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HYDROGEOCHEMISTRY AND GROUNDWATER QUALITY OF MICHIKA AREA NE NIGERIA

Gabriel Ike Obiefuna, Peter Hassan Sini and AbubakarMaunde
Department of Geology
Modibbo Adama University of Technology, Yola, Nigeria

ABSTRACT

The aim of this study is to assess the quality of the shallow groundwater quality of Michika area of Nigeria for irrigation and domestic purposes. Geological mapping revealed the area is underlain by granitic rocks of Pan-African age. These rocks are grouped into three types: coarse grained biotite granites, coarse porphyritic granites and medium grained granites which are intruded by the new basaltic rocks of Tertiary age. Forty water samples collected from wells tapping shallow aquifer were used. Chemical analyses were performed in the laboratory employing standard methods viz Atomic Adsorption Spectrophotometry for cations and conventional titration for anions. In addition ions in milligram per liter were converted to mill equivalent per liter and anions balanced against cations as a control check of the reliability of the analyzed results. The analyzed chemical parameters were interpreted and the result revealed that most of the samples are slightly acidic to alkaline, largely soft with fairly low to moderate concentrations of dissolved solids that fall within the international limits for domestic purposes. However, the concentration of iron and nitrate in less than 1% and 25% respectively is higher than the maximum acceptable concentration of 0.3 mg/l and 10 mg/l respectively and should be treated before use. The hydro geochemistry of the study area indicate two water type that is Ca-mg-$HC0_3$ and Na-$C0_3$ for both hand dug well and boreholes Thus most of the samples will neither cause salinity hazards nor have an adverse effect on the soil properties and are mostly suitable for domestic and irrigation purposes.

Keywords; groundwater quality, geological mapping, chemical analyses, Michika Area, NE Nigeria

INTRODUCTION

Groundwater is one of the most valuable natural resources, which supports human health, socio-economic development and functioning of ecosystems (Zekster, 2000; Steube*e tal.*, 2009). Groundwater has become an important water resources issue due to rapid increase of population, rapid industrialization, unplanned urbanization and too much use of fertilizers and pesticide in agriculture (Joarder*et al.,* 2008). The quality of groundwater is critical in the regions that are characterized by a semi-arid/arid climate and dominated by agricultural activities and where the water quality is generally affected by diffuse contamination originating from intense irrigated agriculture (Saidi et al., 2009). Rapid urbanization, especially in developing countries like Nigeria, has affected the availability and quality of groundwater due to its overexploitation and improper waste disposal. The means of water supply to the area are through hand-dug wells, boreholes and surface water. These sources of water supply especially through hand-dug wells and surface water are polluted due to human activities such as domestic, industrial and agricultural. These activities include the use of pit latrines by most residents and indiscriminate dumping of household solid waste as well as the use of agricultural fertilizers in farming activities, which contribute to the contamination of water from different sources in the study area. Most of the hand-dug wells are shallow and are often left open, which renders the well susceptible to contamination by surface water during heavy rainstorms (precipitation) as well as storm runoff from fertilizers. This unfortunate situation has led to the prevalence of water borne diseases. Furthermore, the study area is an agricultural community that largely uses shallow groundwater tapped by hand-dug well and surface water resources for irrigation purposes. It therefore becomes imperative to regularly monitor the quality of groundwater and to device ways and means to protect it. It is against this background that hydrogrochemical assessment of shallow groundwater of Michika Area is being carried out. Based on this study, recommendation that will serve as useful guide in arresting the situation will be made.

STUDY AREA

It covers an area extent of about 188.5km^2.and lies within latitudes 10^o 32^{I}N to 10^o 14^{I}N and longitudes 13^o 19^I E to 13^o 25^I E. It is bounded to the east by Republic of Cameroon, to the south by Mubi Local Government Area of Adamawa State, to the west by AskiraUba Local Government Area of Borno State and to the north by Madagali Local Government Area respectively. The area is traversed by one major highway that runs from Yola to Maiduguri. Other minor roads are Michika – Yammu/ Warakanza, Michika- Kopa- Kwapale/Villegwa andThe area falls within the Basement Complex of the northeastern Nigeria. These roads link the villages and provide access routes to hilly areas. The study area is hilly to the eastern part and relatively flat to the west. Despite the hilly nature of some parts of the study area, there are still good road networks, foot-paths and tracks that made it accessible (Figure 1)

The Mandara Mountains is the most striking and outstanding landform in the southeastern part of the study area. It is characterized by high relief ranging between 289.56m and 1,036.33m above mean sea level and covers about 50% of the study area. It is largely dissected by sharp and numerous steep sided valleys. Several residual Isenberg's and isolated domes litter the extensive upland plains of Mandara Mountains giving rise to a picturesque open undulating topography that extends to Cameroun Republic. Most of the rivers in the study area take their source from Mandara Mountains to the southeastern part and flows northeastwards. The northern, southwestern and northwestern part is characterized by flat low lands with patches of granite outcrops. The River Wantse takes its source from the southeastern part of the area and flows northwestwards whereas River Rafin Nanda takes its source from the northeastern part and flows toward the northern part of the study area. River Thaii take its source from the eastern part of the study area and flows toward the north central part to join River Yedsarem. The study area exhibit dendritic drainage pattern which is characteristic of areas with homogeneous rocks like granites and clays. The underlying rocks in the area aid the formation of dendritic pattern of drainage network. The soils of the Mandara Mountains are coarse, stony and shallow (Areola, 1983). They are characterized by alternating bands of light gravelly and dark loamy clayey soils (Daral, 1991). The valley in between the rivers has alluvial flood plains comprising mainly coarse quartzite materials. It is hilly to the eastern part of the study area and relatively flat to the west. Despite the hilly nature of some part of the study area, there are still good road networks, foot-paths and tracks in the area, although the study area is poorly drained (Fig 1)

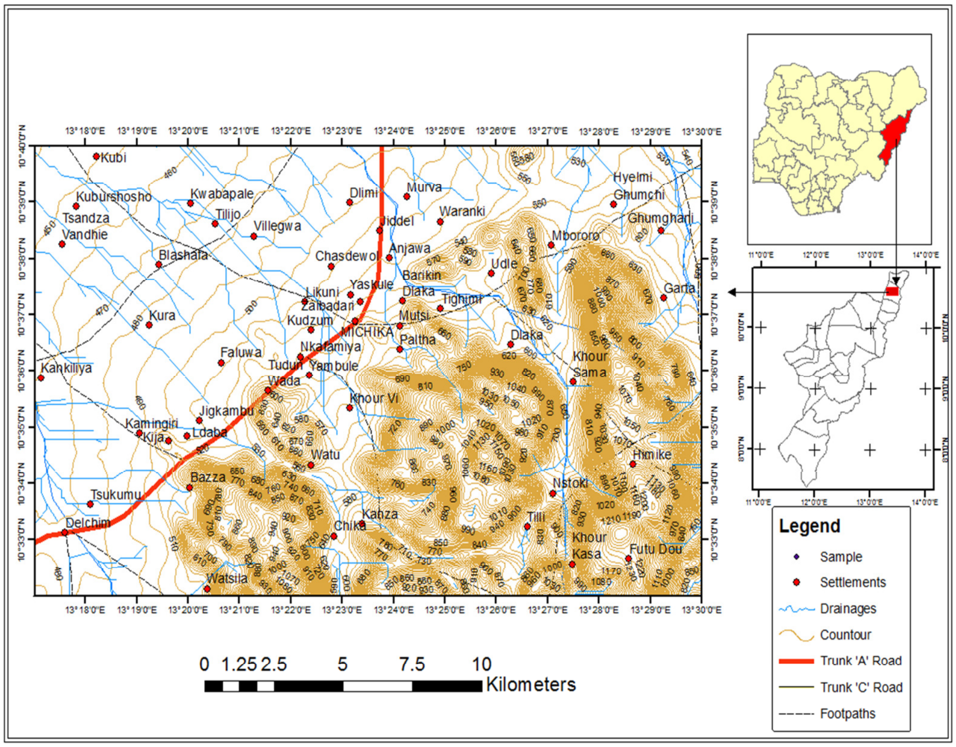

Figure 1: Topographic map of Michika and its environs (USA Survey Agency, 2010)

The study area which falls within the semi-arid climatic zone of Nigeria in Sub-Saharan Africa is characterized by two distinct seasons; a hot dry season lasting from October to April and a cool rainy season lasting from April to October. These seasonal climatic conditions are caused by the north-south fluctuations of a zone of discontinuity between the dry continental air mass and the humid maritime Atlantic air mass (Garnier, 1967). At the surface it forms a boundary called a surface of discontinuity which lies further south during dry season. Thus showing a south-ward movement of winds and pressures from the high pressure zones of the Sahara. Then, during the rainy season the zone of discontinuity moves northwards. The Saharan air causes the dry season which is accompanied by low relative humidity and intense aridity that makes the atmosphere very dusty. Temperature goes low during the harmattan sub-season and the rainy season follows the advancing Atlantic Maritime Air which is acompanied by high humidity and intense rains and high vapour pressure. Peak rainfall occurs during the months of August to September. There is characteristic "August break" lasting about two weeks in which the rains more or less cease. This occurs during the months of August but may extend to early September. The area is covered by a mantle of gravels, coarse sands, loamy and clayey soils with the grain-size of the soil decreasing with increasing distance from the hills.

From hydrogeochemcal point of view there is no specific pointed references to previous work evaluating the groundwater qualities in the study area. Althoughsome regional studies were carried out namely Falconer (1911); Carter *et al.,* (1963); Du preeze and Barber (1965); and Kiser (1968), they did not give detailed information on the physicochemical assessment of groundwater quality in the study area, as is detailed as this study. These studies which discussed the geography, geology and groundwater quality of the Benue Trough were only speculative of groundwater conditions in the study area. Therefore, previous work including published and unpublished are quite inadequate for physicochemical assessment of groundwater quality in the study area.

Du preeze and Barber (1965) in their work on the distribution and chemical quality of groundwater in Northern Nigeria showed that these waters are calcium or sodium bicarbonate type waters. According to them deviation from the bicarbonate type are less common and suggested that regional chemical characteristics of the water are controlled by the climatic and geological conditions which cause local irregularities. Kiser (1968) gave some details on the geology and chemical quality of groundwater in the Old Northern Nigeria. A few number of literatures are also available regarding the assessment of groundwater quality data based on different irrigation indices in different parts of the world (Quddus and Zaman 1996; Talukder*et al.,* 1998; Shahidullah et al 2000; Sarkar and Hassan, 2006; Raihan and Alam, 2008). Quddus and Zaman, (1996) studied the irrigation water quality of some selected villages of Meherpur District of Bangladesh and argued that some of the following ions such as calcium, magnesium, sodium, bicarbonate, sulphate, chloride, potassium, boron and silica are more or less beneficial for crop growth and soil properties in little quantities.

Talukder*et al.,* (1998) reported that poor quality irrigation water reduces soil productivity, changes soil physical and chemical properties, creates crop toxicity and ultimately reduces yield. Shahidullah*et al.,* (2000) assessed the groundwater quality in Mymensigh District of Bangladesh and observed a linear relationship between Sodium Absorption Ratio (SAR) and Soluble Sodium Percentage (SSP). They also discovered that the groundwater could safely be used for long-term irrigation. Sarkar and Hassan (2006) investigated the water quality of a groundwater basin in Bangladesh for irrigation purposes and observed that standard water quality indices like pH, EC, SAR. RSBC, MAR, PI, KR and TDS are within the acceptable range for crop production. Raihan and Alam (2008) presented a pictorial representation of groundwater quality throughout the Sunangan District that allowed the delineation of groundwater based on its suitability for irrigation purposes. Current related work elsewhere (Mahagi et al 2018; Sefie et al 2018; Abdelshafy et al 2019; Chen et al 2019 and Umamageswari et al 2019) carried out hydrogeochemical assessment of groundwater of parts of India, Egypt, China, Afganistan and Malaysia.

