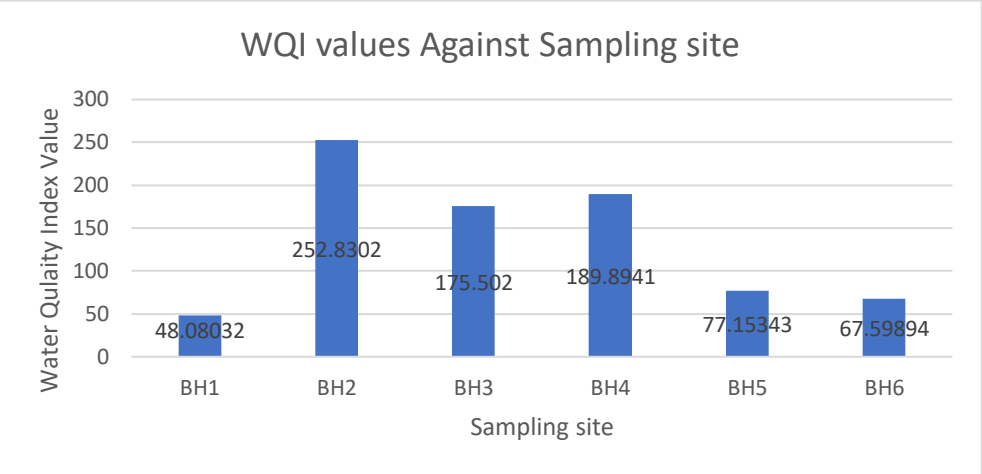


Figure 4. 6 above displays the water quality index ratings of all the sampled boreholes.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Based on the utilisation of WQI, this study presents the assessment of groundwater quality from the areas around Lake Chilwa in six different sampling sites. The overall conclusion is that some indicators put into indication mostly microbial pollution because most of the boreholes were found to possess high coliforms as compared to maximum permissible limits for MoIWD and MBS for untreated water. It had been also concluded that the WQI method may be a very effective tool for determining the quality of water vulnerable to pollution and communicating it to the less knowledgeable people as well as stakeholders within the water industry. One of the advantages of employing a water quality index in assessing the general quality of the water is that it sums up numerous data into a single value in an unbiased, rapid, and logical way, it evaluates different areas and detects changes in water quality and also the index value can relate to the potential use of that source of water.

5.2. Recommendations

There is a requirement for civic education of the communities to boil and if possible, chlorinate drinking water from these boreholes to scale back the number of disease-causing micro-organisms. Additionally, there is a need for frequent water quality monitoring activities using the water quality index approach so that appropriate action is taken for those boreholes that produce water of unacceptable quality by the legislative makers.

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7. APPENDICES

Appendix 1

Table 7. 1 showing how the water quality index was calculated in the Microsoft Excel version 2016.

		BH1		BH2		BH3		BH4		BH5		BH6	
PARAMETERS	Wn	Qn	WnQn	Qn	WnQn	Qn	WnQn	Qn	WnQn	Qn	WnQn	Qn	WnQn
pH	0.38364	74.8421	28.7122	73.7895	28.3084	71.578947	27.46033	74	28.389136	72.210526	27.7026	71.315789	2.5991405
EC	0.00104	51.0286	0.05314	43.4571	0.04525	61.014286	0.0635342	63.328571	0.0659441	52.8	0.05498	84.857143	3.092662
Turbidity	0.14578	0	0	18	2.62408	6	0.8746923	0	0	16	2.33251	0	0
TSS	0.12149	11.6667	1.41733	40	4.8594	6.6666667	0.8099003	6.6666667	0.8099003	6.6666667	0.8099	16.666667	0.6074252
TDS	0.00182	58	0.10569	49.35	0.08993	69.3	0.1262837	72.05	0.131295	60.125	0.10956	96.525	3.5179031
Nitrate	0.03645	0.96	0.03499	1.655	0.06032	39.9	1.4541759	1.095	0.0399078	3.325	0.12118	2.12	0.0772645
Total coliform	0.07289	24	1.74938	2028	147.823	1260	91.84269	1680	122.45692	408	29.7395	1000	36.445512
Fecal coliform	0.07289	0	0	728	53.0647	504	36.737076	308	22.450435	0	0	468	17.0565
Salinity	0.01822	0.04	0.00073	0.3625	0.00661	0.5375	0.0097947	0.5575	0.0101592	0.76	0.01385	0.51	0.0185872
Temperature	0.14578	109.8	16.0069	109.4	15.9486	110.6	16.123495	106.6	15.540366	111.6	16.2693	114.8	4.1839448
	1		48.0803		252.83		175.50197		189.89406		77.1534		67.598939
WQI			48.0803		252.83		175.50197		189.89406		77.1534		67.598939

Table 7.2 below shows how the three variables (temperature, pH, ammonia, and TSS) which are the independent ones tries to explain the dependent variable which is fecal coliform. It has been obtained using Minitab 17 tool by the fit regression model.

```
Model Summary

      S    R-sq  R-sq(adj)  R-sq(pred)
45.1979  98.08%     90.41%       0.00%


Coefficients

Term                Coef  SE Coef  T-Value  P-Value   VIF
Constant            7302     3528     2.07    0.287
pH                  -441      340    -1.30    0.418  5.36
Temperature(°C)  -154.0     53.9    -2.86    0.214  2.44
TSS(mg/l)         17.75     8.55     2.08    0.286  2.73
Ammonia (mg/l)    15.34     6.28     2.44    0.247  3.76


Regression Equation

Fecal Coliform(cfu/100mg/l) = 7302 - 441 pH - 154.0 Temperature(°C)
+ 17.75 TSS(mg/l)+ 15.34 Ammonia (mg/l)
```

TABLE 7.4 ANALYSIS OF VARIANCE

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	442202.9	5	88440.58396	0.168974432	0.973068192	2.36827
Within Groups	31403775	60	523396.2488			
Total	31845978	65				

.

