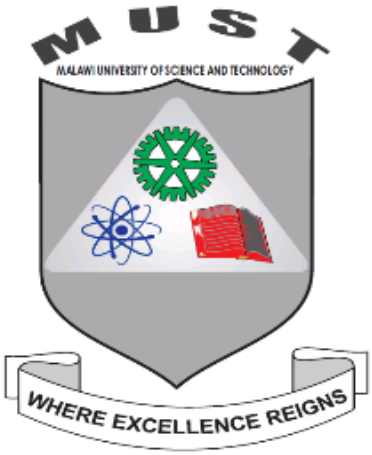


ASSESSMENT OF GROUNDWATER QUALITY IN TA N'GABU, CHIKWAWA

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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 Bachelor of Science degree in Earth Science.

JULY, 2021

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ABSTRACT

Groundwater resources in some parts of the lower section of the Shire River valley, Malawi, are not potable for rural domestic water supply due to high salinity. Knowledge of spatial variation of water quality is essential in locating and sustaining usable water supplies. In this study, a comprehensive assessment of the quality of groundwater from the Malemia village has been conducted to determine salinity status of boreholes, assess the spatial variation of water salinity among the boreholes and show the relationship between the groundwater chemistry and the geology of the Malemia village in TA Ngabu. Groundwater samples were collected from four boreholes in Malemia Village and at each borehole two samples were collected. Then the samples were analysed for physical chemical parameters. The results were evaluated and compared with WHO and MBS water quality standards. Sodium and bicarbonate are dominant ions among cations and anions. EC, TDS, Chlorine, Carbonate, Bicarbonate, Calcium, Magnesium and Sodium exceeded the acceptable limits of WHO and MBS drinking water recommended guideline. The correlation matrix shows that physical- chemical parameter of the borehole water significantly affects the salinity in the area. On that note TA Ngabu has high salinity levels which is caused by rock-water interactions and evaporation-sedimentation processes as revealed by Gibbs diagram. The piper trilinear diagram shows that all groundwater samples are calcium magnesium bicarbonate type (Ca-(Mg)-HCO_3) which are associated with high salinity. The studied results reveal that the groundwater in TA Ngabu is brackish and slight to moderate saline, this shows that salinity is an issue in the area as evidenced by people in the study area who abandoned the boreholes because of high salinity levels and opt for unprotected water sources for water supply. To respond to the salinity problems in the area: desalination water treatment methods should be employed, experienced and suitably qualified hydrogeologists should be employed for good borehole siting and management in areas of high salinity levels and finally monitoring programs should be put in place to frequently monitor the quality of the water being used by people in the TA Ngabu.

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ACRONYMS/ABBREVIATIONS

EC: Electric conductivity (in µs/cm)**,** Best Measure of Salinity

GIS: Geographical Information Systems

MBS: Malawi Bureau of Standards

Mg/L: Milligrams per Litre

pH: Hydrogen Ion Activity

TDS: Total Dissolved Solids

NTU - Nephelometric Turbidity Units

WHO: World Health Organization

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ASSESSMENT OF GROUNDWATER QUALITY IN TA N'GABU, CHIKWAWA

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Water is essential to sustain human life and is at the Centre of Sustainable Development Goals (SDGs) which target to ensure availability and sustainable management of water and sanitation for all by 2030 (UN, 2015). Lack of access to sufficient water supply of acceptable quality leads to incidences of waterborne and sanitation related diseases which affect public health and the country's economic productivity (WHO/UNICEF, 2015). Most water used for drinking comes from groundwater that makes groundwater resources to be more important than any other sources. Mostly, water is drawn from an aquifer which happens to be formed from rocks. Some aquifers do not provide portable water for drinking due to the interaction of water and rocks which changes physical-chemical properties of water and one adverse impact is salinity. The high saline water cause diarrhoea and abdominal pain as it has been evidenced by (Chakrabrty, Khalid, & Islam, 2019). The groundwater is obtained through the means of hand-pumped boreholes which mostly provides untreated, unmonitored and even with poor quality water. Malawi experiences saline water conditions particularly in the Lower shire valley, Eastern Bwanje valley and around Lake Chilwa. As such, the utilization of groundwater in these areas is limited due to high content of fluoride, sulphates, nitrates and total dissolved solids.

Significant studies on water quality in Malawi have been undertaken but there is limited literature on the issues of water salinity status of different aquifers (Rango et al, 2012S). So this project assesed the groundwater quality from boreholes in Malemia village within Tradition Authority Ngabu in Chikwawa and to determine if the water is safe for consumption and other domestic purposes. This will be done through comparing with the standards recommended by the World Health Organisation (WHO) and the Malawi Bureau Standards (MBS).

1.2 PROBLEM STATEMENT

Salinity in ground and surface water is common in Malawi. One of the reasons for high

salinity is the alluvial deposits as shown in lower shire (Missi, 2018). The salinity challenge is also c

1.3 RESEARCH QUESTIONS

This research seeks to answer the following question:

- What is the salinity status of the boreholes in Malemia village, TA Ngabu and does the groundwater meet the appropriate drinking standards?
- What is the salinity levels among the boreholes in study area?
- How can groundwater's hydrochemistry be related to the underlying geology?

1.4 RESEARCH OBJECTIVES

The main objective of this research is to assess the suitability of the groundwater for drinking purpose for basic human needs. And it has the following specific objectives:

- To determine the salinity status of boreholes in Malemia village, TA Ngabu by measuring physical chemical paramters of water.
- To assess the spatial distribution of salinity levels among the boreholes in the study area.
- To show the relationship between the groundwater's hydrochemistry and the underlying geology.

1.5 SIGNIFICANCE OF THE STUDY

Water is at the core of sustainable development and is critical for socio-economic development, health, and human survival. There are some water uses including domestic, recreation, and industrial purposes (Monjerezi, 2012). For example, the benefits of water can range from drinking, washing, and irrigation of crops. The results of this study will provide helpful information to local policy-makers managing the important fresh groundwater resources and allocation of usable supplies in the study area. This study will help people in TA Ngabu to start using quality water for domestic purposes. This study will also help to bridge the knowledge gap by evaluating drinking water quality and adoption rate of household water treatment and storage (HWTS) practices. Data that will be generated by this study may help high water salinity-affected

countries to take preventive measures and develop appropriate policies and community action plan

CHAPTER 2: LITERATURE REVIEW

2.1 METHODOLOGIES AND MATERIALS FOR ASSESSING GROUND WATER QUALITY

Several researchers have proposed different methods for analysing water quality data. Monjerezi and Ngongondo (2012) used Water Quality Index (WQI), total hardness (TH), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), and salinity hazard (EC) as the most effective ways to communicate water quality. These methods help to highlight the spatial variation in quality and major ion content of groundwater in the lower section of the Shire River valley (Chikhwawa district) and evaluates the suitability of the groundwater for irrigation and drinking purposes for sustainable agriculture and basic human needs, respectively. All water samples were analysed for physical characteristics and main chemical components using standard methods. Temperature, pH (ISO 10523-1:1994) and electrical conductivity (EC) (ISO 7888:1985) were measured in the field, while the rest of the parameters (Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, , , and total dissolved solids (TDS)) were determined in a laboratory using the procedures in APHA(2005). The concentrations of Na^+, K^+, Ca^{2+} and Mg^{2+} were determined using fl ame atomic absorption spectroscopy (Buck Scientific Model 200A) whereas ,and Cl^- were determined using acid and silver nitrate titrations, respectively (APHA, 2005). The concentration of sulphates was determined turbidimetrically (barium sulphate; APHA 2005) and TDS were determined gravimetrically by evaporation (APHA, 2005).

Khan and Jhariya (2017) assessed the groundwater quality for drinking purpose using Water quality index (WQI) and Geographic Information System (GIS). Eight water quality parameters were considered to ascertain water quality index and these were pH, chloride, fluoride, calcium, magnesium, alkalinity, hardness and nitrate. The Local standards (Bureau of India Standards (BIS, 2009) and international standards (WHO standards) were considered to assess the suitability of groundwater for drinking purposes and for the calculation of WQI. The methods help in proper planning and management of available water resource for drinking purpose.

Grimason, et al., (2013) assessed the quality of using water quality. samples of water from each b

Chidya and Matamula (2016) assessed water quality by evaluating the selected physico-chemical quality of water from boreholes. The following physico-chemical parameters were measured in situ: pH, water temperature, and conductivity (EC) using precalibrated portable and digital multi-Parameter PCSTestr (model 35, EUTECH Instruments, USA). Turbidity was measured using a calibrated portable Turbidimeter (model no. DRT-15CE, HF scientific, Inc., 3170 Metro Parkway, USA). Prior to calibration and water sample measurements, the cuvettes used for instrument calibration and sample measurement were indexed as described in the operation and maintenance manual for the meter. The following chemical parameters were analysed in the laboratory within the recommended time frame: Nitrate (NO^{-}_{3}), Sulphate (SO^{2-}_{4}), Fluoride (F^{-}), Magnesium (Mg), Calcium (Ca), Iron (Fe) and Zinc (Zn) (APHA, 1998; EPA, 2009; WHO, 2008). The anions (NO^{-}_{3}, SO^{2-}_{4} and F^{-}_) were measured using the DIONEX 2000i Ion Chromatography (IC) system while cations (Mg^{2+}, Ca^{2+}, Fe^{+} and Zn^{+}) were measured using a Sequential Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) (JobinYvonne JY-24). The results of the study were compared with national (Malawi Bureau of Standards (MBS)) and international standards (World Health Organization (WHO) for drinking water. The method help to determine the suitability water for drinking and other domestic uses.

2.2 GROUNDWATER IN MALAWI

Groundwater is of variable quality and quantity which is recharged in aquifer from broad interfluves. Generally, aquifers in Malawi have a limited lateral extent with a lenticular shape. Monjerezi and Ngongondo (2012) documented the four major aquifer units in Malawi. These are weathered basement rocks, Karoo and Cretaceous sedimentary rocks, weathered basalts, and unconsolidated alluvial deposits. Water in weathered basement complex aquifers shows hydraulic continuity with water in the alluvial valley floor. The Quaternary alluvial aquifer exists along the Lake Malawi shores and Lower Shire valley within the Great Rift Valley floor. On the central axis of the valley, water level contours show that groundwater flows towards the shire river. The water table for unconsolidated alluvial deposits is within three- six-meter depth (Monjerezi and Ngongondo, 2012). Data on groundwater quality in aquifers in Malawi is scarce in

referenced scientific publications. Groundwater compositions appear to be spatially variable and hi

2.3 SALINITY ISSUES IN MALAWI

Salinization of water resources is one of the most prominent incidents of water quality degradation, particularly in arid and Semi-arid zones. A report by the British Geological survey (BGS, 2004) documented that groundwater in some parts of Malawi is characterized by high salinity as a result of evaporative concentration or dissolution of evaporative minerals in sedimentary rocks. Some areas affected by salinity are; the Lake Chilwa basin and lower shire in southern Malawi. Down the shire river valley, Neno has also reported areas of high saline water (MoIWD, 2011).