This work is aimed at carrying out the hydrogeochemical characteristics and quality assessment of groundwater quality of Michika Area Northeastern Nigeria. As at present there is no detailed report on the physicochemical assessment of groundwater quality of the study area. Previous geological appraisal lacked in depth on the geological and hydrogeochemical information. This study will give further information on hydrogeochemical framework of groundwater occurrences which is necessary for effective management and future development of groundwater in the study area. This is thus the first attempt towards detailed evaluation of the groundwater chemistry as well as the sources and causes of groundwater pollution in the study area.

MATERIALS AND METHODS

Field Methods

Reconnaissance field trips were made during which topographical and geological maps were employed in the identification of the rock formations as well as their structural and stratigraphical relationships. Geological field mapping was undertaken in order to collect, identify and study the field occurrences and structural relationship of all the rock types present in the study area. Fresh and unweathered rock samples were broken for hand specimen examination. Preliminary observation and identification of each constituent mineral were carried out using magnifying lens. Other structural imprints like joints trends, dimensions of xenoliths, veins and dykes were also recorded. Sources of groundwater contaminants were located and plotted on a map. This was followed by detailed surface and subsurface geological and hydrogeological studies during which geological boundaries were demarcated and hydraulic parameters measured. An inventory of wells in the area was taken which included determining locations with Global Positioning System (GPS) and documentation of each well site, including land-use, soil type and geology.

LABORATORY METHODS

Petrographic Analyses

For the petrographic studies, seven rock samples were cut into chips with a micro-cutting machine and subsequently polished on glass ground plate using carborundum to obtain required thickness and a perfectly smooth surfaces. The cut rock samples were thereafter mounted on a clean glass slide with adhesive. The prepared slides were examined under the petrological microscope to identify mineralogical features that were not hitherto seen with unaided eyes in the rock samples.

Chemical Analyses of water samples

Analytical Techniques/ procedures

For water analyses and assessment regarding the suitability of water for human consumption and other domestic purposes, specialized sampling and sampling procedures are required. A total of forty shallow ground water samples consisting of hand-dug wells and shallow boreholes were collected from different locations between the months of August and September, 2015 which are the peak of the rainy season. The water samples were analyzed for various parameters in the newly equipped chemical laboratory of the Adamawa State Water Board Yola, Nigeria. Various physicochemical parameters like temperature, pH, turbidity, total dissolved solids (TDS), total hardness, dissolved oxygen (DO), electrical conductivity (EC), chloride, sulphate, total alkalinity, fluoride, iron, calcium, magnesium, nitrate-nitrogen were been measured using TDS/Conductivity meter/UV spectrophoto meter . In general, the standard methods recommended by APHA, AWWA, WPCF, (1998), USEPA, (2003) were adopted for determination of various physico-chemical parameters. A brief description is given as follows.

All multi-probes of the kit were calibrated together using the same standards and procedures and all the measurement were taken in the field. Electrical conductivity was calibrated against 0.005, 0.05 and 0.5 M standard potassium chloride solutions. pH was calibrated with standard buffer solution at pH-4 and pH-9.2. Dissolved Oxygen was calibrated against zero solution (sodium sulphite) and an air saturated beaker of water checked with a Winklers's titration. Temperature is factory set and cannot be adjusted but was checked against a standard mercury thermometer for consistency between multi-probes. Turbidity probe was calibrated with standard solution of 400 NTU using hydrazine sulphate and hexamethylenetetramine. Dissolved Oxygen was also measured at the site by modified Winkler's method. For the determination of hardness, 50 ml of sample was buffered at pH 8-10 (NH_4Cl and NH_4OH) and titrated against standard EDTA using Erichrome Black T indicator. Calcium was measured by titrating the water sample against standard EDTA using murexide indicator. Magnesium was determined by calculation method using the formular proposed by APHA, AWWA, WPCF, (1998).

$$Mg(Mg/l) = (Total\ Hardness - mgd\ Calcium\ Hardness) \text{ x } 0.243 \quad (1)$$

K^+ (mg/l) and Na^+ (mg/l)

were determined in chemical laboratory of the Adamawa State Water Board Yola, Nigeria using HACH digital Spectrophotometer (Model DR 2040, USA).

The total alkalinity was measured by titrating the sample against N/50 solution of sulphuric acid using methyl orange and phenolthalein indicator respectively. Chloride content was measured by titrating against N/50 solution of silver nitrate using potassium chromate as indicator. Fluoride, sulphate, nitrate-nitrogen and iron were determined spectrophotometrically following the standard procedure recommended by APHA, AWWA, WPCF (1998). All the samples were assessed for charge balance and most of them were within the acceptable range of ±5.The Total Dissolved Solids (TDS) was calculated employing the following equation (Richards, 1954).

$$TDS(mg/l) = (0.64\ x\ EC\ x\ 106)\ (\mu S/\mathrm{cm}) \qquad (8)$$

\ Where electrical conductivity (EC) and TDS were expressed in µS/cm and mg/litre respectively.

RESULTS AND DISCUSSION

Geology of the Study Area

The study area is part of the Hawal Massif which is one of the three Massifs that occur within the eastern province of the Basement Complex of Northeastern Nigeria. The major rock type in this area includes the Newer Basalt, coarse grained biotite granites, coarse porphyritic granites and medium grained granites (Figure 2). These rocks which have been subjected to tectonism leading to fracturing such as joints, faults, dykes and veins were intruded by the Newer Basaltic rocks. They have undergone complete weathering, decomposition and lateritization leading to about six meters to 20 meters of unconsolidated weathered overburden layer consisting of gravels, clays, laterites and sands. Fine to coarse grained and porphyritic granites, granodiorites and biotite granites have experienced faulting and shearing and are intruded in places by pegmatites. They are found in Kwalia, Michika, Kura, Watu, Jigalambu and Bazza areas. Coarse porphyritic biotite granites is predominantly scattered as small outcrops in the northwest, western and southern part of the study area. The essential minerals found in these rocks are feldspar, quartz and biotite while associated accessory minerals include iron oxide and sphene. The medium grained granite occurs at the eastern part around Moda as intrusive bodies characterized by numerous bodies of mafic minerals, veins of quartz and pegmatites. Fine grained granites consist of massive equip-granular crystals of quartz and biotite. Cataclastic granodiorite which is a massive grey plutonic rock with feldspar and quartz megacrysts are found in the northeast and southern parts of the study area. Gneisses and migmatites are the older rocks within the Hawal Massif basement underlying mainly low lying areas or occurring as residual hills. The gneisses are generally strongly foliated and banded and in places are commonly dissected by quartzo-feldspathic dykes and veins and are imparted with migmatitic signatures in Mubi and Gombi areas. The gneisses have been affected by tectonism leading to folding, shearing and faulting. Pegmatite commonly occur as tabular intrusives within the gneisses. The gneisses are extensively intruded by granitic rocks of Pan African Orogeny (600±150ma) and exist as elliptical bodies within the metamorphic rocks as xenoliths (Islam *et al.,* 1989).

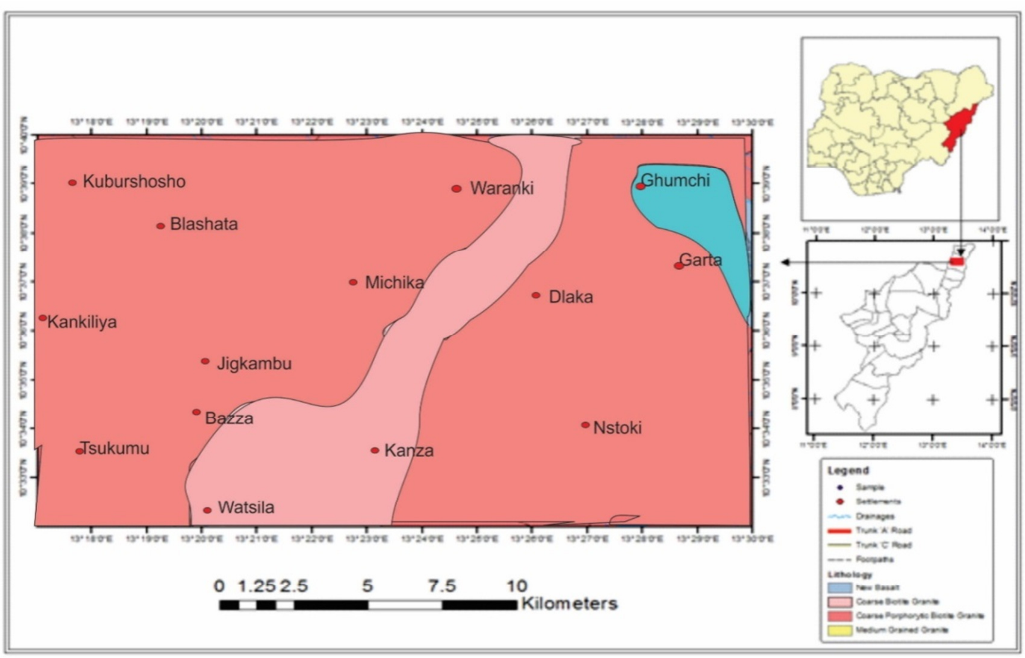

Figure 2: geological map of Michika and Its environs.

Coarse-Porphyritic Granites

The porphyritic granites occur diagonally and occupies the northeastern and northwestern half of the study area. It constitute more than 80% of the land mass. it consists of the phenocryst of whitish feldspar in a groundmass of quartz and biotite crystals. It is phaneritic in texture with large crystals or phenocrysts floating in a groundmass. They are formed when a column of rising magma is cooled in two stages. In the first stage the magma is cooled slowly deep in the crust creating the large crystal grains with a diameter of 2 mm or more. In the final stage the magma is cooled rapidly in a relatively shallow depth creating small grains that are usually invisible to an unaided eye. Most of the igneous rocks in the study area display this degree of porphyritic texture (Plate 1).

Coarse Biotite Granites

The coarse biotite granites occurs diagonally as a lenticular stretch of rock running from the northeastern part to the southwestern part and occupies about 15% of the study area. It is found mainly in Watsila, Kanza and Chike to the south and around Paitha, Tighimi and Udle to the north. It is coarse-grained, light coloured igneous rock composed mainly of feldspar and quartz with minor amounts of mica such as biotite and amphibole such as hornblende (Plate 1). It is felsic intrusive granular and phaneritic in texture with interlocking somewhat equigranular matrix of feldspar and quartz with scattered darker biotite mica and amphibole (often hornblende). They are massive (lacking any internal structures), hard and tough.

Medium Grained Granite

The medium grained granite occurred to the northeastern part around Mbororo and underlies less than 1% of the study area. It is light coloured and composed mainly of quartz and feldspar with minor amounts of mica, amphiboles and accessory minerals such as sphene and apatite. It is massive, intrusive, granular and phaneritic in texture (Plate 2).