Table 7.5 Below is showing the electrode detailed specifications and measurement limits of multiprobe aqua meter AP700-800.

Optical Dissolved Oxygen	Range	0 – 500.0% / 0 – 50.00 mg/L
	Resolution	0.1% / 0.01mg/L
	Accuracy	0 - 200%: ± 1% of reading. 200% - 500%: ± 10%
Conductivity (EC)	Range	0 – 200 mS/cm (0 - 200,000 µS/cm)
	Resolution	3 Auto-range scales: 0 – 9999 µS/cm, 10.00 – 99.99 mS/cm, 100.0 – 200.0mS/cm
	Accuracy	± 1% of reading or ± 1µS/cm if greater **(see note 2)**
TDS*	Range	0 – 100,000 mg/L (ppm)
	Resolution	2 Auto-range scales: 0 – 9999mg/L, 10.00 – 100.00g/L
	Accuracy	± 1% of reading or ± 1mg/L if greater **(see note 2)**
Resistivity*	Range	5 Ω•cm – 1 MΩ•cm
	Resolution	2 Auto-range scales: 5 – 9999 Ω•cm, 10.0 – 1000.0 KΩ•cm
	Accuracy	± 1% of reading or ± 1 Ω•cm if greater **(see note 2)**
Salinity*	Range	0 – 70 PSU / 0 – 70.00 ppt (g/Kg)
	Resolution	0.01 PSU / 0.01 ppt
	Accuracy	± 1% of reading or ± 0.1 unit if greater **(see note 2)**
Seawater Specific Gravity*	Range	0 – 50 σ_t
	Resolution	0.1 σ_t
	Accuracy	± 1.0 σ_t
pH	Range	0 – 14 pH / ± 625mV **(see note 3)**
	Resolution	0.01 pH / ± 0.1mV
	Accuracy	± 0.1 pH / ± 5mV
ORP	Range	± 2000mV **(see note 3)**
	Resolution	0.1mV
	Accuracy	± 5mV
Depth (-D models only)	Range	± 0 – 60.00 m
	Resolution	1cm
	Accuracy	± 0.2% FS
Temperature	Range	-5°C – +50°C (23°F – 122°F)
	Resolution	0.01°C
	Accuracy	± 0.1° C

Ammonium / Ammonia†	Range	0 – 9,000mg/L (ppm)
	Resolution	2 Auto-range scales: 0.00 - 99.99 mg/L, 100.0 – 8,999.9 mg/L
	Accuracy	± 10% of reading or 2ppm (whichever is greater)
	MLD[1]	1.0 ppm
	Interfering Ions[2]	Potassium, Sodium and Magnesium
	pH Range[3]	5 - 8
Chloride	Range	0 – 20,000mg/L (ppm)
	Resolution	2 Auto-range scales: 0.00 - 99.99 mg/L, 100.0 – 19,999.9 mg/L
	Accuracy	± 10% of reading or 2ppm (whichever is greater)
	MLD[1]	2.0 ppm
	Interfering Ions[2]	Bromide, Iodide, Cyanide and Sulphide
	pH Range[3]	2 - 11
Fluoride	Range	0 – 1,000mg/L (ppm)
	Resolution	2 Auto-range scales: 0.00 - 99.99 mg/L, 100.0 – 999.9 mg/L
	Accuracy	± 10% of reading or 2ppm (whichever is greater)
	MLD[1]	0.05 ppm
	Interfering Ions[2]	Hydroxide (OH-)
	pH Range[3]	4 - 8
Nitrate	Range	0 – 30,000mg/L (ppm)
	Resolution	2 Auto-range scales: 0.00 - 99.99 mg/L, 100.0 – 29,999.9 mg/L
	Accuracy	± 10% of reading or 2ppm (whichever is greater)
	MLD[1]	0.5 ppm
	Interfering Ions[2]	Chloride, Bromide, Fluoride, Sulphate, Chlorate and Perchlorate
	pH Range[3]	3 - 10
Calcium	Range	0 – 2,000mg/L (ppm)
	Resolution	2 Auto-range scales: 0.00 - 99.99 mg/L, 100.0 – 1,999.9 mg/L
	Accuracy	± 10% of reading or 2ppm (whichever is greater)
	MLD[1]	0.05 ppm
	Interfering Ions[2]	Magnesium, Barium, Lead, Zinc and Sodium
	pH Range[3]	4 - 9

Appendix 2: Showing WHO and MBS guidelines standard for water quality

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

Appendix 3

The figures below show some of the materials that were used for sample analysis both in the laboratory and field.



Membrane filtration unit



Incubator for Total coliform



pH meter dipped into a basin



Borosilicate glass bottles



Autoclaving Machine



Analyses of coliforms



Multiprobe Aqua meter package



Analyses of nitrate and ammonia

The figures below show all the sampled boreholes



Jali police station Borehole (BH1)



Dzinja borehole (BH3)



Pilimiti borehole (BH6)



Jali epicentre borehole (BH2)



Jali Anglican borehole (BH4)