2.4 PROCESSES THAT CONTROLS CHEMICAL COMPOSITION OF GROUNDWATER

2.4.1 WATER-ROCK INTERACTION

Groundwater chemistry is largely a function of mineral composition, the formation through which it flows due to rock-water interaction. Evaporation and concentration, dilution due to precipitation also can change the chemical composition of groundwater but rock-water interaction is the major process because solid phases (inorganic and organic matter) are the primary sources and inks of dissolved constituents of groundwater (Champamba et al, 2009). During groundwater movement along its path from recharge to discharge areas, a variety of chemical reactions with solid phases take place. These chemical reactions will vary spatially and temporally, depending on the chemical nature of the initial water, geological formations and residence time. The resulting concentrations of major ions of groundwater can be used to identify the intensity of rock-water interaction and chemical reactions (Elango and Kannan, 2007). (Rivett et al, 2018) have inferred that evaporation-direct and indirect (capillary action), chemical weathering and dissolution of (halite and gypsum) evaporitic salts, and upwelling in faulted areas. Carbonate weathering, silicate weathering, halite, gypsum dissolution and precipitation are common in an alluvial aquifer system.

2.4.2 WEATHERING AND DISSOLUTION

calcium and magnesium are the dominant ions found in groundwater it reveals that

dissolution of carbonate minerals is responsible for them. During infiltration or along the flow, groun

2.4.3 GROUNDWATER TYPES

Groundwater is classified into different types according to the percentage of chemical constituents present in it. This difference in groundwater rose mainly from different kinds of rock-water interaction (Krishna , Logeshkumaran , Magesh , Godson , and Chandrasekar, 2014). Generally, Ca-HCO_3, Ca-Mg-HCO_3, Ca-Cl, Na-HCO_4, Na-Cl, Ca-SO_4 and Na-SO_4 are the important groundwater types found throughout the world. A piper ternary diagram (Piper, 1944) helps us to classify groundwater simply as in Fig. 1. Dissolution of calcite, dolomite, gypsum and halite will give rise to Ca-HCO_3, Ca-Mg-HCO_4, Ca-SO_4 and Na-Cl type of groundwater, respectively. Huge amount of Ca and HC03 ions from calcite is responsible for Ca-HCO_3; Ca, Mg and HCO_3 ions that come from dolomite is responsible for Ca-Mg-HCO_3; Ca and SO_4 ions that come from gypsum is responsible for Ca-SO_4; Na and Cl that come from halite is responsible for Na-Cl.

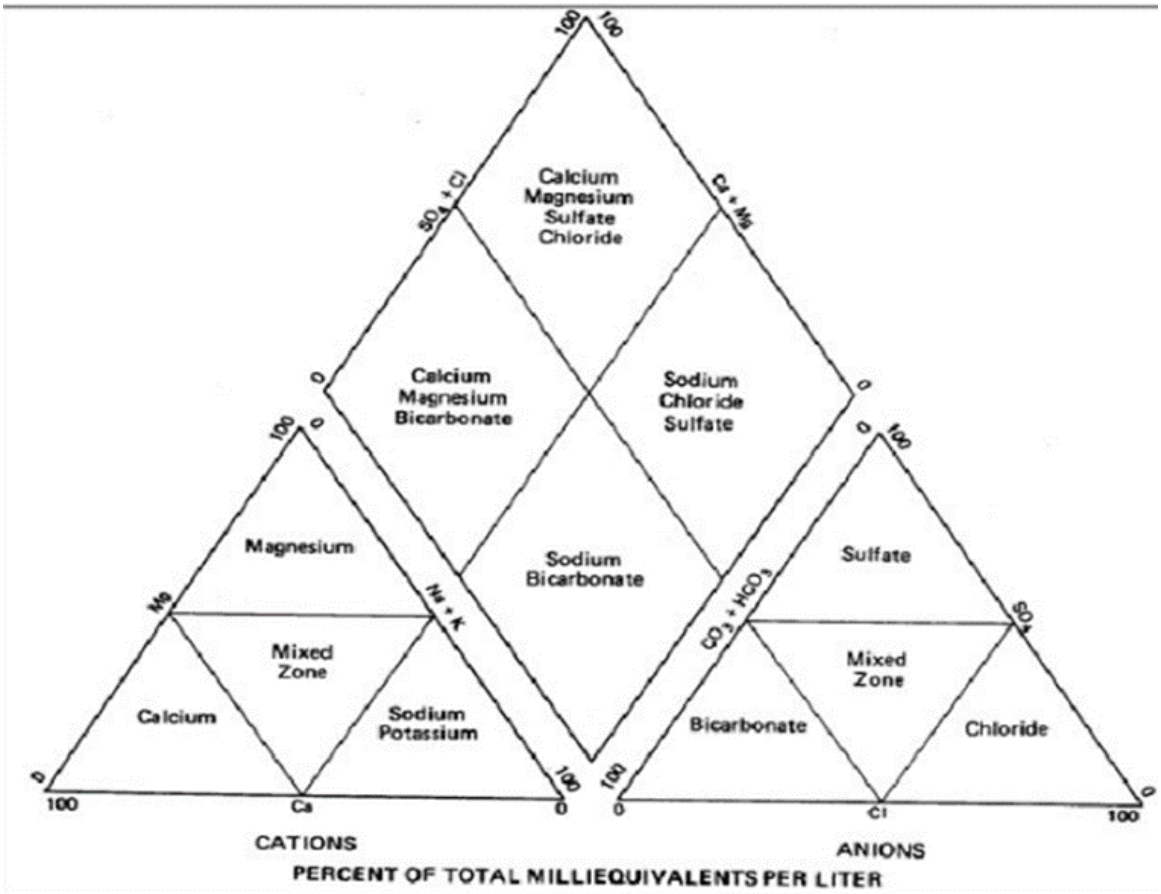


Figure 1: Piper diagram showing groundwater types (Piper, 1944)

2.4 GROUNDWATER SALINITY OCCURRENCE IN TA NGABU

The salinity problem faced by TA Ngabu is defined through the salinity occurrence relevant to drinking water supply. Salinity generally increases down the hydraulic gradient, and with river proximity, recognizing alluvial aquifers in Southern Malawi (Chilton and Smith-Carrington, 1983). The key mechanisms that controls the salinity occurrence in TA Ngabu are evaporation-direct and indirect (capillary action), chemical weathering and dissolution of (halite and gypsum) evaporitic salts, and upwelling in faulted areas (Rivett et al., 2018). Elevated salinity with river proximity arise from shallow water table phreatic evaporation, low hydraulic gradients across the plain, and the low flows in the frequent, low permeability, silt-clay laminations that promote evapo-concentration of groundwater solutes (Bath, 1980). Cyclic periods of wetting and drying following flood events also promote soil salinisation and sodification through capillary rise; evaporites re-dissolve in rainy season precipitation infiltrating back into shallow groundwater further enriching salinity.

2.5 GROUNDWATER QUALITY IN MALAWI: LOWER SHIRE

The alluvial deposits of the lower Shire have a high content of salts and influence the water quality in the region (Sajidu, Masamba, Thole, & Mwatseteza, 2008). High sulphate concentrations have also been reported in some areas of weathered basement. Further, fluoride problems are expected to be high because of Great East African Rift that affects the country. High fluoride concentrations have been reported in some parts of the alluvial aquifers as well as in the basement. In addition, groundwater resources in Chikwawa, lower shire, comprises of high concentration of solutes which were analyzed in several ranges that caused to be suggested that hydrochemistry is controlled by various intermixed processes, including, mixture of saline water and water-rock interaction (Monjerezi and Ngongondo, 2012). Groundwater has been a main source of water in several places of Chikwawa and including, rural areas in Malawi (Southern Africa Development Corporation (SADC, 2002). Even though, this is well known but the chemical quality of groundwater in lower shire has received little attention from the scientific community.

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Water quality refers to the chemical, physical, and biological characteristics of water based on the standards of its usage. Water quality depends on physical, chemical and biological parameters contained in water. The physical parameters include Electric conductivity (EC), pH, Temperature, Dissolved oxygen (DO) and Total Dissolved solids (TDS). The chemical parameters are: natural inorganic constituents commonly dissolved in water that are mostly likely to affect water use include bicarbonate, carbonate, calcium, magnesium, Nitrate, Chlorides, fluoride, Manganese, Cadmium, arsenic, Iron and lead (Mkandawire, 2008). Table 1 below shows the characteristics of water that the water quality.

Table 1: Characteristics of water that affect Water Quality (Flitts, 2012)

PHYSICAL PARAMETER	PRINCIPAL CAUSE	SIGNIFICANCE	REMARKS
pH (Hydrogen ion activity)	Dissociation of water molecules and of acids and bases dissolved in Water	The pH of water is a measure of its reactive characteristics. Low values of pH (pH<4), indicate a corrosive water that will tend to dissolve metals and other substances that it contacts. High values of pH, (pH>8 .5) indicate an alkaline water that, on heating, will tend to form scale. The pH affects the treatment and use of water.	pH values: Less than 7, water is acidic. Value of 7, water is neutral. More than 7, water is basic.
Electrical conductance	Substances that form ions when dissolved in water	Most substances dissolved in water dissociate into ions that conduct an electrical current. As such EC is a valuable indicator of the amount of material dissolved in water. The	Conductance values indicate the electrical Conductivity, in micro-seimens of 1 cm3 of water at a temperature of

		larger the conductance, the more mineralized the water.	25°C. The EC can be classifie
Total dissolved solids	Mineral substances dissolved in water	It is a measure of the total amount of minerals dissolved in water. It is a very useful parameter in the evaluation of water quality. Water containing less than 500 mg/L is preferred for domestic use and for many industrial processes	USGS classification of water based on TDS (mg/L): Less than 1,000: Fresh. 1,000-3,000: Slightly saline. 3,000-10,000: Moderately Saline. More than 35,000: Briny

2.6 WATER QUALITY STANDARDS

Water Quality Standards and Guidelines are primarily aimed at protecting public health and aquatic life. The standards and guidelines are established case wise by each country to regulate the levels of contaminants permitted in their various water sources (Flitts, 2012). They consist of the water quality criteria to protect users, determine if they are being attained, water body's designated uses, and anti-degradation policies to protect high-quality water bodies. Water quality degradation has attracted the attention of many organizations such as WHO in efforts to promote a worldwide response to water quality deterioration. The WHO Guidelines for Domestic-Water Quality (GDWQ) covers the Physical, chemical and microbiological aspects of water quality (WHO, 2018).This research used the MBS and WHO standards in the analysis of the physical-chemical analysis of water and these standards are presented in table 2 below.