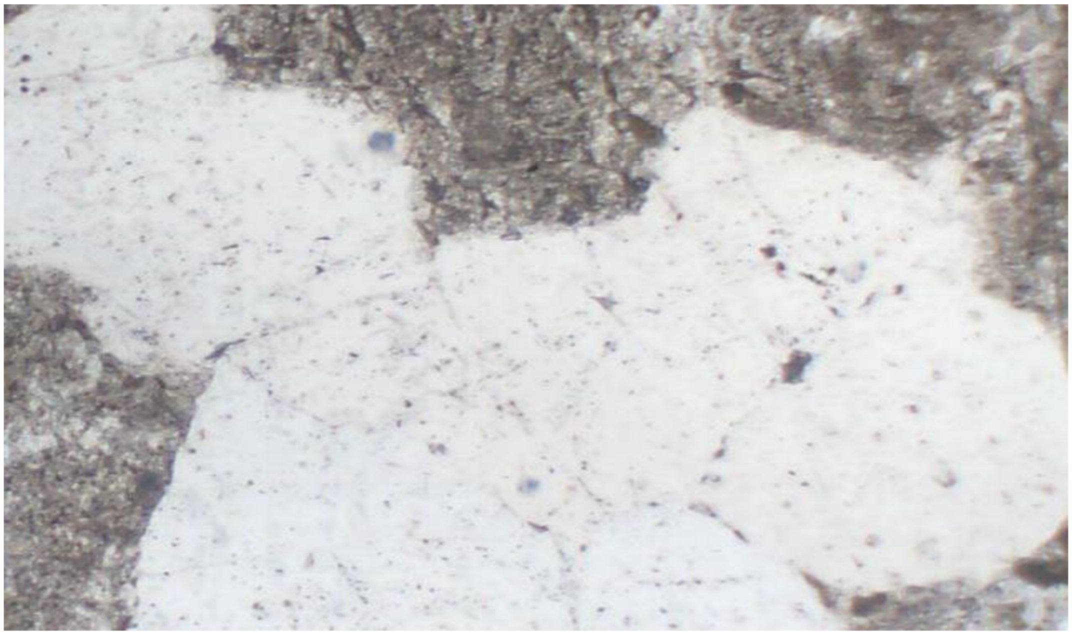

Plate 1: Photomicrograph Showing Coarse Porphyritic Granite under Plain Polarized Light (Magnification x 100)

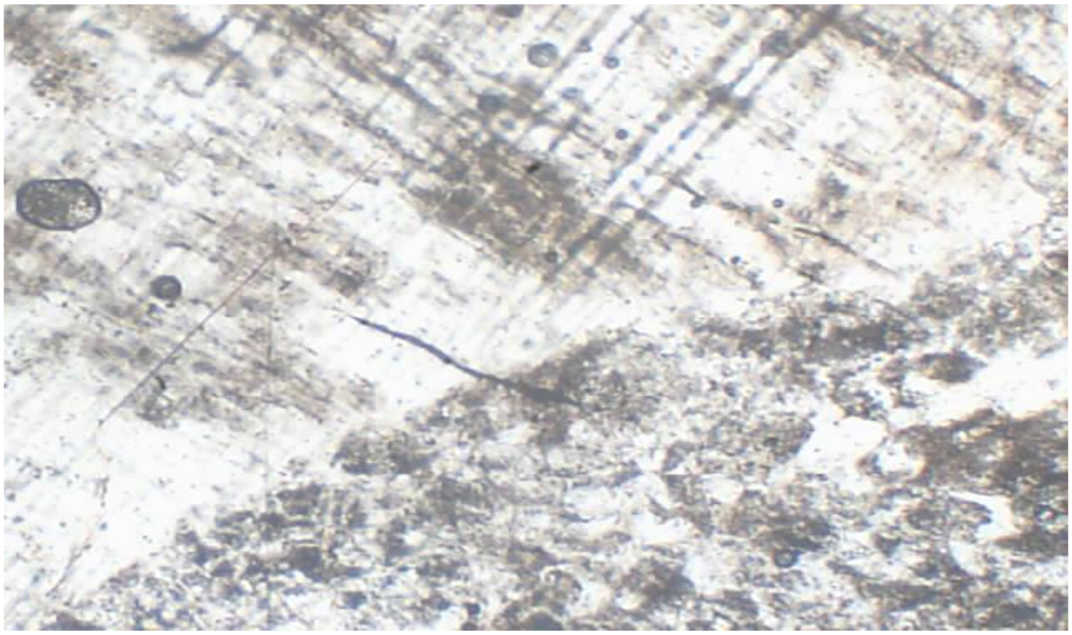

Plate 2: Photomicrograph of medium grained granite under plain polarized light (Magnification x 100)

Coarse Grained Biotite Granites

The coarse biotite granites occurs diagonally as a lenticular stretch of rock running from the northeastern part to the southwestern part and occupies about 15% of the study area . It is found mainly in Watsila, Kanza and Chike to the south and around Paitha, Tighimi and Udle to the north. It is coarse-grained, light coloured igneous rock composed mainly of feldspar and quartz with minor amounts of mica such as biotite and amphibole such as hornblende (Plate 3). It is felsic, intrusive, granular and phaneritic in texture with interlocking somewhat equigranular matrix of feldspar and quartz with scattered darker biotite mica and amphibole (often hornblende). They are massive (lacking any internal structures), hard and tough.

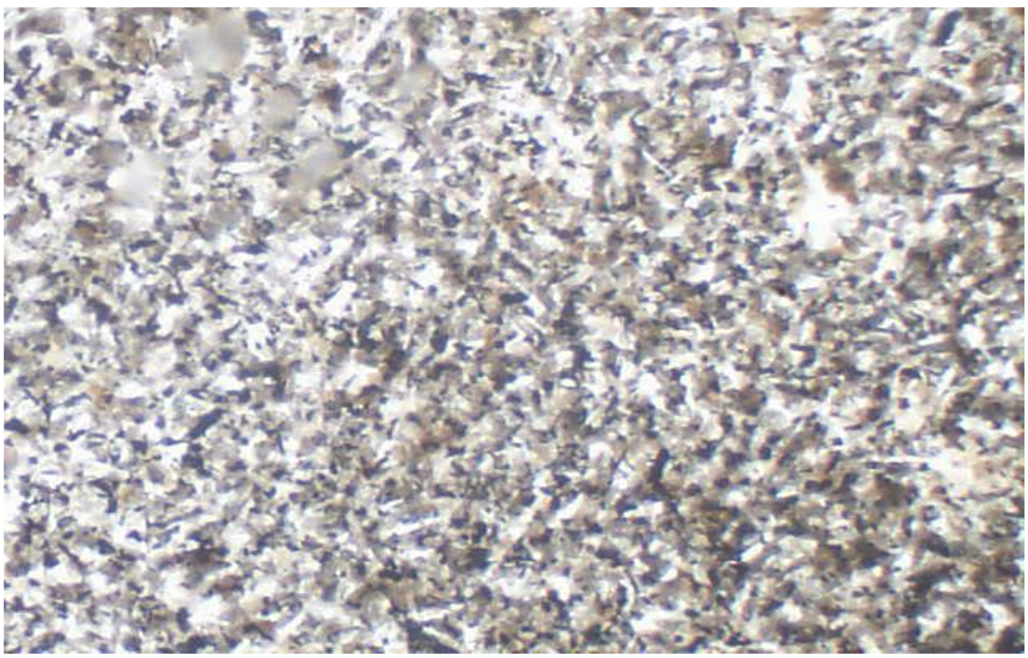

Plate 3: Photomicrograph showing coarse grained biotite granite under cross polarized light (Magnification x100)

Newer Basalts

The Newer Basalt occurred to the northeaster extreme around Ghumchi and Ghumghari as an isolated outcrop and underlies about 5% of the study area (Figure 4). The basalt is dark-coloured,glassy to fine grained and interspersed with visible mineral grains such as plagioclase feldspar, pyroxene and olivine.

It commonly occurs as lava flows and dyke-like intrusion and tabular in places. The texture consist essentially of glassy, massive, porphyritic, vesicular and scoria. The porphyritic varieties consist of phenocrysts of olivine or a calcium-rich plagioclase formed prior to the extrusion that brought the lava to the surface and embedded in a finer grained matrix. In some places the basalt has rapidly weathered to brown or rust-red oxides and hydroxides clay materials.

Unconsolidated Weathered Overburden Materials

The unconsolidated weathered overburden materials consist of a mantle of gravels, coarse sands, loamy and clayey soils with grain sizes decreasing with increasing distance from the hills. The soils are unconsolidated to poorly cemented, loose and thus susceptible to both surface and subsurface erosion. They are quite extensive and cover about 50% of the study area.

GEOLOGIC STRUCTURES

Dykes and Veins

A dyke is a discordant igneous rock or solidified magma cutting through the overlying sediments or body of a host rock. Granitic dykes are observed at Michika, Tudun Wada, Garta, and Kamale areas. The dykes in the outcrop are not affected by weathering of the country rock in which they occur. They can be pronounced in the field because they weather differently from the rock they penetrate. The dykes are found mainly in the northeastern part of the study area and trend mainly in the NE-SW direction. They range from 1 m to 1.6 m in thickness which indicates pan African orogeny. Veins are fractures filled with remobilized minerals such as quartz, feldspars or both. Veins indicate high albeit transient, pore fluid pressure during deformation and are commonly associated with pressure solution seams called quartzofeldsphatic veins. Veins can be identified in the field based on color difference or textural differences with its host rock (Carter *et al.,* 1963). The quartzofeldspatic veins observed are found in the southern part of the study area around Watsila, Kaoza and Chika and are more felsic than the host rock. These are due to the presence of quartz and feldspar which makes them lighter coloured. They trend mostly in NE-SW directions (Table 1 and Figures 3 to 6).

The dykes and veins run through some of the major rocks found around the study area and mark the last phase of intrusive activities in the study area (Bassey, 2007). They run through some of the major rocks found around the study area.

Faults

Fault is a planner discontinuity between rocks where there has been an observable amount of displacement. Faults are rarely single planner unit; normally they occur as parallel set of plane along which movement has taken place to a greater or lesser extent. Faults are produced as the results of the forces that act within the earth and displace and distort the rock within the earth. These forces result from the load of the overlying rocks whereas others arises from the large scale movement of materials composing adjacent part of the core or mantle. Some parts of the study area are observed to be highly faulted and while some faults are inherited from offloading by erosion causing some minor fractures, others resulted from stresses acting on the study area. They trend mostly in NE-SW and NW-SE direction.

Joints

Joints were observed and recorded in most parts of the study area. The Joints are small-scale parting in a bulk surface of a material which are irregular in shape. There is a contraction at the middle, which results from the cohesive forces acting on the grains and crack occurs. They trend mostly in NE-SW and directions with minor E-W direction.

Table 1: Orientation of Lineaments in the Study Area

Location	Strike (General Trend)
Michika	40,74,64,25,160,90,197,210,80, 225,237,45,70,82,20155,220,230,74,50
Tudun Wada	50,78,70,30,170,98,190,230,85,220 240,47,76,87,205,60,210,228,76,48
Garta	60,64,74,42,190,70,210,86,30,36 94,187,152,60,220,240,70,47,54,88
Kamale	123,50,42,66,180,90,234,90,33,38 90,192,154,60,210,232,80,40,30,52

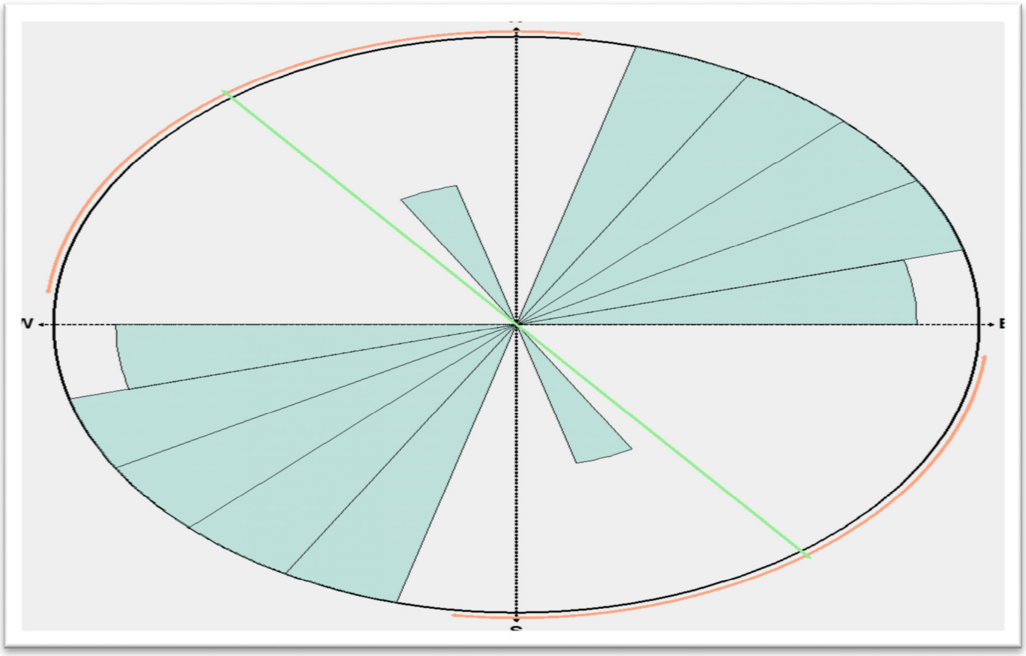

Figure 3: Rose Diagram of Lineaments in Granitic Rocks of Michika Area Total Number of Points = 2029

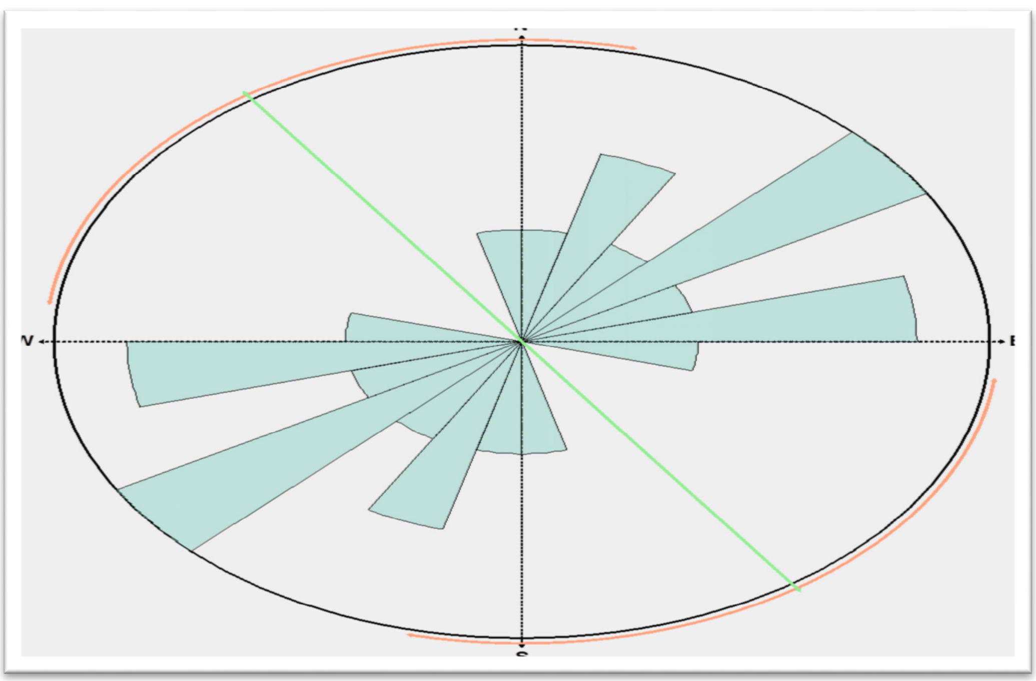

Figure 4: Rose Diagram of Lineaments in Granitic Rocks of Tudun Wada

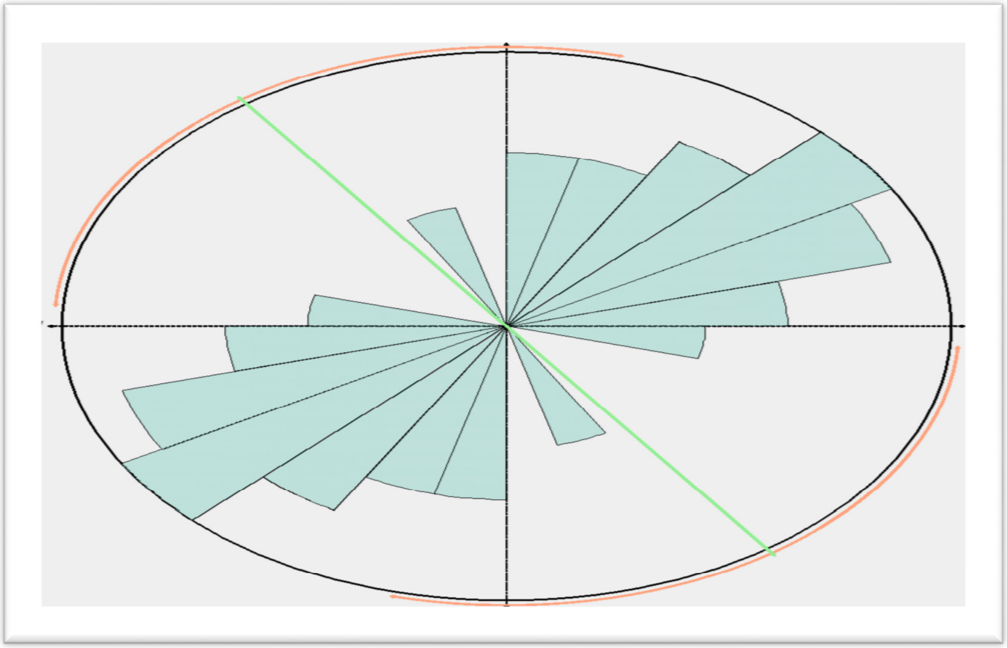

Figure 5: Rose Diagram of Lineaments in Granitic Rocks of Garta Area

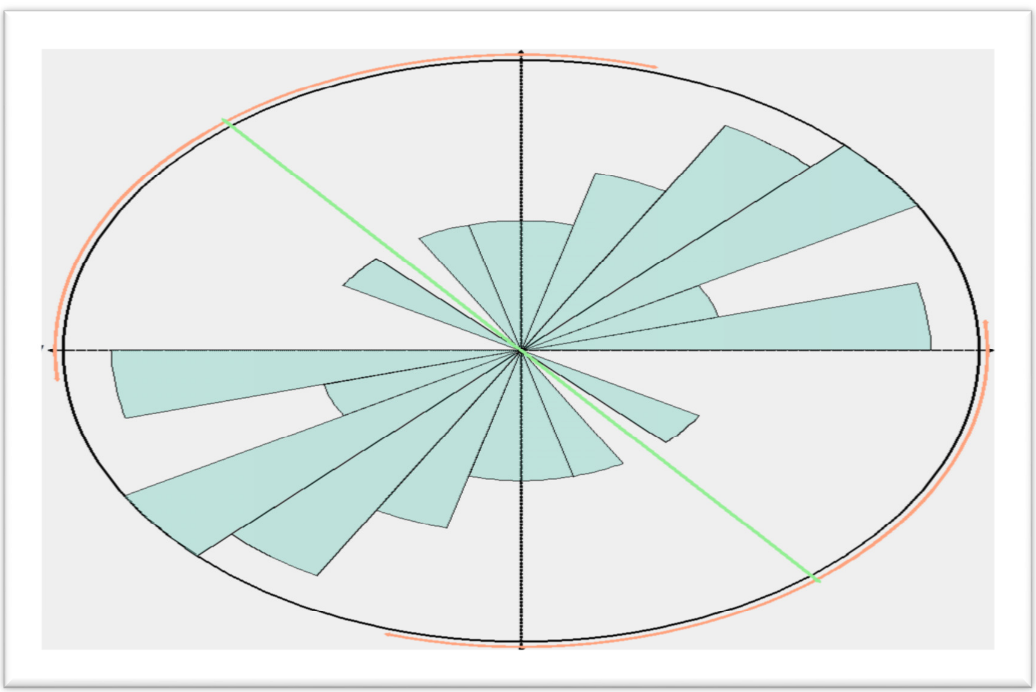

Figure 6: Rose Diagram of Lineaments in Granitic Rocks of Kamale Area

FIELD GEOLOGY AND PETROGRAPHIC DESCRIPTION

From the study of the rock samples in both plane polarized and cross polarized lights the following minerals were observed: quartz, feldspar, mica and accessory minerals. Quartz is generally anhedral in crystal form, has weak birefringence and shows grey to white first order interference. It has low relief, shows undulose extinction and is colourless in plane polarized light. Feldspar is colourless under plane polarized light, sub-hederal in crystal form and shows low relief and weak birefringence. It is also non-pleochroic and shows grey to white first order interference, parallel extinction and Carlsbad twinning.

Table 2 is a summary of the mineralogical composition and percentages. Microscopic examination of the granitic rock samples in cross polarized light revealed the presence of varying composition of constituent minerals such as feldspar, quartz, muscovite and opaque minerals (iron oxide). Feldspar is the most abundant mineral in granitic igneous rocks, its cleavages are noticeable, and its thin, bright and parallel lamella of polysynthetic twinning conform to the albite law (Jimoh, 2011). Plagioclase feldspar shows euhedral form crystals whereas quartz shows an irregular, subhedral body, greyish to whitish colouration and occupies the interstitial space of plagioclase feldspar. Muscovite displays a brownish green to pinkish blue colouration whereas plagioclase feldspar appear cloudy probably due to the alteration processes in them. Microscopic examination of basaltic igneous rocks collected from Hyelimi, Ghumghar and Ghumchi areas reveal fine grained massive basalt with phenocrysts of olivine set in a groundmass of pyroxene, plagioclase and iron oxide (Table 3). Plagioclase is colourless under plane polarized light and non pleochroic and cleave in two directions with very low relief and weak birefringence. Interference colour is grey to white of first order and extinction is oblique and exhibit albite twinning. Pyroxene is light under polarized light and non pleochroic with perfect cleavage in two directions. It exhibit prismatic structure with very high relief and strong birefringence. Interference colour is greenish to dark green under cross polarized light and displays symmetric extinction with polysynthetic twinning. Olivine is colourless under plane polarized light, non pleochroic with no cleavage.