Table 2: Water Quality Standards. World Health Organization (WHO) Drinking Water Guidelines (WHO, 2011) and Malawi Bureau of Standards (MBS) Maximum Permissible Levels (MBS, 2005)

CONSTITUENTS	UNITS	WHO GUIDELINES	MBS GUIDELINES

pH		6.5 – 8.5	6 – 9.5
Total dissolved solid (TDS)	mg/L	1000	1000
Electrical Conductivity (EC)	µS/cm	1500	3500
Turbidity	NTU	5	25
Temperature	^{0}C	Not stated	Not stated
Sodium	mg/L	200	500
Potassium	mg/L	12	Not stated
Magnesium	mg/L	50	150
Calcium	mg/L	75	200
Fluoride	mg/L	1.5	2
Chloride	mg/L	250	250
Nitrate	mg/L	45	50
Sulphate	mg/L	250	400
Bicarbonate	mg/L	300	Not stated
Carbonate	mg/L	500	Not stated

2.7 GEOLOGY OF CHIKWAWA

The lower Shire Valley alluvial plain forms a low, gently declining topography with steep granitic escarpment at the eastern valley boundary reaching some 1000 m above sea level and comprises a basement of Precambrian to lower Palaeozoic Mozambique belt, high-grade charnockitic granulites and biotite-hornblende gneisses (semi-pelitic). Lower shire is associated with Shire River, the western bank of the River, it is unconformably overlain or faulted against, thick (km-scale) sequences of Karoo sedimentary rocks (Bradford, 1973). (Ibrahim & Alex, 2008)The upper Karoo underlies much of the alluvium and comprises grits, (arkose) sandstones, shales, mudstones and marls tends to be calcite-cemented and indurated; primary porosity is hence low and permeability relates to secondary fracturing or bedding plane enlargements (Smith-Carrington and Chilton, 1983). The climax of Karoo faulting was the eruption of volcanic basalts and dolerites during the early Jurassic period. Also present are hydrothermal fault rocks, associated with the Karoo boundary faults. The Ngabu area is a piedmont plain

consisting of large volumes of Quaternary alluvium sediments from fluvial deposition associated wit

Ngabu is characterised by four main series common across south-eastern Africa, the Precambrian Basement complex, the Karoo formation, the Cretaceous Lupata sandstone and unconsolidated Quaternary alluvium (Figure 3 below). Basement rocks occur in the west, where the Panga escarpment and associated formations show evidence of faulting (Bennet, 1972). The Lupata sandstone and Karoo basalt outcrops form the western higher ground escarpment and underlie the valley floor depositional alluvium. The alluvial deposits of the Lower Shire Valley can be up to 150 m thick (Smith-Carington and Chilton, 1983). Soils classified as being of the Makande Plain, are characterised by lithomorphic vertisols, shallow lithomorphic vertisols/lithosols and topovertisols. These contain clays and clayey loams formed from the basaltic rocks to the west. Alluvial calcimorphic soils that characterise areas towards the western bank of the Shire River are often saline and sodic in nature, attributed to high evaporation rates and soil capillary action (Monjerezi, 2012).

This geology best characterizes the aquifer properties and composition of groundwater in the district. The study area lies in alluvial aquifers with high yielding to excess of 10 L/s and is underlain by mineralized gneissic basement complex (Champamba et al, 2009). The aquifer is rich in minerals like hornblende and hornblende-biotite-gneiss, magnetite, holocrystalline Augite-labradorite, apatite, sphene, halite, and gypsum. This geology best characterizes the groundwater parameters of the area. Generally high salt rich-mineralogy contribute to high salinity concentration in groundwater in Chikwawa including TA Ngabu.

ASSESSMENT OF GROUNDWATER QUALITY IN TA N'GABU, CHIKWAWA

CHAPTER 3: METHODOLOGY

3.1 RESEARCH DESIGN

The study employed the quantitative and qualitative methods. Assessment of physical and chemical parameters of boreholes in this project involved the following three main steps: Sample collection, Sample treatment and Laboratory analysis. Water samples were collected from four water sources (Boreholes) and Available standard data (physical and chemical) from the WHO and MBS was compared with the data from the study area. The geology of the study area was geologically analysed with reference to the geology of the lower shire as whole. The simple random sampling was used to have a sample size of the boreholes. Desk study was carried out in order to obtain qualitative data.

3.2 STUDY AREA

The study area is situated in the lower Shire valley in Chikwawa district, traditional authority Ngabu (GVH Malemia) in the southernmost part of the Malawi. The area is geographically located as 16□ 58′ 0″ south, 35□ 13′ 0″ east. The Shire River, the biggest river in Malawi, runs through the valley accounting for the outflow from Lake Malawi to the Zambezi River. TA Ngabu covers an area of 1093 km^2 with a population of 145,000, one third of the Chikwawa District (National Statistical Office of Malawi, 2008). This predominantly rural population is sparsely distributed, averaging 132 people per km^2 reaching up to 500 - 1500 people per km^2 in townships. TA Ngabu experiences some of Malawi's greatest climate variability. It has the lowest rainfall within the Chikwawa District from c. 200 mm up to 950 mm per annum in wet years (Monjerezi and Ngongondo, 2012). Most precipitation (90%) occurs between November and April causing vulnerability to both drought and flood. Food security is limited and aid often required (Ibrahim and Alex, 2008). The area is vulnerable to climate change expected to cause rising average temperatures, rainfall variability and reduced soil moisture. Ngabu is famous for its livestock and charcoal production, leading to overgrazing and deforestation concerns (Rivett, 2018).

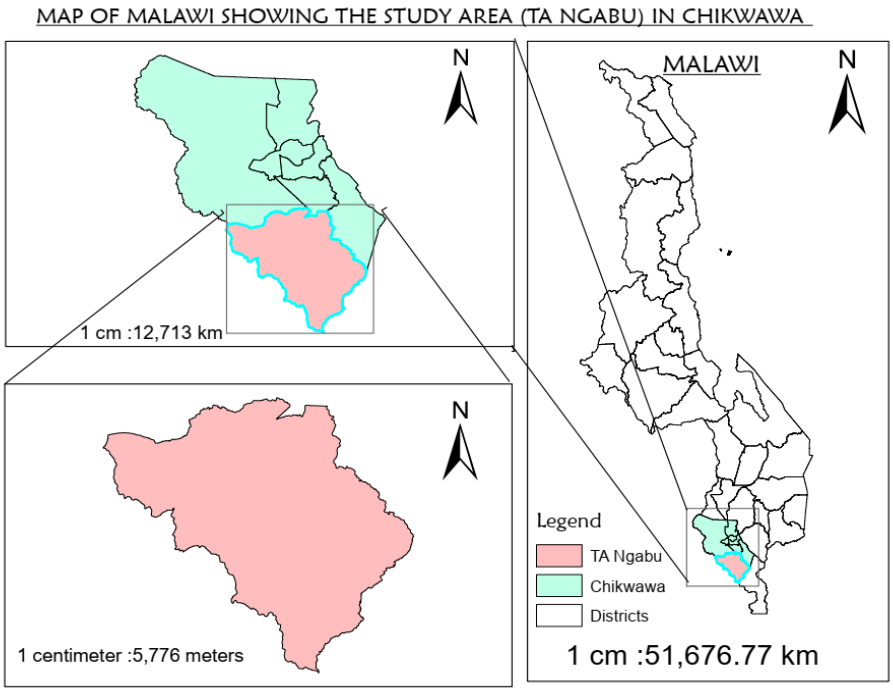


Figure 2: Map showing the location of TA Ngabu in chikwawa district

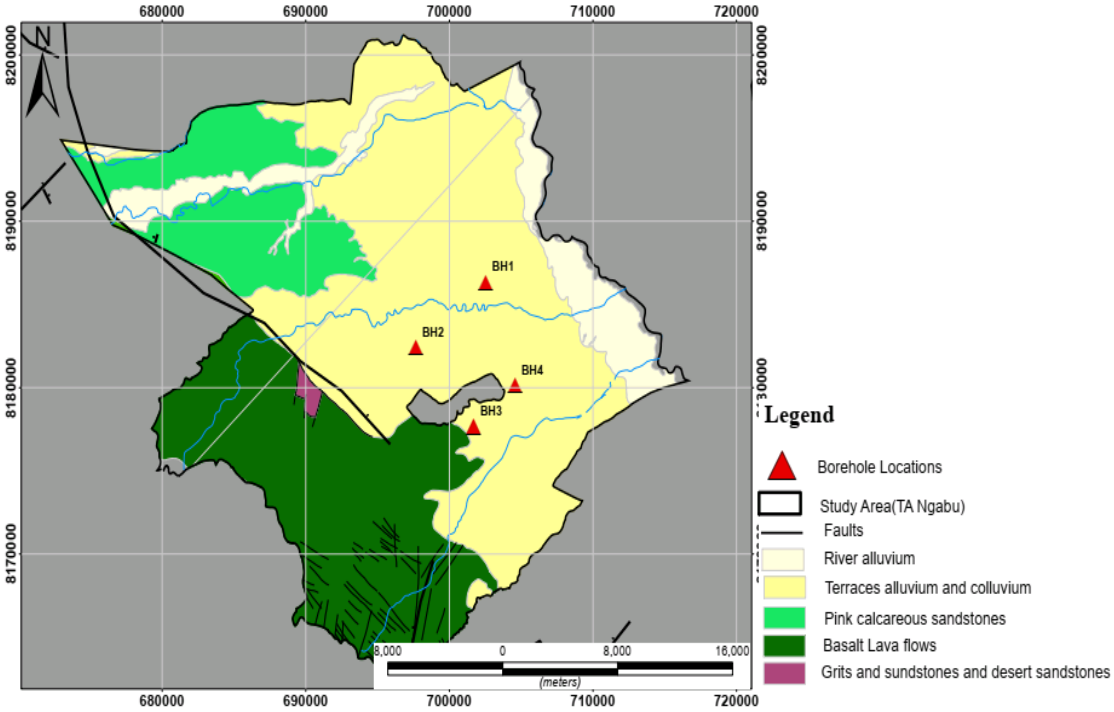


Figure 3: Geology Map of TA Ngabu showing the borehole locations

3.3 MATERIALS

The following materials were used in this study; multi-meter probe (HANNA instrument model 991300N, HANNA meter is used to measure multiple parameters such as temperature, Total dissolved solids, electrical conductivity and pH), 10L polyethylene bucket, pen, notebook, tissue paper, marker, 250ml plastic bottles, Cooler box, GPS (for taking coordinates of the sampling point), acid, and Camera (for taking photos at sampling point and during analysis). 250ml Plastic bottles were used for sampling. Water samples were taken from four boreholes. Two samples were obtained from each borehole. Water was allowed to run for at least a minute before sampling from a borehole. The samples were transported in a cooler box to the laboratory. Preservation was carried out by refrigeration. Analysis was done within 48 hours.