Table 2: Summary of mineralogical composition of Igneous Rocks (gneisses, migmatite, pegmatite, diorite, biotite)

S/No	Location	Sample Number	Mineral in plane polars	Mineral in cross polars	Mineral percentage
1	Michika Central	A	-	Quartz Feldspar Mica Iron oxide	52.5 21.5 25.6 0.4
2	Kwatabe	B		Quartz Feldspar Mica Iron oxide	54.5 32.5 9.0 3.0
3	Hyelimi	C	Olivine Pyroxene Iron oxide	Plagioclase Olivine Pyroxene Iron oxide	20.9 27.5 35.1 16.5
4	Garta	D	Muscovite	Quartz Feldspar Mica Iron oxide	62.0 25.7 12 0.3
5	Ghumghar	E	Olivine Pyroxene Iron oxide	Plagioclase Olivine Pyroxene Iron oxide	29.5 28 31 11.5
6	Ghumchi	F	Olivine Pyroxene Iron oxide	Plagioclase Olivine Pyroxene Iron oxide	21.5 31 31.5 16
7	Dlaka	G		Quartz Feldspar Mica Iron oxide	64.0 23.4 12.0 0.6

It is anhederal to subhedral and has low to moderate relief and birefringence with first order interference colour. It has parallel extinction with no twinning. Iron oxide is opaque, non pleochroic with no cleavage. It is anhederal with high relief and no birefringence and non-twinning.

HYDROGEOLOGY OF THE STUDY AREA

The study area is underlain by the Precambrain Basement Complex rocks consisting of medium grained granite, coarse grained biotite granite, coarse porphyritic biotite granite and the Newer Basalt. These rocks which have been subjected to tectonism leading to fracturing such as joints, faults, dykes and veins are intruded by the newer basaltic rocks. Furthermore, these basement rocks have undergone complete weathering, decomposition and lateritization leading to about 6 meters to 20 meters of unconsolidated weathered overburden layers consisting of gravels, clays, laterites and sands.

Two aquifer units have been identified in the study area based on geological reconnaissance and hydrolithologic analyses of borehole logs. These are the unconsolidated weathered overburden aquifer and the fractured basement aquifer. The fractured fresh basement aquifer consists of rocks that have been subjected to tectonism leading to fracturing and consist of jointed, fissured and faulted rocks. The unconsolidated weathered overburden aquifer consists of loose unconsolidated to poorly materials such as gravels, sands and clays with grain-size decreasing with increasing distance from the hills. They are tapped mainly by hand-dug wells and shallow boreholes and cover about half of the study area.

The depth to static water level in this aquifer varies from 2.9 meters to 9.7 meters with a mean value of 7.28 (Table 3). Well locations and hydraulic head distribution as well as the groundwater flow direction in the study area. It suggests the occurrence of groundwater mound at isolated points to the northwest, north and diagonally across the northeast and southwestern part and discharges naturally into rivers and streams (Figure 7).

The Description of the representative Borehole logs from Michika Area

The major aquifer zones in the study area varies from highly weathered, weathered, and fractured zones, this were evaluated from the drilled boreholes within the study area. The various lithologs gives more information on the hardness of the formation (Tables 4, 5, and 6). Figure 8show the geologic cross section respectively whereas the various representative lithologs from some selected boreholes from the study area are presented in Figure 9.

Table 3: Depth to Static Water Level of Wells in the Study Area.

LOCATION	WELL No.	SWL (m)	ELEVATION OF WELL ASL (m)	HYDRAULIC HEAD (m) ASL	NORTHING	EASTING
Michika Central	BH 1	6	416	410	010 41' 575″	013 24' 504″
Yammu	BH 2	9.6	673	663.4	010 36' 139″	013 21' 857″
Jidil	BH 3	7.2	608	600.8	010 34' 379″	013 19' 497″
Huzuku	HDW1	7.8	633	625.2	010 37' 120″	013 23' 370″
Meze	HDW2	8.7	718	709.3	010 38' 349″	013 21' 735″
Kwatabe	BH4	8.4	666	657.6	010 37' 839″	013 22' 513″
Tudun Wada	HDW3	8.2	812.7	804.5	010 29' 532″	013 30' 902″
Futu	BH5	9.0	795	786	010 25' 617″	013 28' 364″
Dlaka	BH6	6.9	620	613.1	010 33'962″	013 23' 322″
Bize	HDW4	9.3	618	608.7	010 23' 123″	013 34' 158″
Garta	HDW5	8.7	780.3	699.6	010 34' 341″	013 23' 837″
Simike	HDW6	6.5	807	800.5	010 28' 493″	013 32' 703″
Kamale	BH7	8.3	827.3	819	010 28' 512″	013 32' 909″
Mbororo	BH8	3.7	630.7	627	010 32' 080″	013 22 ' 798″
Warakanza	BH9	6.5	849.3	842.8	010 28' 788″	013 32' 201″
Watsila	HDW7	2.9	625	622.1	010 33' 300″	013 23' 521″
Kubi	HDW8	5.6	614	608.4	010 38' 578″	013 24' 422″
Bazza	HDW9	5.2	607	601.8	010 28' 522″	013 32' 231″
Viboka	HDW10	9.7	785.3	775.6	010 36' 435″	013 30' 786″
Zukui	BH 10	7.4	622	614.6	010 26' 267″	013 28' 590″

NB: BH = Borehole and HDW = Hand Dug Well.

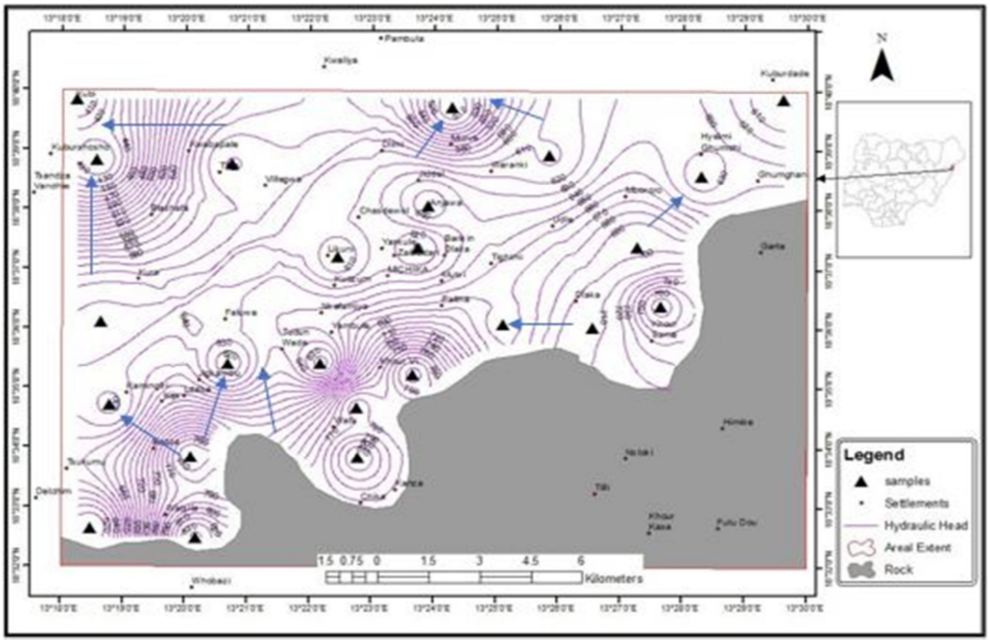

Figure 7: Sample Locations of Boreholes, hydraulic head distribution and groundwater flow direction

Table 4: Showing the Lithologic Description of Borehole from Michika

S/No	Depth (m)	Time(min)	Lithological descriptions	Remarks
1	0 - 3	6:40-6:50	Top soil	
2	3 - 6	6:50-7:00	Top soil	
3	6—9	7:00-7:10	Clay	
4	9—12	7:10-7.20	Clay	
5	12-15	7:20-7:30	Clay	
6	15-18	7:30-7:40	Highly weathered basement	
7	18-21	7:40-7:50	Highly weathered basement	
8	21 -24	7:50-8:00	Fractured basement	Productive
9	24-27	8:00-8:10	Fractured basement	" "
10	27-30	8:10-8:20	Fractured basement	" "
11	30-33	8:20-8:30	Weathered basement	" "
12	33-37	8:30-8:40	Weathered basement	" "
13	37-40	8:40-8:50	Weathered basement	" "
14	40-43	8:50-9:00	Weathered basement	" "
15	43-47	9:00-9:40	Fractured Basement	" "
16	47-50	9:40-9:0	Fractured Basement	" "
17	50-53	10:30-10:40	Fresh basement	Non productive
18	53-57			
19	57-60			
20	60-63			
21	63-67			
23	67-70			
24	70-73			
25	73- 77			
26	77-80			

Table 5: Showing the Lithologic Description of Borehole from Bazza

S/No	Depth (m)	Time(min)	Lithological descriptions	Remarks
1	0 - 3	7:30-7:40	Top soil	
2	3 - 6	7:40-7:50	Top soil	
3	6—9	7:50-8:600	Alluvium	
4	9—12	8:00-8.10	Alluvium	
5	12-15	8:20-8:30	Alluvium	
6	15-18	8:30-8:40	Highly Weathered basement	
7	18-21	8:40-8:50	Highly Weathered basement	Productive
8	21 -24	8:50-9:00	Weathered basement	" "
9	24-27	9:00-9:10	Weathered basement	" "
10	27-30	8:10-8:20	Weathered basement	" "
11	30-33	8:20-8:30	Weathered basement	" "
12	33-37	8:30-8:40	Weathered basement	" "
13	37-40	8:40-8:50	Weathered basement	" "
14	40-43	8:50-9:00	Weathered basement	" "
15	43-47	9:00-9:40	Weathered basement	" "
16	47-50	9:40-9:50	Weathered basement	" "
17	50-53	90:50-11:00	Fresh granite	Non -productive
18	53-57			

19	57-60
20	60-63

Table 6: Showing the lithologic description of Borehole from Dlaka

S/No	Depth (m)	Time(min)	Lithological descriptions	Remarks
1	0 - 3	7:30-7:40	Top soil	
2	3 - 6	7:40-7:50	Top soil	
3	6—9	7:50-8:600	Clay	
4	9—12	8:00-8.10	Clay	
5	12-15	8:20-8:30	Alluvium	
6	15-18	8:30-8:40	Highly Weathered basement	Productive
7	18-21	8:40-8:50	Highly Weathered basement	Productive
8	21 -24	8:50-9:00	Weathered basement	" "
9	24-27	9:00-9:10	Weathered basement	" "
10	27-30	8:10-8:20	Weathered basement	" "
11	30-33	8:20-8:30	Weathered basement	" "
12	33-37	8:30-8:40	Weathered basement	" "
13	37-40	8:40-8:50	Weathered basement	" "
14	40-43	8:50-9:00	Weathered basement	" "
15	43-47	9:00-9:40	Weathered basement	" "
16	47-50	9:40-9:50	Weathered basement	" "
17	50-53	90:50-11:00	Fresh granite	Non -productive
18	53-57			
19	57-60			
20	60-63			