3.4 SAMPLE COLLECTION AND DATA ANALYSIS

3.4.1 SAMPLE COLLECTION

This research used Chidya and Matamula (2016) method because of its accuracy and due to the available materials. This research analysed small number of water parameters due to the limited available funds for analysis. The method will help to determine the suitability of water for drinking and domestic uses based on salinty levels of the water.

The groundwater samples considered in this study were collected from 4 locations (BH1, BH2, BH3 and BH4 in Table 3 below) on 25 May, 2021 within the study area and analysed as part of a project addressing the occurrence and evolution of saline groundwater resources in Tradition Authority Ngabu (Group Village Head Malemia).

Table 3: Groundwater identity and Location

SAMPLE IDENTITY	LOCATION	GPS COORDINATES
BH1	Chilumba	36L, 702454 8186431
BH2	Ngweremani	36L, 697525 8182432
BH3	Panadza	36L, 701617 8177689
BH4	Kulima	36L, 704499 81880201

The samples were collected from boreholes, which are being extensively used for drinking and other domestic purposes by people in the area. The samples were collected using 250mL sterile polypropylene bottles. The samples were preserved and transported using standard procedures (APHA, 2005; WHO, 2008). The water samples were analysed at southern water Laboratory. All the laboratory and field equipment were washed thoroughly with distilled water and handled as prescribed in the standard

operation procedures to avoid cross contamination and alteration of the samples (APHA, 1998). Fu

At each borehole point, two water sample set were collected. Water samples were collected using standard sampling procedure of American Public Health Association (APHA, 2005). The first sample set were collected in 250ml plastic bottles for chemical analysis of inorganic constituents. The plastics bottles were rinsed before sample collection. These water samples were acidified with HNO_3 (to pH < 2) and it was stored in a cooler box to be analysed for major cations, Acidification of water samples helps in preventing the precipitation of unstable metals such as iron and it also reduces the tendency of some of the metals to absorb onto the surface of the container which can affect the results of certain parameters. The second sample set were collected in 250ml plastic bottles and were stored unacidified to be analysed for major anions. The bottles were labelled with unique identification number (From BH1 to BH4) using a permanent marker. Then the samples were sealed and placed in a cooler box and covered with ice to avoid contamination and the effects of light and temperature thereby protecting them during transportation. They were taken to Southern water laboratory (Ministry of Forestry and Natural resources) in Blantyre.

3.4.2 ON-SITE ANALYSIS

The borehole water sample were collected in a cleaned 10L polyethylene bucket. Temperature, pH, electrical conductivity and Total Dissolved Solids (TDS) were measured in the field using portable HANNA meter. The equipment was calibrated on a daily basis using standard solutions at Southern Water Laboratory in Blantyre. Analyses were conducted as soon as water samples were collected. The multi-meter probe (portable HANNA instrument model 991300N) was turned on and the probe was dipped into the bucket till it immersed. Readings were taken after stabilization and recorded. Thereafter, the multi-meter probe was removed from the bucket and carefully dried with a tissue paper. Then it was turned off and placed back in its package box till the next sampling site. Geographical coordinates on site were recorded by GPS (model GPS map 64, GARMIN). Rock samples were taken from the site for mineralogical analysis. During sampling, Observations were made with reference to site conditions and any possible source of pollution.

3.4.3 LABORATORY ANALYSIS

On arrival in Southern Water Laboratory in Blantyre, the samples were filtered through a 0.45 micrometer membrane filter vacuum pump. Water parameters that were measured from acidified samples were: sodium, Potassium, magnesium, calcium, chloride, Nitrate, and sulphate. Water parameters measured from non-acidified samples were turbidity, carbonate and bicarbonates. HI88703-turbidimeter was used to determine the turbidity of the water samples. Carbonates and bicarbonates of the water samples were measured by the direct titration of the water sample with a standardized solution of acid by following titration procedures. Chloride was determined by titration of the water samples with standard silver nitrate solution using potassium chromate as indicator. The analysis of sulphates and nitrate were done by using 10 ultraviolet (UV) spectrophotometer. For sulphates analysis, sulphate standard solutions were used and (UV) spectrophotometer was set at 430nm wavelength while for nitrate analysis, nitrate standard solutions and (UV) spectrophotometer was set at 410nm wavelength. Analysis of potassium and sodium was done by using 410-Shrewood flame photometer. Magnesium and Calcium were measured using Atomic Absorption Spectrometer.

3.4.4 STATISTICAL DATA TREATMENT

The data obtained in form of physical-chemical parameters of groundwater were plotted in tables and graphs, piper diagram using WG chart, Pearson correlation table using XLSTAT and Microsoft Excel. Pearson correlation matrix is used to determine the interrelationship between the groundwater parameters. Results are presented in the form of the mean, standard deviation (SD), maximum, minimum and have been compared with national (Malawi Bureau of Standards Maximum Permissible Levels) and international (World Health Organization Health-Based Guidelines Values) standards (Tables 4 and 5).

ASSESSMENT OF GROUNDWATER QUALITY IN TA N'GABU, CHIKWAWA

CHAPTER 4: RESULTS AND DISCUSSION

ASSESSMENT OF GROUNDWATER QUALITY IN TA N'GABU, CHIKWAWA

4.1 GROUNDWATER CHEMISTRY

The results for measured water quality parameters during the experiments are summarized in tables below.

Table : Summary of results of physical and chemical compositions of borehole water samples. All values are in mg/L except pH, temperature (°C), electrical conductivity (EC) (µS/cm), and PH (PH units)

Water Parameters	BH1 (chilumba)	BH2 (Ngweremani)	BH3 (Panadza)	BH4 (Kulima)	WHO STDS	MBS
PH	7.45	7.3	7.36	7.73	6.5-8.5	6-9.5
EC	11865	3326	2270	6115	1500	3500
TDS	5930	1612	1135	3050	1000	2000
Temperature	30.9	31.9	32.2	31.8	25	****
Turbidity	2.6	1.2	0.8	1.8	5	25
	182	12	98	110	250	800
	1.4	3.84	4.2	2	45	50
	1054	98	112	438	250	750
	992	280	36	285	350	****
	2052	142	918	2020	500	****
	974	142	164	268	75	250
	108	234	126	306	50	200
	990	86	98	416	200	500
	0.5	0.9	1.6	0.7	12	****

**** No data found

MBS: Malawi Bureau Standards, WHO: World Health Organisation Standards

(SO_4^{2-}): Sulphate, (NO_3^-): Nitrate, (Cl^-): Chlorine, (CO_3^{2-}): Carbonate, (HCO^-_3): Bicarbonate, ($Ca^{+)}$: Calcium, (Mg^{2+}): Magnesium and (Na^+): Sodium

Table 5: Summary statistics of the physical and chemical compositions of water samples from bore

Descriptive statistical

Variable	Observations	Minimum	Maximum	Mean	Std. deviation
PH	4	7.3	7.73	7.46	0.19
EC	4	2270.0	11865.0	5894.0	4298.437
TDS	4	1135.0	5930.0	2931.75	2158.204
Temp	4	30.9	32.2	31.7	0.560
Turbidity	4	0.8	2.6	1.6	0.783
	4	12.0	182.0	100.5	69.692
	4	1.40	4.2	2.86	1.370
	4	98.0	1054.0	425.5	447.477
	4	36.0	992.0	398.25	412.542
	4	918.0	2052.0	1548.5	575.046
	4	142.0	974.0	387.0	395.173
	4	108.0	306.0	193.5	93.386
	4	86.0	990.0	397.5	423.529
	4	0.5	1.6	0.925	0.479

The Following graphs compares the results above with the drinking water guidelines for WHO. WHO STDS means recommended WHO standard as shown on the Figures below.

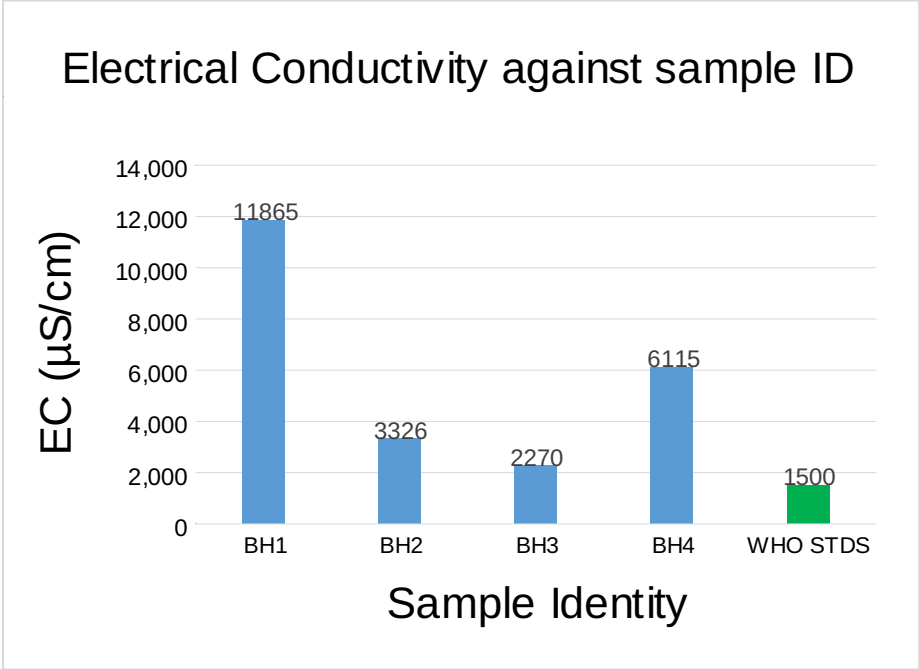


Figure 4: Plot of concentrations of Electrical Conductivity for Boreholes in Malemia area. Also shown on the plot is a bar representing World Health Organization (WHO) maximum permissible concentrations in drinking water (WHO, 2011)

The value of EC for the boreholes is between 2,270 and 11,865 µs/cm. According to the classification of EC (Table 1), 25 % of the total groundwater samples (BH3) falls under the type II (medium enrichment of salts), and 75 % of the samples (BH1, BH2, and BH4) falls under the type III (high enrichment of salts). All groundwater samples were above the Maximum Permissible Limit in drinking water for EC as specified by WHO (2011) of 1,500 µs/cm. In Malawi, it is not new for borehole water to report high concentrations of EC as earlier studies have reported EC values of up to 4,600 µS/cm in Nkhotakota, 7,700 µS/cm in South Rukuru, 4,000 µS/cm in Livulezi and Dowa West (Chilton and Smith-Carington, 1984). Sajidu et al., (2008) reported also high EC values for borehole water supplies 6,600 µS/cm in Nsanje and 6,800 µS/cm in Mangochi.