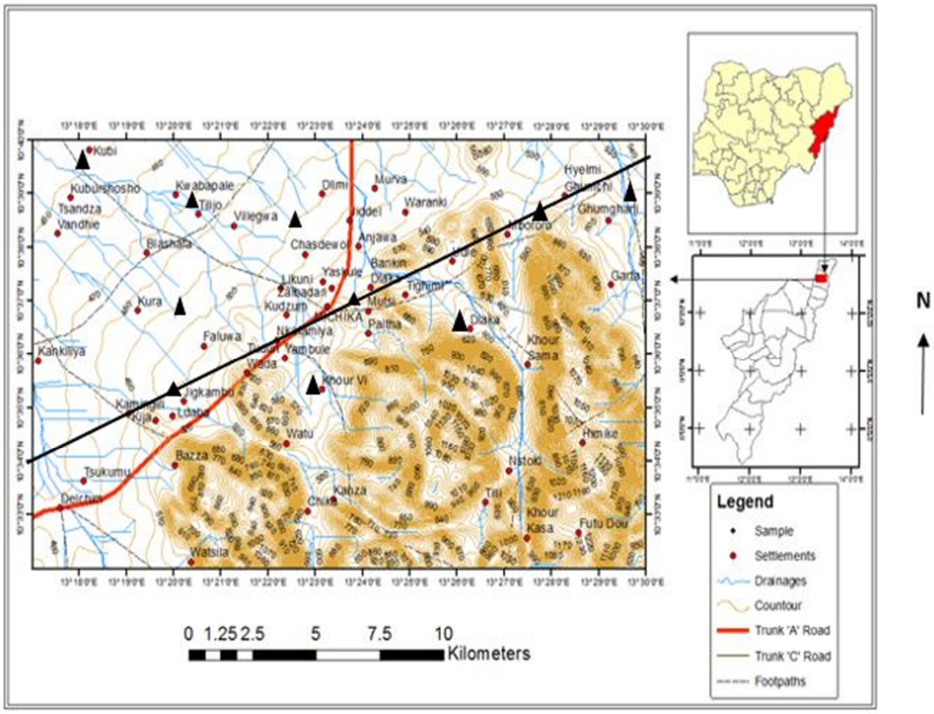

Figure 8: Topographic Map Showing the Geologic Cross Section from the Study Area

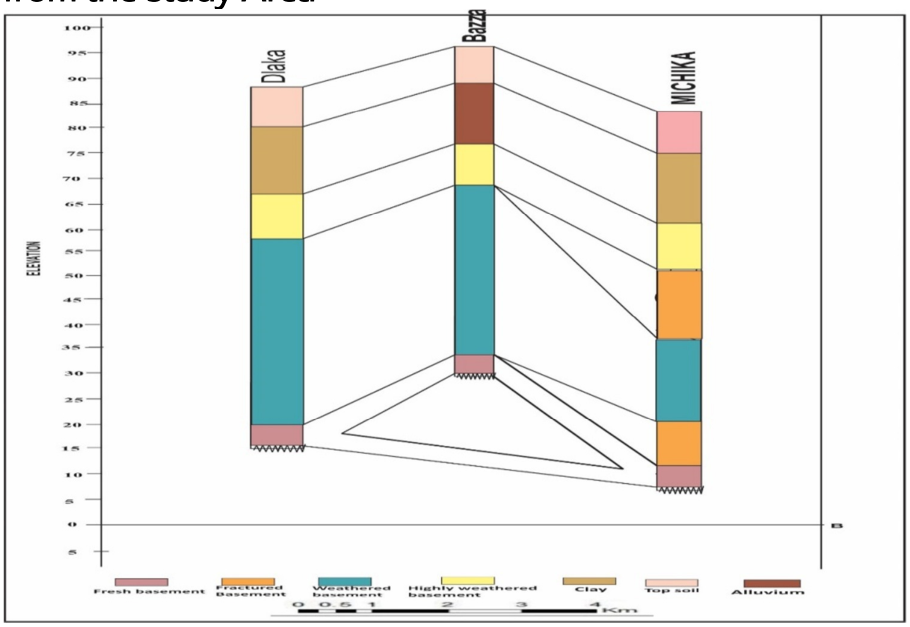

Figure 9: The representative Lithologs obtained from the selected in the study area

Water Quality Data

Details and a summary of the physicochemical parameters for the different water sources for the shallow groundwater are summarized in Tables 11 and 12. The water temperature, electrical conductivity, turbidity and pH values are expressed in ^{o}C, µs/cm, NTU, pH unit respectively whereas the rest of the parameters are expressed as mg/l. The results of the analyzed parameters of shallow groundwater of the different locations of the study area are compared with the WHO (2011) standard for drinking water.

Shallow Groundwater Chemical Data

Temperatures of shallow groundwater from (Hand-dug wells and shallow boreholes) ranged from 23.7 to 31 ^{o}C. The values of EC varyied from 25 to 165 µS/cm whereas the total dissolved solids varyied from 130 to 280 mg/l. The EC and TDS are relatively low in comparison to the WHO (2011) standard of 1400 µS/cm for EC and 1000 mg/l for TDS indicating that the waters are also fresh. However, the analyzed physical parameters are temperature, turbidity, pH, EC and TDS. Results show that the temperature of the sampled water ranged between 23.7 ^{o}C to 31^{o}C with mean value of 29.66 ^{o}C, the least value was recorded in Michika Central (BH1) and the highest value in Huzuku (HDW1), pH ranged between 5.1 and 7.6, with the mean value of 6.26, the least value was recorded in Bize (HDW4) and the highest value in Tudunwada (HDW3), EC ranged between 25 and 165 µs/cm with the mean value 92.3 µs/cm, whereas the least and high value found in Kwatabe (BH4) and Tudunwada (HDW3) respectively. The TDS ranged between 130 to 310 mg/l with means value 192 mg/l whereas the least and high values were recorded in Kwatabe (BH4) and Futu (BH5) respectively. The chemical parameters analyzed were the major cations (Mg^{2+}, Ca^{2+}, Fe^{2+}, Na^{+} and K^{+}.) and anions (Cl^{-}, HCO_3, NO_3^{-}, SO_4^{2-} and CO_3^{2-}). Their concentrations vary from one location to the other depending on the local geology of the area and other human related activities.

The results of these chemical parameters show that magnesium, ranged between 5 mg/l in Thuri borehole (BH15) and 36 mg/l in Warakanza borehole (BH9) with a mean value of 14.11 mg/l. The calcium value ranged between 36 mg/l in Minkisi borehole (BH18) and 124 mg/l in Michika Central (BH1) with the mean value of 69.68 mg/l. The Fe^{2+} ranged between 0.00 in Moda borehole (BH12) to 1.00 mg/l in

Simike hand-dug well (HDW6) with a mean value of 0.26 mg/l. The total hardness ($CaCO_3$) values varied from 8.9 mg/l in Minkisi borehole (BH18) to 312 mg/l in Michika Central with the mean value of 165 mg/l. The bicarbonate values varies from 53.6 mg/l in Minkisi borehole to 361.32 mg/l in Michika Central borehole (BH1) with mean value of 152.25 mg/l. The Chloride revealed values of 31 mg/l in Garta hand-dug well (HDW5) to values of 206 mg/l in Sangere borehole (BH13) with a mean value of 85.10 mg/l. The nitrate nitrogen varied from 4 mg/l in Kubi hand-dug well (HDW8) to values of 14 mg/l in Dlaka and Warakanza boreholes (BH6 and BH9) with a mean value of 8.75 mg/l. The sulphate disclosed values of 32 mg/l in Kubi hand-dug well (HDW8) to values of 128 mg/l in Yammu borehole (BH2) with a mean value of 51.25 mg/l. The carbonate values varied from 53 mg/l in Minkisi borehole (BH18) to values of 187 mg/l in Michika Central borehole (BH1) with a mean value of 101.92 mg/l..

The pH values varied from 5.10 to 7.60 indicating acidic to slightly alkaline water which could be attributed to rainfall and the absence of buffering materials within the aquifers. The data on chemical composition (Table 11) showed that the mean concentrations of the cations in groundwater were Na (55.83 mg/l), Ca (69.68 mg/l), K (2.03 mg/l) and Mg (14.11 mg/l). The values of chloride concentrations varied from 31 to 206 mg/l whereas the value of sulphate concentration varied from 32 to 128 mg/l. The relative concentration of both chloride and sulphate could be attributed to anthropogenic waste reactions.

Nitrate values ranged from 4 to 14 mg/l with mean of 8.75 mg/l (as N) for the groundwater samples. Thus most of the samples have lower concentrations reflecting little pollution (egCustodio and Llamas, 1983) and less than 10 mg/l (WHO 2011) maximum recommended value for drinking purposes, (Table 12).

CONT: Results of Chemical Analyses of Shallow Groundwater Samples in the Study Area

S/N	SAMPLE LOCATION	Temp ^{0}C	PH	TURBN TU	TDS Mg/L	COND µS/Cm	TOTAL HARDNESS	Ca^{2+} Mg/l	CO_3 Mg/l	$NaCl_2$ Mg/l	Cl^- Mg/l	Na+ Mg/l	K^+ Mg/l	Fe^{2-} Mg/l	$S0_4$ Mg/l	NO_3 Mg/l	Mg^+ Mg/l	CU^+ Mg/l	HCO_3 Mg/l
21	WoroNgiki BH11	31	5.2	1.0	260	130	217	87	130	147	89	57	0.3	0.3	56	9	12	0.01	131.1
22	Moda BH12	31	5.8	1.2	180	90	146	59	87	280	170	110	1.0	0.0	52	6	8	0.00	87.7
23	Sangere BH13	31	6.5	1.2	200	98	176	70	106	339	206	133	0.3	0.1	58	8	6	0.02	106.8
24	Hausari BH14	31	5.8	1.1	170	84	126	50	76	293	178	115	0.5	0.2	39	7	10	0.01	76.9
25	Jang BH15	31	5.6	2.0	210	105	144	58	86	190	115	75	0.4	0.3	50	5	8	0.00	86.9
26	Thuri BH16	31	6.5	1.8	140	70	109	44	65	78	48	32	1.0	0.1	35	8	5	0.01	65.8
27	Kwabapale BH17	31	7.2	1.5	200	100	176	70	106	180	110	70	0.8	0.2	60	10	9	0.01	107.2
28	Minkisi BH18	31	6.8	1.0	180	90	8.9	36	53	60	36	24	0.3	0.3	48	14	10	0.00	53.6
29	Wato BH19	31	6.5	1.2	130	65	217	87	130	75	45	30	2.0	1.0	55	6	6	0.00	131.3
30	Sinagali BH20	31	5.8	1.1	160	80	13	53	79	150	80	50	1.4	0.5	48	8	12	0.01	80.1
31	Kurvi BH21	31	6.5	1.0	150	75	221	88	133	112	68	44	1.3	0.2	37	5	8	0.00	134.2
32	Kuda BH22	31	5.8	1.2	190	90	126	50	76	200	120	80	0.8	0.1	45	9	5	0.02	78.1
33	Pambila BH23	31	6.8	1.0	210	100	284	113	170	95	60	135	0.2	0.3	58	10	6	0.00	172
34	Madzi BH24	31	6.5	1.0	176	80	146	59	87	120	70	50	1.0	0.0	52	5	8	0.00	89.1
35	Rafisanye BH25	31	5.8	1.1	160	80	98	40	55	86	52	34	0.5	0.0	38	7	11	0.01	56.1
36	Luhu BH26	31	6.0	1.2	180	90	140	56	82	165	100	65	0.0	0.1	60	8	8	0.00	83.2
37	Karyanga BH27	31	7.1	2.0	220	110	145	57	85	165	64	41	0.1	0.2	42	6	10	0.00	86.8
38	Bulabuli BH28	31	6.5	1.5	140	70	125	60	77	147	89	57	0.2	0.4	40	10	8	0.01	61.3
39	Dlaka BH29	31	7.0	1.0	190	85	200	80	120	68	40	28	0.6	1.0	50	12	9	0.01	81.4
40	Kwabursho sho BH30	31	6.8	1.0	150	65	150	90	90	190	110	80	0.4	0.5	55	9	10	0.00	92.1

Table 7: Summary of physicochemical parameters of the shallow groundwater in the Study Area

PARAMETER	RANGE	MEAN	WHO (2011)
pH (unit)	5.1 – 7.6	6.26	6-5 – 8.5
Temperature (^{o}c)	23-31	29.66	-
Conductivity (µS/cm)	25- 165	92.3	140
Sodium (mg/l)	11.5-135	55.83	200
Potassium (mg/l)	0-11	2.03	55
Calcium (mg/l)	36-113	69.68	75
Magnesium(mg/l)	5-36	14.11	50
Iron (mg/l)	0-1.00	0.26	0.3
Chloride (mg/l)	31-206	85.10	250
Sulphlate (mg/l)	32-128	51.25	400
Bicarbonate (mg/l)	53.6-361.32	150.25	1000
Nitrate –N (mg/l)	4-14	8.75	10
TDS (mg/l)	130-310	192.05	1000
Total Hardness (mg/l)	8-312	165.80	500
CO_3	53-187	101.92	120
Turbidity (NTU)	1-2.4	1.40	5

Major Ions in Different Water Sources of the Study Area

Major ions in the shallow groundwater in the area are given in the Tables 9 and 10. The Ca^{2+}+Mg^{2+}+CO_3+HCO_3 major iontype was identified for water samples from hand-dug wells whereasCa^{2+}+ CO_3+HCO_3 and Na^{+} +K^{+}+ CO_3+HCO_3 majortypes are identified for the water samples from shallow boreholes. For the hand-dug well the dominant ions are largely Ca^{2+} for cations and CO_3^{2-}+ HCO_3^{-} for anions. The shallow boreholes also indicate Ca^{2+} and Na^{+}+K^{+} as the major cations and largely $CO^{2-}{}_3$+ HCO_3 as the major anions. The Ca^{2+}+Mg^{2+}hydrogeochemical facies were identified for the hand-dug wells, The major cations and the major anions were identified for shallow boreholes in the study area (Tables 15 and 16).

Table 8: Classification of the Water Samples of hand-dug wells of the study area on the basis of their major ion percentages

S/No	Well types	Major Cation Types	Major Anion Types
1	HDWI HUZUKU	Ca^{2+}	$CO_3 + HCO^-_3$
2	HDW2 Meze	Mg^{2+}	$CO_3 + HCO^-_3$
3	HDW3 Tudunwada	Ca^{2+}	$CO_3 + HCO^-_3$
4	HDW4 Bize	Ca^{2+}	$CO_3 + HCO^-_3$
5	HDW5 Bize	Ca^{2+}	$CO_3 + HCO^-_3$
6	HDW6 Simike	Ca^{2+}	$CO_3 + HCO^-_3$
7	HDW7 Watsila	No dominant	$CO_3 + HCO^-_3$
8	HDW8 Kubi	Ca^{2+}	$CO_3 + HCO^-_3$
9	HDW9 Bazza	Ca^{2+}	$CO_3 + HCO_3$
10	HDWIO Viboka	Ca^{2+}	$CO_3 + HCO_3$

Table 9: Classification of the Water Samples of shallow boreholes of the study area on the basis of their major ion percentages

S/No	Well types	Major Cations Types	Major Anion Types
1	BHI Michika Central	Ca^{2+}	$CO_3 + HCO^-_3$
2	BH2 Yammu	Mg^{2+}	$CO_3 + HCO^-_3$
3	BH3 Jidil	$Na^+ + K^+$	$CO_3 + HCO^-_3$
4	BH4 Kwatabe	Mg^{2+}	$CO_3 + HCO^-_3$
5	BH5 Futu	Ca^{2+}	$CO_3 + HCO^-_3$
6	BH6 Diaka	No dominant	$CO_3 + HCO^-_3$
7	BH7 Kamale	No dominant	$CO_3 + HCO^-_3$
8	BH8 Mbororo	No dominant	$CO_3 + HCO^-_3$
9	BH9 Warakanza	No dominant	$CO_3 + HCO^-_3$
10	BH10 Zukul	Ca^{2+}	$CO_3 + HCO^-_3$
11	BH11 WuroNgiki	$Na^+ + K^+$	SO_4^{2-}
12	BH12 Moda	$Na^+ + K^+$	SO_4^{2-}
13	BH13 Sangere	$Na^+ + K^+$	$CO_3 + HCO^-_3$
14	BH14 Hausari	$Na^+ + K^+$	SO_4^{2-}
15	BH15 Jang	Mg^{2+}	SO_4^{2-}
16	BH16 Thuri	Ca^{2+}	$CO_3 + HCO^-_3$
17	BH17 Kwabapale	Ca^{2+}	$CO_3 + HCO^-_3$

18	BH18 Minkisi	Ca^{2+}	$CO_3 + HCO^-_3$
19	BH19 Wata	Ca^{2+}	$CO_3 + HCO^-_3$
20	BH20 Sinagali	No dominant	$CO_3 + HCO^-_3$
21	BH21 Kurvi	Ca^{2+}	$CO_3 + HCO^-_3$
22	BH22 Kuda	$Na^+ + K^+$	$CO_3 + HCO^-_3$
23	BH23 Pambila	No dominant	$CO_3 + HCO^-_3$
24	BH24 Madzi	No dominant	$CO_3 + HCO^-_3$
25	BH25 Kafisanye	No dominant	$CO_3 + HCO^-_3$
26	BH26 Luhu	No dominant	$CO_3 + HCO^-_3$
27	BH27 Karyanga	Ca^{2+}	$CO_3 + HCO^-_3$
28	BH28 Bulabuli	Ca^{2+}	$CO_3 + HCO^-_3$
29	BH29 Dlaka	Ca^{2+}	$CO_3 + HCO^-_3$
30	BH30 Kwaburshoshi	Ca^{2+}	SO_4^{2-}

Assessment of Physicochemical Qualities of Groundwater

Geochemical properties and principles that govern the behavior of dissolved chemical constituents in groundwater are referred to as hydrogeochemistry. The dissolved constituents occur as ions, molecules or solid particles, these constituent not only undergo reactions but also redistribution among the various ionic species or between the liquid and solid phases. The chemical composition of the shallow groundwater is related to the solid product of rock weathering and changes with respect to time and space as well as anthropogenic activities. Therefore, the variation on the concentration levels of the different hydrogeochemical constituents dissolved in water determines its usefulness for domestic, industrial and agricultural purposes. However, the use of water for any purpose is guided by standard set by the World Health Organization and other related agencies. In this study, the results of the analyzed chemical parameters in the study area were correlated with those of the Nigeria standard (2007) and that of World Health Organization (WHO, 2011).

Total Hardness (mg/l) as ($CaCO_3$

The water samples from all the settlements in the study area with few exceptions are moderately hard to very hard with values ranging between 8 mg/l and 312 mg/l compared to the maximum allowable limits of WHO (2011) Standard of 150mg/l. The relatively high hardness values recorded in the water samples may be due to anthropogenic activities such as the excessive application of lime to the soils in agricultural areas.

Calcium (Ca^{2+}) (Mg/l)

Calcium contributes to the hardness of water and it is the fifth most common element found in most natural waters. It is an important contributor to water hardness. The calcium concentration of the samples having values that are above the WHO (2011) recommended limit. The possible sources of this calcium in the study area are from the weathering of plagioclase feldspar as well the calc-alkaline rocks that are rich in alkaline earth metals such as magnesium and calcium.

Magnessium (Mg^{2+}) (mg/l)

Magnesium is one of the most common elements in the earth's crust. It is present in all natural waters. It is an important contributor to water hardness. The magnesium concentration none of the samples having magnesium values that are above the (WHO 2011) recommended limit of 30 mg/l. The potential sources of magnesium include weathering of ferro-magnesium igneous rocks that underlies the study area.

Iron (Fe^{2+}) (mg/l)

Iron is a very common element found in many of the rocks and soils of the earth's crust. It is also an essential trace element for animal growth. Soluble ferrous iron is present in natural water with a low Eh. The iron concentration of the samples having iron values that are above the WHO (2011) recommended limit of 0.30 mg/l. The potential sources of iron in the study area include weathering of ferro-magnesium minerals in rocks that underlies the study area.

Sulphate (SO_4^{2-}) (mg/l)

Sulphate occurs in water as inorganic sulphate salts as well as dissolved gas (H_2S). It is not a noxious substance although high sulphate in water may have a laxative effect on people. The

Sulphate concentration in study area with none of the samples having sulphate values above the WHO (2011) recommended limit of 400 mg/l.

Bicarbonate (HCO_3^-) (mg/l)

Bicarbonate combines with calcium carbonate and sulphate to form heat retarding, pipe clogging scale in boilers and in other heat exchange equipment. The bicarbonate concentration have none of the samples having bicarbonate values that are above the WHO (2011) recommended limit of 1000 mg/l. Potential sources of bicarbonate in the study area include oxidation of organic matter as well as carbon dioxide content of the atmosphere and respiration by plants and soil organisms.

Nitrate (NO_3^-) (mg/l)

Nitrate nitrogen concentration have one of the samples having nitrate values that are above the WHO (2011) recommended limit of 10 mg/l. Sources of nitrate in water include human activity such as application of fertilizer in farming as well as human and animal wastes. The study area is highly populated and the human waste management system is poor (shallow pit toilets and open defecation in the bushes is a common practice) and also the use of nitrogenous fertilizer and animal dung in farming is rampant. The migration of the chemical in these locations is facilitated by sandy nature of the superficial geology.

Chloride (Cl^-) (mg/l)

A major ion that may be associated with Individual Septic Disposal System (ISDSS) is chloride (Canter and Knox, 1985). Chloride is present in all natural waters but in relatively small amounts. However, chloride also can be derived from human sources such as human excreta as well as weathering of igneous rocks. Chloride is present in relatively small amounts in igneous rocks. The chloride concentration have none of the samples having chloride values that are above the WHO (2011) recommended limit of 250 mg/l. Potential sources of chloride in the study area include atmospheric sources human excreta.

Total Dissolved Solid (TDS)

Total Dissolved Solid (TDS) generally reflects the amount of minerals content that is dissolved in the water and controls its suitability for domestic, agricultural and industrial uses. High concentration of total dissolved solids may cause adverse taste effects. Highly mineralized water may also deteriorate domestic plumbing appliances. The total dissolved solids (TDS) concentration have with none of the samples having TDS values that are above the WHO (2011) recommended limit of 500 mg/l.
The TDS of the study area falls within the WHO (2011) recommended limit of 500 mg/l and thus suitable for human consumption (domestic) and agricultural purposes.

Electrical Conductivity (μS/cm)

Electrical conductivity (EC) is a measure of the ability of water to conduct an electric current. It is used to estimate the amount of dissolved solids. It increases as the amount of dissolved mineral (ions) increases. The EC concentration have with two of the samples having EC values that are above the WHO (2011) recommended limit. The shallow groundwater is for domestic and agricultural purposes.