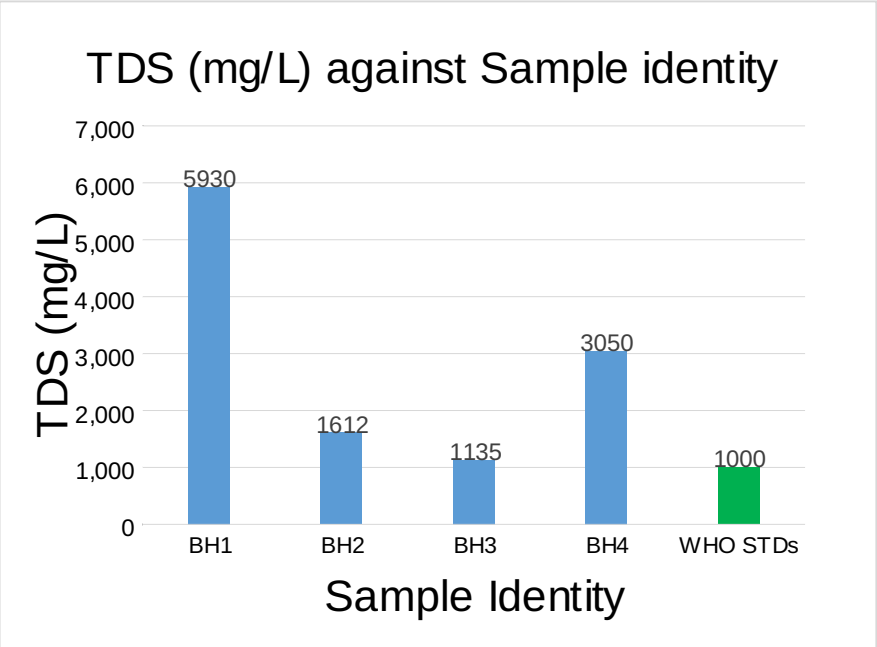
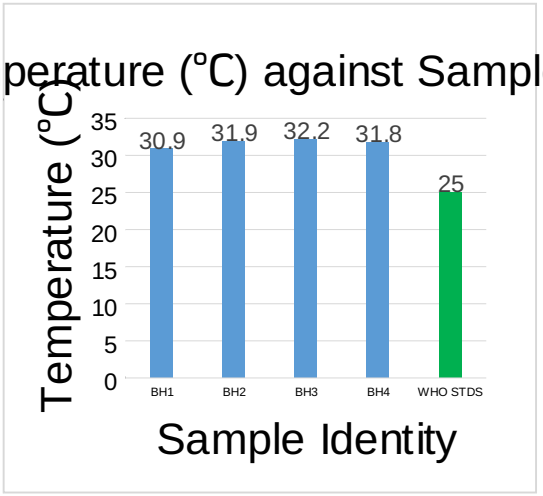


Figure 5: Plot of Total Dissolved Solids for Boreholes in Malemia area. Also shown on the plot is a bar representing World Health Organization (WHO) maximum permissible concentrations in drinking water (WHO, 2011)

Water with high TDS values indicates that water is highly mineralized. Desirable limit for TDS is 500 mg/L and maximum permissible limit is 1000 mg/L which prescribed for drinking purpose (WHO, 2011). TDS for the boreholes in the study area ranges from 1,135 mg/L to 5,930 mg/l. All groundwater in the study area were above the maximum permissible limit of 1000 mg/L. According to TDS classification (Table 2.) the groundwater from BH2 and BH3 is classified as brackish with slight saline (TDS between 1,000-3,000 mg/L) which is 50 % of the total water samples whereas the groundwater from BH1 and BH4 is considered moderately saline (TDS between 3000 to 10000 mg/L) taking the other 50 % of the total samples. High TDS concentrations makes water non-portable and it causes abdominal pain to consumers as evidenced in

the Group Village Malemia. The dominant processes controlling groundwater of medium to high TD



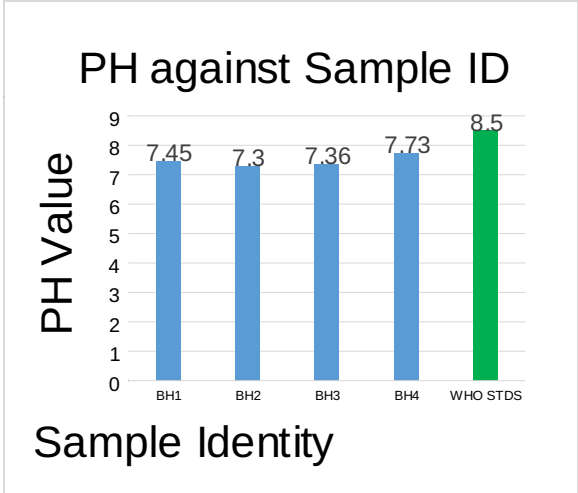


Figure 6: Plots of pH (1) and Temperature (2) for Boreholes in Malemia area. Also shown on the plots is a bar representing World Health Organization (WHO) maximum permissible concentrations in drinking water (WHO, 2011)

The temperature variation ranges from 30.9℃ to 32.2℃ with a mean value of 31.7. These high wa

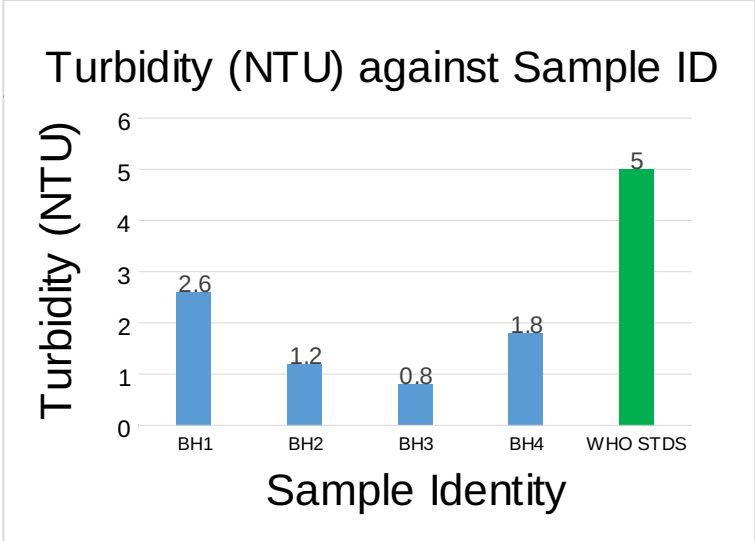


Figure 7: Plot of Turbidity for Boreholes in Malemia area. Also shown on the plots is a bar representing World Health Organization (WHO) maximum permissible concentrations in drinking water (WHO, 2011)

Turbidity of water depends on the quantity of solid matter present in the suspended state. It is a measure of light emitting properties of water and the test is used to indicate the quality of water discharge with respect to colloidal mater (Flitts, 2012). The more total suspended solids in the water, the murkier it seems and the higher the turbidity. The turbidity of the boreholes ranges from 0.8 to 2.6 NTU with a mean of 1.6. All the boreholes reported lower turbidity than the recommended WHO value of 5.0 NTU. Among the boreholes BH1 reported high turbidity levels. Calcium and Sulphate ions are among the known influence of iron corrosion (WHO, 2011) that consequently increase turbidity levels. At this site the borehole revealed signs of corrosion on the pump head and around the base of the pump which attributed to the elevated turbidity levels.

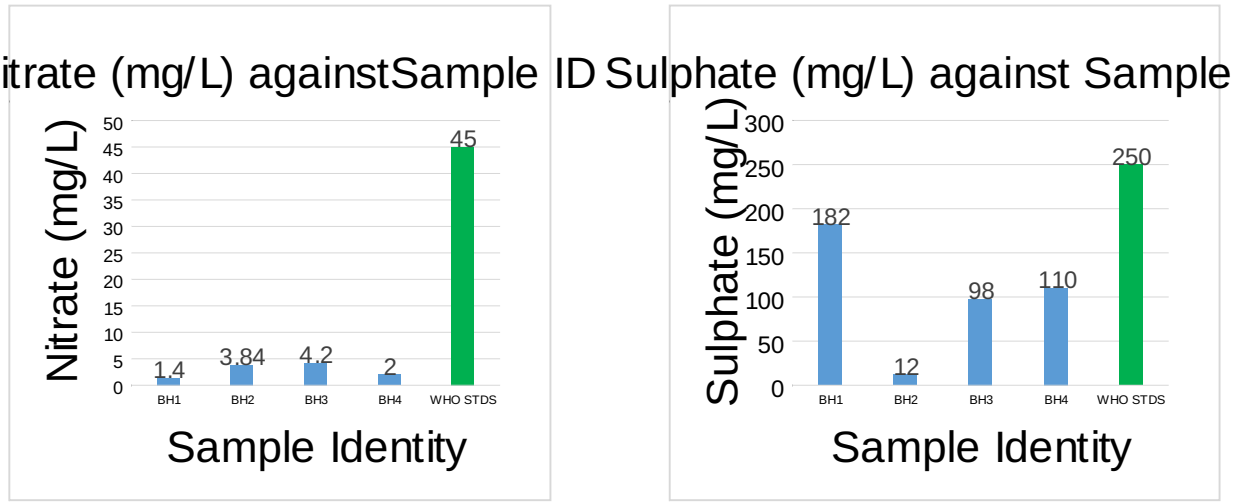


Figure 8: Plots of Nitrate (1) and Sulphate (2) for Boreholes in Malemia area. Also shown on the plots is a bar representing World Health Organization (WHO) maximum permissible concentrations in drinking water (WHO, 2011)

The value of nitrate in the boreholes is observed between 1.4 mg/L and 4.2 mg/l with an average value of 2.86 mg/l. All samples are not exceeding the permissible limit of 45 mg/l as per WHO standard. The concentration of sulphate is likely to react with human organs if the concentration exceeds the maximum allowable limit of 250 mg/l (WHO, 2011) and causes a laxative effect on human system with the excess magnesium in groundwater. The content of sulphate is observed from 12 mg/L to 182 mg/l. However, the sulphate concentration in groundwater of the study area is within the maximum allowable limit in the entire samples. Although sulphate is lower than the permissible limit of WHO, its presence in the water is attributed to chemical weathering and dissolution of gypsum ($CaSO_4$) evaporitic salt in TA Ngabu (Rivett, 2018).