Hydrogen Ion Concentration (pH)

The pH is a measure of the hydrogen ion concentration in water. The pH value of water indicates whether the water is acidic or alkaline. Drinking water with a pH values of between 6.5 to 8.5 is generally considered satisfactory. Acid water tend to be corrosive to plumbing and faucets, particularly, if the pH is below 6. Alkaline waters are less corrosive whereas water with a pH above 8.5 may tends to have a bitter or soda-like taste. The pH concentration of the samples having pH values that are above the WHO (2011) recommended limit of between 6.5 and 8.5., as such the water in the study area is not suitable for domestic uses. All the analyzed parameters of the water samples of the study area with the exception of hydrogen ion concentration (pH) fall within the WHO (2011) recommended limits. Furthermore about 52.5% of these samples have pH values that are within the WHO (2011) recommended limits of between 6.5 and 8.5. These indicate that the samples are largely potable for human consumption and other domestic purposes. The assessment of some contamination indicators such as pH, sulphate, chloride and nitrate indicate that the shallow groundwater is largely suitable for human consumption. The concentration of iron in all the analyzed samples is within the WHO (2011) recommended limits of 0.3 mg/l and thus suitable for domestic purposes.

HYDRO-GEOCHEMISTRY

Hydro-geochemical zones

Piper trainer diagrams are plotted in this study to illustrate chemical differences between water samples from the hand-dug wells and shallow boreholes (Piper, 1944) show the relative concentrations of the different ions from the individual samples based on average values for each location. The different water sources include the shallow groundwater tapped mainly by hand-dug wells and shallow boreholes. Two types of hydrogeochemical facies based on the classification given by Deutsch (1997) were identified for both the hand-dug wells and the shallow borehole samples in the study area.

These include Ca-Mg-HCO_3, and Na-HCO_3type, (figure 14 and 15). The water samples are thus characterized mainly by CO_3+ HCO_3^- and SO_4 indicating groundwater mixing and flushing as well as significant water rock interaction. The Ca^{2+}+Mg^{2+}- HCO_3^- major ion type based on the classification given by Deutsch (1997) was identified for hand-dug wells whereasMg^{2+}- HCO_3^- and Na^{2+} +K^+- $HCO_3^-$and Ca^{2+}- HCO_3^- types are identified for the shallow boreholes. For the hand-dug wells the dominant ions are largely Ca^{2+} for captions and CO_3+HCO_3^- for anions whereas the shallow boreholes indicate largely Ca^{2+} , No dominant, Mg^{2+} and Na^++K^+ as the major captions and CO_3+HCO_3^- and SO_4^{2-} as the major anions. The major process for the evolution of the water type is weathering and redox reaction. The water samples from hand-dug wells are characterized mainly by HCO_3 indicating fresh water (with TDS less than 200 mg/l) whereas shallow boreholes characterized by HCO_3^- and SO_4^{2-}indicate significant water rock interaction. The results also indicate that both the shallow boreholes are more mineralized in comparison than those of the hand-dug well water samples suggesting longer residence time.

Gibbs (1970) proposed two diagrams to understand the hydrogeochemical factors that control the groundwater chemistry by plotting a graph of the ratio of cations (Na+K/Na+K=Ca) in milliequivalent per liter against TDS in milligram per litre as well as the ratio of anions (CL/CL+HCO3) in milliequivalent per litre against TDS in milligram per litre. The Gibbs plot of the shallow ground waterasmples revealed that the datsets plot within the evaporation dominance portion (Figures 12 and 13). This indicates that the groundwater chemistry are strongly controlled by evaporation processes expecially during the dry season period of the year. Thus evaporation processes apart from human activity is the key factor that controls the chemistry of groundwater in the study area (Alam 2013; Raju et al 2011).

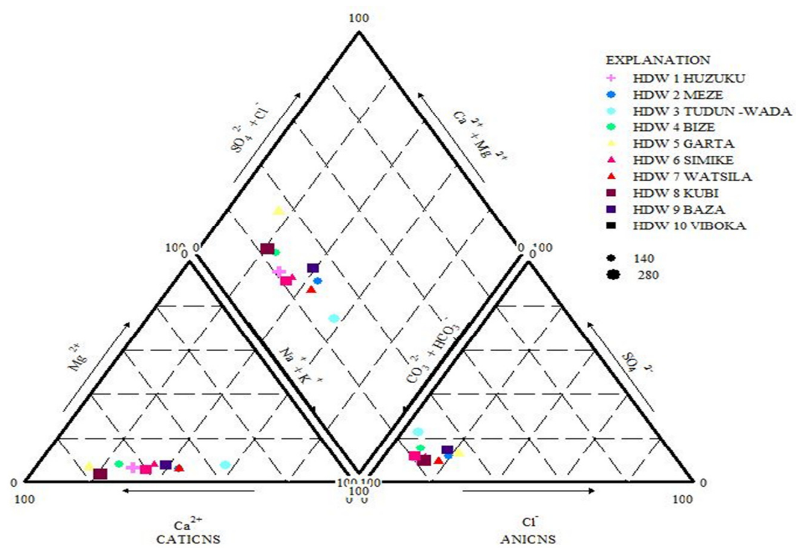

Figure 10: Piper trilinear diagrams for water samples for hand-dug wells in the study area indicate one water types (Na-HCO3).

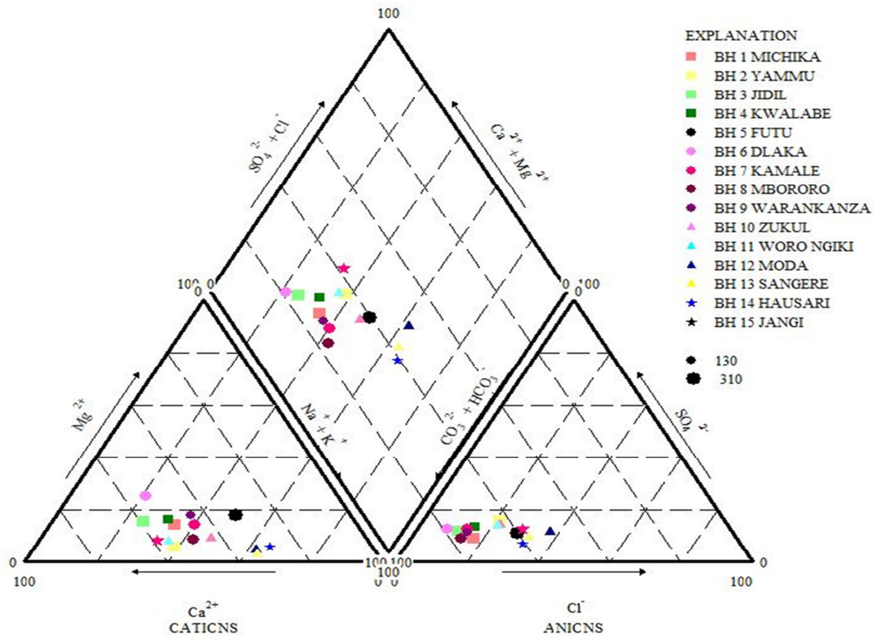

Figure 11: Piper trilinear diagrams for water samples for borehole in the study area indicate one water types (Ca-Mg-HCO3)

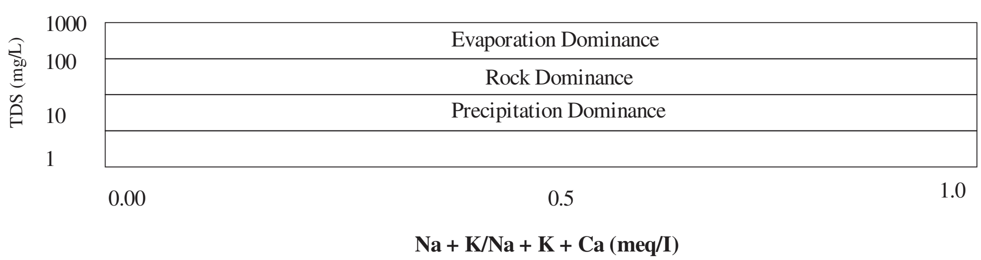

Figure 12 Mechanism controlling groundwater chemistry (Gibbs 1970)

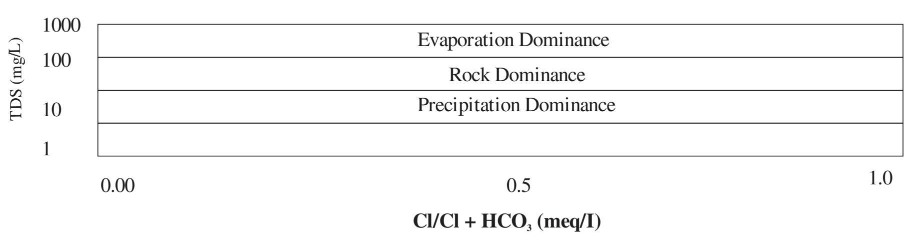

Figure 13 Mechanism controlling groundwater chemistry (Gibbs 1970)

SUMMARY

The area falls within the Basement Complex of the Northeastern Nigeria and covers an area of about 188.5km^2. It lies within latitudes 10^o 32'N to 10^o 14'N and longitudes 13^o 19' E to 13^o 25'E. It is bounded to the east by Republic of Cameroon, to the south by Mubi Local Government Area of Adamawa State. To the west by AskiraUba Local Government Area of Borno State and to the north by Madagali Local Government area respectively. The area is traversed by one major highway that runs from Yola to Maiduguri. Minor roads are Michika – Yammu/ Warakanza, Michika-Kopa-kwapale/Villegwa and Michika-Moda/Mandara roads. These roads link the villages and provide access routes to hilly areas. The study area is hilly to the eastern part and relatively flat to the west. Despite the hilly nature of some parts of the study area, there are still good road networks, foot-paths and tracks that made it accessible. The study area is part of the Hawal massif which is one of the three Massifs that occur within the eastern province of the Basement Complex of Northeastern Nigeria. The major rock types in the area include the Newer Basalt, coarse grained biotite granite, coarse porphyritic granite and the medium grained granites. These rocks which have been subjected to tectonism leading to fracturing such as joints, faults, dykes and veins were intruded by the New Basaltic rocks. The structure trend NE-SW which indicate pan African orogeny. The grain-sizes of granitic igneous rocks range from 2.2mm to 0.43mm indicating fine to coarse grained igneous rocks whereas the mineralogical composition consist essentially of 53% to 69 % quartz, 22% to 33 % feldspar and 0.3% to 3.0 % iron oxide. The basaltic rock mineralogical composition consist essentially of 20.9 % to 29.5% plagioclase, 27.5% to 31% olivine, 31% to 35.1% pyroxene and 11.5% to 16.5% iron oxide. From the hydrogeochemical analysis, the piper trilinear diagrams for groundwater samples (both borehole and hand- dug wells) in the study area indicate two water types Ca-Mg-HCO_3 and Na-HCO_3.

CONCLUSION

From the field and laboratory findings on the present study the conclusion is as follows.

- The study area is underlain by Precambrian basement complex of northern Nigeria the rock were under gone tectonic deformation which result into fault, joint, vein, dyke.
- The study area is trending NW-SE which indicate pan African orogeny.
- Most of the water sample are slightly acidic to alkaline, largely soft and fairly low to moderate concentration of dissolve solids that falls within the international limits for domestic purposes.
- Thus most of the sample will neither cause salinity hazards nor have an adverse effect on soil properties and are mostly suitable for domestic and irrigation purpose.

RECOMMENDATIONS

Based on the findings of the present research and the encountered limitations the following recommendations may be made for future studies:

1. Environmental Isotopic study of the groundwater can be carried out to determine the absolute age and history of the groundwater. The origin of the groundwater could be determined through studies of deuterium content of the shallow groundwater whereas the age and history of the groundwater could be confirmed through studies of tritium and radiocarbon (^{14}C) contents of the groundwater.
2. Trace element geochemistry of groundwater and the rock types of the study area can be carried out to assess the quality of the shallow groundwater.

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