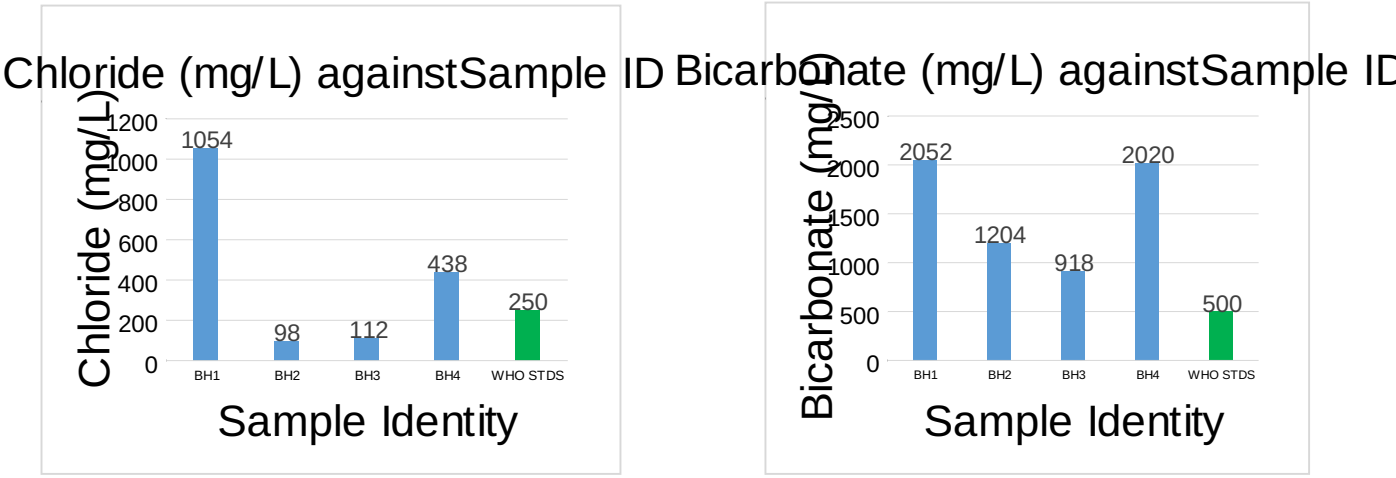
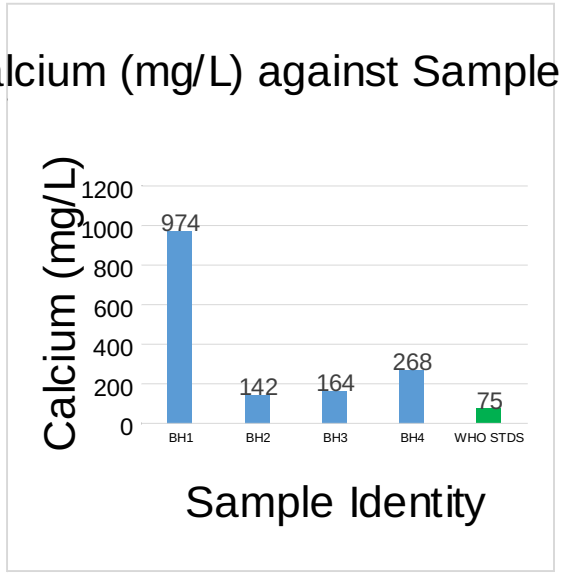


Figure 9: Plots chloride (1) and bicarbonate (2) for Boreholes in Malemia area. Also shown on the plots is a bar representing World Health Organization (WHO) maximum permissible concentrations in drinking water (WHO, 2011)

The range of chloride is found to vary between 98 mg/L and 1054 mg/l for water samples. WHO (2011) the desirable limit for chloride is 250 mg/l. In the study area it has been found that in certain locations the chloride concentration exceeds the maximum permissible limit. The chloride concentration in groundwater of the study area exceeded the maximum allowable limit of 250 mg/l in two samples (BH1 and BH4). High concentrations of chloride in water cause salty taste in the area (Rivett, 2018). The high concentrations of chloride are attributed to the weathering, leaching of sedimentary rocks and clay soil in Malemia area. These soils are often saline and sodic in nature, attributed to high evaporation rates and soil capillary action (Monjerezi, 2012).

Among the anions, Bicarbonate is the one of the most dominant anion in the area and it is observed from 918 mg/L to 2052 mg/l with the mean of 1548.5 mg/L. All the samples exceeded the permissible limits of bicarbonate of 500 mg/L as per WHO standards. The carbonate concentration of groundwater in the study area ranges from 36 mg/L to 992 mg/L. Only one sample (BH1 = 992 mg/L) reported high concentration of carbonate whereas the other samples were below the maximum permissible limit of

350 mg/L as prescribed by WHO (2011). The high concentration of carbonate at BH1 is attributed t



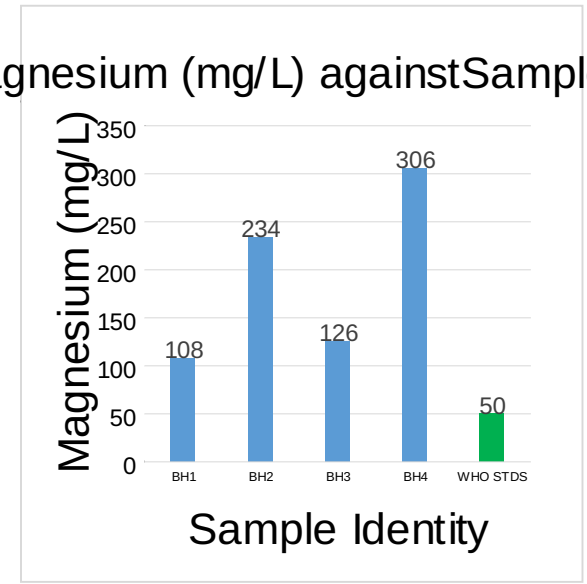


Figure 10: Plots Calcium (1) and Magnesium (2) for Boreholes in Malemia area. Also shown on the

Calcium varies from 142 mg/L to 974 mg/L with mean of 387.0. Magnesium varies from 108 mg/L to 306 mg/L. The maximum concentration of calcium ions can cause abdominal ailments and is undesirable for domestic purposes as it causes encrustation and scaling. Maximum permissible limit of Magnesium is 75 gm/L whereas Calcium is 50 mg/L as per WHO guidelines (2011). Both Magnesium and Calcium in all the samples in the study area were above their maximum permissible limits of WHO guidelines. Ferromagnesian minerals are the principal sources for higher content of magnesium and calcium in the groundwater. Weathering of biotite, which is the most abundant Ferromagnesian-mineral in most granite and gneisses of the basement, and hornblende contributes Magnesium as well as potassium to the solutes in water. The high Calcium waters could be derived by preferential weathering of anorthite rich plagioclase in more mafic gneisses with low Na (or Albite). The significant levels of Calcium and Magnesium ions in the area can be also attributed to the intrusion from the basement rock, which is alluvial in nature.

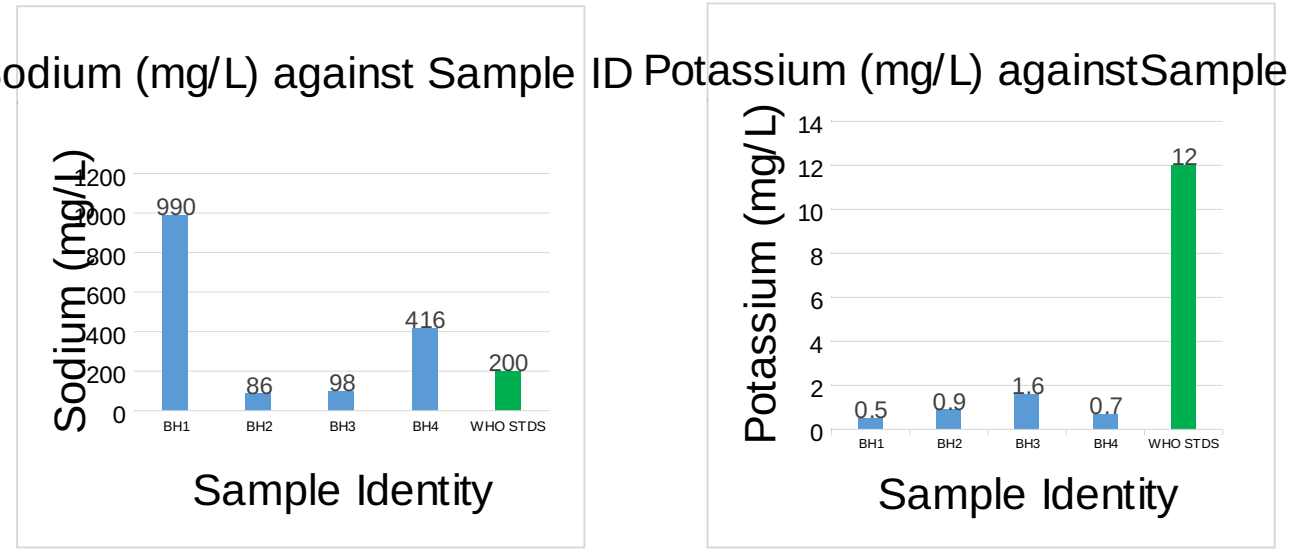


Figure 11: Plots Sodium (1) and Potassium (2) for Boreholes in Malemia area. Also

shown on the plots is a bar representing World Health Organization (WHO) maximum permissible c

Among the cations, Sodium is the dominant ion among the cations in the area and ranges from 86 mg/L to 990 mg/l with the mean value of 397.5 mg/L. It was found that 50 % of groundwater samples (BH2= 86 mg/L and BH3=98 mg/L) were below the permissible limits of 200 mg/L as prescribed WHO by (2011) whereas the other 50 % (BH1=990 mg/L and BH4=416 mg/L) were above the permissible limits. The high concentration of sodium is because of the silicate weathering and dissolution of soil salts stored by the influences of evaporation in the area. Evaporative salt (mainly halite) dissolution is therefore conceived to be a plausible process for the observed elevated Na^+ ion content. Dissolution of evaporates containing Cl^- and Na^+ add these constituents to the water in equivalent amounts (Monjerezi and Ngongondo, 2012). The salty taste of water in the study area is due to high concentrations of sodium chloride and calcium chloride. Potassium ranges from 0.5 mg/L to 1.6 mg/L with the mean of 0.925 mg /L. All the groundwater samples were found to be below the maximum permissible limit of 12 mg/L.

Table 6: Showing Pearson correlation matrix for sample parameters using XLstat software

Correlation matrix (Pearson):														
Variables	PH	EC	TDS	Temp	Turbidity	SO42-	NO3-	Cl-	CO32-	HCO-3	Ca2+	Mg2+	Na+	K+
PH	**1**	0.315	0.319	-0.147	0.421	0.406	-0.650	0.317	0.079	0.733	0.104	0.591	0.326	-0.439
EC	0.315	**1**	**1.000**	**-0.981**	**0.984**	0.807	-0.922	**0.993**	**0.966**	0.847	**0.965**	-0.287	**0.994**	-0.805
TDS	0.319	**1.000**	**1**	**-0.979**	**0.984**	0.813	-0.922	**0.995**	**0.964**	0.847	**0.965**	-0.290	**0.995**	-0.800
Temp	-0.147	**-0.981**	**-0.979**	**1**	**-0.958**	-0.711	0.847	**-0.963**	**-0.998**	-0.766	**-0.967**	0.344	**-0.962**	0.809
Turbidity	0.421	**0.984**	**0.984**	**-0.958**	**1**	0.738	**-0.962**	**0.963**	0.937	0.918	0.904	-0.115	**0.965**	-0.889
SO42-	0.406	0.807	0.813	-0.711	0.738	**1**	-0.759	0.867	0.680	0.645	0.835	-0.477	0.867	-0.362
NO3-	-0.650	-0.922	-0.922	0.847	**-0.962**	-0.759	**1**	-0.908	-0.809	**-0.983**	-0.797	-0.059	-0.912	0.861
Cl-	0.317	**0.993**	**0.995**	**-0.963**	**0.963**	0.867	-0.908	**1**	0.946	0.820	**0.976**	-0.354	**1.000**	-0.737
CO32-	0.079	**0.966**	**0.964**	**-0.998**	0.937	0.680	-0.809	0.946	**1**	0.723	**0.965**	-0.379	0.944	-0.791
HCO-3	0.733	0.847	0.847	-0.766	0.918	0.645	**-0.983**	0.820	0.723	**1**	0.681	0.240	0.826	-0.892
Ca2+	0.104	**0.965**	**0.965**	**-0.967**	0.904	0.835	-0.797	**0.976**	**0.965**	0.681	**1**	-0.528	**0.973**	-0.647
Mg2+	0.591	-0.287	-0.290	0.344	-0.115	-0.477	-0.059	-0.354	-0.379	0.240	-0.528	**1**	-0.345	-0.265
Na+	0.326	**0.994**	**0.995**	**-0.962**	**0.965**	0.867	-0.912	**1.000**	0.944	0.826	**0.973**	-0.345	**1**	-0.740
K+	-0.439	-0.805	-0.800	0.809	-0.889	-0.362	0.861	-0.737	-0.791	-0.892	-0.647	-0.265	-0.740	**1**
Values in bold are different from 0 with a significance level alpha= 0.05														

The correlation matrix above indicates salinity (TDS or EC) relationships with the various chemical parameters. Salinity (TDS and EC) demonstrated statistically significant positive correlations with pH, bicarbonate, chloride, carbonate, sulfate, sodium and calcium these ions are derived from continual weathering and dissolution of rocks. Negative correlation relationship of salinity (TDS or EC) with nitrate shows that the salinity in Malemia area is not influenced by anthropogenic activities including fertilizers and domestic wastes which are sources of nitrate. Positive correlation relationship of sodium with chloride and calcium with Sulphate is attributed to chemical weathering and dissolution of (halite (NaCl), gypsum (CaSO4) evaporitic salt, and upwelling along the faults (Panga fault) in the Malemia area which causes the salty taste of water. Mineralization along fault zones and faulted area-fracture conduits may release deep groundwater salinity to surface. Salinity is the characteristics of layered evaporate occurrence within the alluvial aquifer sediment pile (Monjerezi and Ngongondo, 2012).

4.2 GEOLOGY ASPECT

From figure 3 above about the geology of Chikwawa, the district is made up of various lithological types and this indicates different hydrogeological facies in respect to a particular geology. Chikwawa is underlain by gneissic basement complex and the basement is largely overlain by unconsolidated sediments and metasedimentary rocks that accumulate in the rift basin of Chikwawa. the district has also a lot of geological faults including panga fault, Nkombedzi fault, and other minor faults. The collected rock samples during data collection were analyzed to be gneisses (which is composed of quartz, feldspar, hornblende, and biotite) and dolerites (which is composed of plagioclase, pyroxene, hornblende and quartz. Thus basement complex lithology. This geology outline covers large part of the district including Ngabu. These unconsolidated sediments are dominated by rift basin colluvium, alluvium, lacustrine and fluvial sediments. This geology is rich in salt minerals like hornblende – and hornblendebiotite-gneiss, apatite, sphene, halite, gypsum feldspars, pyroxenes and olivine. A study by Rivett et al (2018) shows that the majority of more saline water points occur within the central basin alluvial deposits. Elevated concentrations also occur in the northwest areas of Ngabu underlain by the Cretaceous Lupata sandstone. The most consistent low-salinity area occurred in the western basin areas where groundwater was drawn

from the Karoo basalt basement rock. The Karoo basalt water points were significantly less saline t

4.3 GROUNDWATER TYPES

Groundwater is classified into different types according to the percentage of chemical constituents present in it. This difference in groundwater rose mainly from different kinds of rock-water interaction. Groundwater samples in the study area (Malemia) were separated into hydrogeochemical facies, according to the ions which made up more than 50 % of the total ionic charge. All samples (100%) were classified as Calcium magnesium bicarbonate type (Ca-(Mg)-HCO_3) this type of water is associated with medium salinity (Rivett et al., 2018). This groundwater composition is derived from the mixture of rock weathering (Dolomite ($CaMg(CO_3)_2$ and limestone ($CaCO_3)_2$), evaporation and dissolution into the aquifer. The rocks of which this type of groundwater comes from are hornblende and hornblende-biotite-gneiss, magnetite, halite and gypsum. These are salt rich minerals and they characterize the alluvial and weathered basement aquifers and TA Ngabu has weathered basement aquifer overlain by alluvial aquifer (Rivett et al., 2018). The significant positive correlation of EC and TDS with pH, bicarbonate, chloride, carbonate, sulfate, sodium and calcium from Table 6 of correlation of sample parameters indicates the salinity. These parameters are derived from continual weathering and dissolution of rocks in the study area. To understand the relationship between the samples and lithology in order to understand the source of the water type found in the study area Gibbs diagram is drawn.

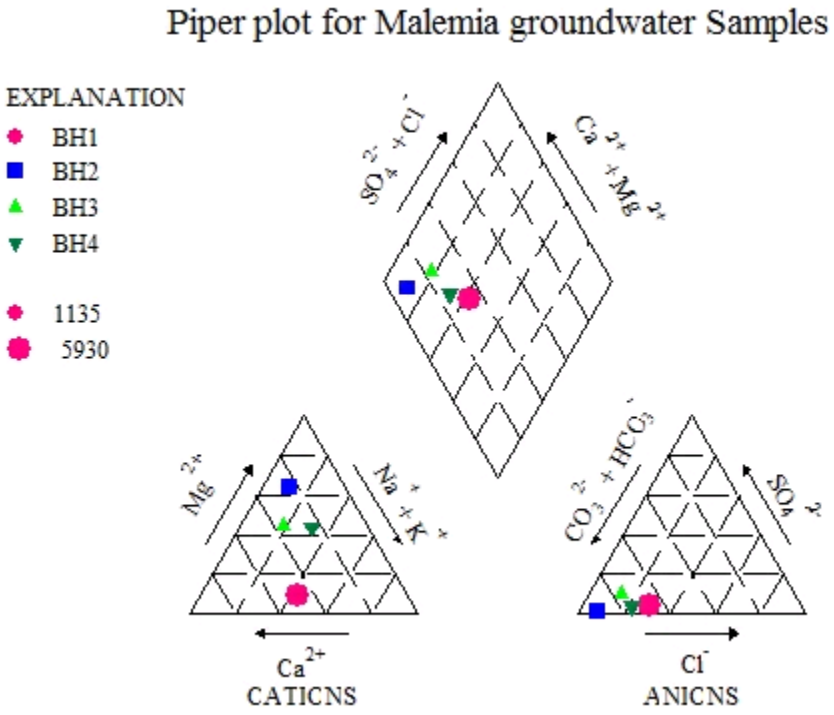


Figure 12: Piper Plot showing the groundwater types in Malemia

4.4 MECHANISM OF ROCK DOMINANCE AND GIBBS DIAGRAM

Gibbs diagram was used to establish the relationship of water composition and aquifer lithological characteristics (Gibbs, 1970). Gibbs diagram is divided in three distinct fields such as precipitation dominance, evaporation dominance and rock–water interaction dominance areas as shown in the Gibbs diagram below. The chemical data of groundwater samples from Malemia Village were plotted on Gibbs diagram (fig. 13). Thus by using the following equation.

Gibbs ratio-1(for anions)=

Gibbs ratio-1 (for cations)=

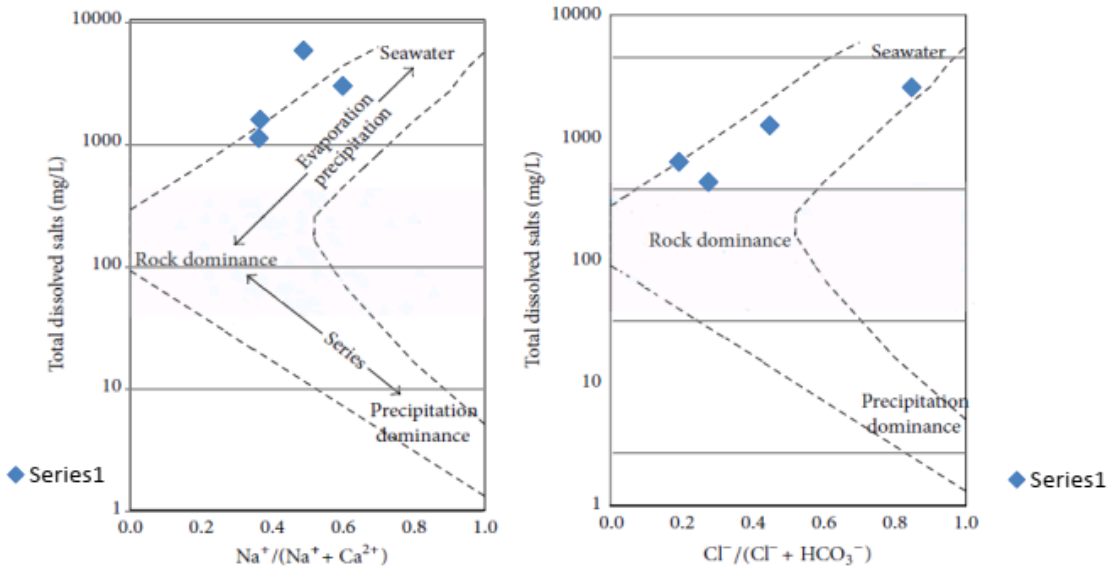


Figure 13: Gibbs diagram, illustrating the mechanism controlling the chemistry of groundwater samples from TA Ngabu (Chikwawa)

The predominant samples fall in the evaporation dominance field of the Gibbs diagram. The evaporation dominance field indicates the dissolution of evaporitic salts minerals such gypsum and halite that were deposited during the preceding dry season due to extreme temperatures in TA Ngabu. The infiltrating water from the dissolution processes increases the major ions concentration in the groundwater. This indicates the interaction between rock chemistry and the chemistry of the percolated waters under the subsurface. Evaporation-sedimentation are the main factor controlling the chemical composition of groundwater at TA Ngabu. which lead to dissolution of evaporate minerals in the following rain season this contributes to groundwater chemistry. Evaporation-sedimentation is due to high temperature in Chikwawa that reach up to 32^0 C in October and is characterised by sedimentary rocks like evaporates. Minerals in evaporates rocks are sulphates, carbonates (calcite, magnesite and dolomite), chlorides as well as sulfocarbonates (Zhang, Ma, & Lu, 2018). The geology can be evidenced from the high concentration of some parameters like bicarbonates, chloride

and sulphates from the collected water samples. The minerals best comprise the alluvial aquifer in

4.3 SALINITY LEVELS (EC AND TDS) ANALYSIS

4.3.1 BH1

Borehole 1 recorded the highest results of EC, TDS as well as Turbidity. The results for EC and TDS were 11865 µs/m and 5930 mg/L. Malawi Bureau of standards recommended that drinking water should not exceed the 3500 µs/m of EC and 1000 mg/L of TDS. WHO guidelines for drinking water recommend a maximum limit of 1500 µs/m for EC and 1000 mg/L of TDS. The findings exceeded the recommended limits for MBS and WHO thus shows that the borehole 3 has high amounts of salts and the water is moderately saline.

4.3.2 BH2

Borehole 2 recorded EC of 3,326 µs/m and TDS of 1,612 mg/L. The EC value is within the acceptable limits of MBS. However, the findings exceeded the recommended guidelines for drinking water of WHO and the borehole 2 water is brackish slightly saline.

4.3.3 BH3

Borehole 3 recoded EC of 2,270 µs/m and TDS of 1,135 mg/L. the findings exceeded the recommended guidelines for drinking water of WHO and the borehole 3 water is brackish slightly saline

4.3.4 BH4

Finally, BH 4 recorded EC of 6,115 µs/m and TDS of 3,050 mg/L. The findings exceeded the recommended guidelines for drinking water of MBS and WHO. This shows that the borehole 4 has high enrichment of salts and the water is brackish moderately saline.

4.4 ASSESS THE SPATIAL DISTRIBUTION OF SALINITY LEVELS

The spatial distribution of salinity is due to geology (aquifer) type, soil type and distance to the nearest river or fault. The more saline water in TA Ngabu occurred within the borehole that were drilled in the central basin alluvial deposits (BH 1, BH2, and BH4).

The low-salinity area occurred in the western basin where groundwater was drawn from the Karoo

ASSESSMENT OF GROUNDWATER QUALITY IN TA N'GABU, CHIKWAWA

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Groundwater salinity occurrence in Ngabu reflect rural, semi-arid, valley alluvial aquifer scenarios elsewhere. Brackish groundwater observed in the study area presented potable drinking-water supply problems. The Findings of physico-chemical parameters that affect the borehole water salinity revealed that concentrations of EC, TDS, Chlorine, Carbonate, Bicarbonate, Calcium, Magnesium and Sodium exceeded the acceptable limits of WHO drinking water recommended guidelines. The high concentrations of physical-chemical parameters of borehole water in the Ngabu revealed the elevated salinity levels. The findings further revealed that Salinity is an issue in the study area and its cause was attributed to geological processes because there were no any artificial sources of contamination that were observed. Piper diagram reveal that the groundwater in TA Ngabu is of calcium magnesium bicarbonate type which is associated with moderate salinity and this water is attributed to continual weathering and dissolution of rocks. Gibbs diagram also shows that major processes that controlled the chemical composition of water in TA Ngabu are water rock interactions and evaporation-sedimentation. Electric conductivity of borehole water and Total dissolved solids were used to quantify the level of salinity hazard. Findings from this study revealed that water in all the four boreholes is brackish and poor for drinking. The findings revealed that there were no significance differences of salinity levels within the boreholes.

5.2 RECOMMENDATIONS0

Furnishing a better response to salinity problems, but continuing to still work at local water point hand-pumped borehole scale, could include the following possible measures:

- Methods of purifying high-level saline water should be developed such as desalination water treatment should be employed for treatment of brackish groundwater for water supply and the measures to avoid the saline water

impacts should be implemented.

- Water monitoring programs should be put in place for frequent monitoring of the quality of water that is being used in Chikwawa district
- Organisations responsible for implementing borehole drilling initiatives should employ suitably qualified or experienced hydrogeologists to supervise the works to ensure that fresh-water layers are targeted for screening, and steps are taken to ensure sub-standard water points are not commissioned for use. A suitably qualified hydrogeologist should be able to identify regional salinity risk, reduce chance of encountering salinity through good borehole siting techniques and supervise borehole construction to identify saline water occurrence before water point is commissioned for use.
- More studies on assessment of ground water quality targeting on salinity should be undertaken in other districts of Malawi especially rural areas.
- Publicizing the data about groundwater salinity occurrence in a particular area by organisation which carry out the groundwater exploration to improve targeting of freshwater and research investigative effort to better understand salinity occurrence and its management.
- Ensuring that a qualified hydrogeologist registered under Malawi Water Resources Regulations (2018) oversees the works. All works should begin with a desk-study to understand the regional risks of salinity and prepare accordingly prior to commencement of site works.

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APPENDICES

APPENDIX 1: Table 7: Lab report for physical and chemical parameter of Malemia borehole water samples

Lab report for physiochemical Parameters of the groundwater samples

REF. No: SWPO.1034 **Date: 30/04/2021**

MINISTRY OF FORESTRY AND NATURAL RESOURCES

(SOUTHERN WATER LABORATORY)

LABORATORY ANALYSIS RESULTS OF BOREHOLE WATER SAMPLES COLLECTED FROM CHIKWAWA DISTRCT FOR SAMSON KWACHERANJI'S RESEARCH PROJECT

SAMPLE IDENTITY	Chilumba	Ngweremani	Panadza	Kulima	MALAWI STANDARDS FOR BOREHOLES & PROTECTED SHALLOW WELLS (MS733:2005)
DATE SAMPLED	25/04/2021	25/04/2021	25/04/2021	25/04/2021	
SAMPLE SOURCE	Borehole	Borehole	Borehole	Borehole	
MAP SHEET/GRID REFERENCE	36L 703148 8179841	36L 702180 8180090	36L 701488 8180410	36L 699188 8180607	
pH Value	7.45	7.3	7.36	7.73	6.0-9.5
CONDUCTIVITY (µs/cm)	11856	3326	2270	6115	3500
TOTAL DISSOLVED SOLIDS, mg/l	5930	1612	1135	3050	2000
CARBONATE (as CO_3^{2-}), mg/l	992	280	36	285	-
BICARBONATE (as HCO_3^-), mg/l	2052	1204	918	2020	-
CHLORIDE (as Cl^-), mg/l	1054	98	112	438	750
SULPHATE (as SO_4^{2-}), mg/l	182	12	98	110	800
NITRATE (as NO_3^-), mg/l	1.4	3.84	4.2	2	45
SODIUM (as Na^+), mg/l	990	86	98	416	500
POTASSIUM (as K^+), mg/l	0.5	0.9	1.6	0.7	-
CALCIUM (as Ca^{++}), mg/l	974	142	164	268	250
MAGNESIUM (as mg $^{++}$), mg/l	108	234	126	306	200
IRON (Fe $^{++}$), mg/l	0.1	0.01	0.13	0.11	3.0
TEMPERATURE (°C)	30.9	31.9	32.2	31.8	

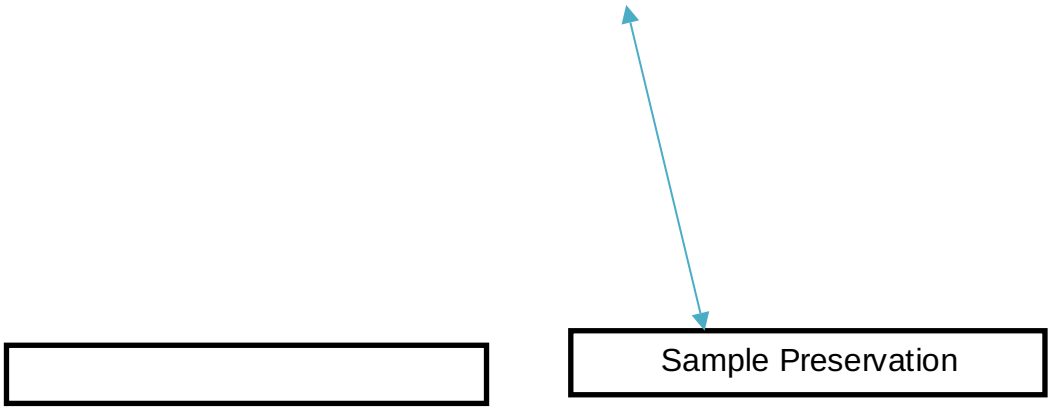


E. Simoko
Assistant Water Chemist
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APPENDIX 2: Procedure for sample collection and on-site analysis







ASSESSMENT OF GROUNDWATER QUALITY IN TA N'GABU, CHIKWAWA



