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Physicochemical Characteristics of Groundwater Quality of Dumne Area NE Nigeria

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***Abstract*— *The aim of this study is to assess the shallow groundwater quality of Dumne Area of northeastern Nigeria for drinking and domestic purposes. The study area is underlain by the alluvium, basalt, gneisses and granitic rocks of northeastern Nigeria. Twenty water samples collected from hand-dug wells and boreholes tapping shallow aquifer were analyzed. Chemical analyses were performed in the laboratory employing standard methods viz Atomic Adsorption Spectrophotometer for cations and conventional titration for anions. In addition ions in milligram per litre were converted to milliequivalent per litre and anion balanced against cations as a control check of the reliability of the analyzed results. The analyzed chemical parameters was interpreted and the result revealed that all other parameters with the exception of pH, potassium, total hardness and zinc falls below the guidelines established by local and international standards. The Gibbs diagrams show that all the groundwater and surface water samples fall within the rock dominance portion indicating that the water quality is largely controlled by water-rock interactions. A plot of the Trilinear diagrams of the water samples indicate Na^++K^+ as the major cations and SO_4^{2-} as the major anions with Na^++K^+ facies as the hydrogeochemical facies. This suggests significant groundwater mixing, water-rock interaction and a common source for both surface water and groundwater samples. Finally it is suggested that all the water samples with high values of pH, Mn^{2+}, phosphate, Fe^{2+} potassium, total hardness and zinc that falls above the guidelines established by local and international standards for drinking and domestic purposes should be treated before use.*

***Keywords*— Groundwater quality, Gibbs diagram, Piper trilinear diagram, Dumne Area, Northeastern Nigeria.**

I. INTRODUCTION

Groundwater is a very important natural resource and plays a significant role in the economy of any country. It is globally important for human consumption irrigation and industrial purposes. It is also important for the support of habitat and for maintaining the quality of base flow to rivers. The chemical composition of groundwater is a measure of its suitability as a source of water for human consumption and for other purposes and also influences ecosystem, health and function (Appelo and Postma 1993). It is thus important to detect change and early warnings of change both in natural systems and resulting from pollution. The chemistry (quality) of groundwater reflects input from the atmosphere, soil and water-rock interactions as well as pollutant sources such as mining, land subsidence, agriculture and precipitation and domestic and industrial waters (Appelo and Postma 1993). Increased understanding of the chemical processes affecting groundwater chemistry of the study area will give an insight into the hydrogeology. Currently groundwater in the study area is intensively used for irrigation processes and other human activities such as industrial and domestic activities. Despite its importance little is known about the natural processes that govern the chemical composition of groundwater or the anthropogenic factors that presently affect them (Garcia et al 2001). This work therefore intends to assess the water quality of the study area.

II. STUDY AREA

The study area lies within longitude 12° 18' E and 12^0 30' E and latitude 09^0 44' N and 09^0 51' N and located in Song Local Government area of Adamawa State. It has an area extent of about 104 km^2. (Figure 1). It is bounded to the north by Gombi and Hong Local Government Areas, to the east by Maiha Local Government Area, to the south by Fufore and Girei Local Government and to the West by Shelleng and Demsa Local Government Area. It is located about 70 Km north of Yola the capital of Adamawa State. The area is accessible by Yola-Dumne- Song-Gombi highway as well as Dotubi-Dumne and Dumne-Humtoi minor roads. It is traversed by several footpaths and tracks that provide access to remote villages and mountains and drained by numerous rivers and streams that take their source from hills in the southwestern part and flows towards the low lands in the northeastern parts.

The study area is characterized by hilly topography with structural ridges and inselbergs surrounding the alluvial plains. The hills surrounding the study area include the Bongo three sisters' rocks, Mujaran, Sawim, Murkumchi, Mudungo, Mbal Yebbe and Kiccei-dada hills. The area is drained mainly by streams with Kuade stream as the major one. The streams take their source from the hilly northwestern and southwestern parts and drains through the plains of northeastern and southeastern parts. Denudational processes such as weathering and erosion affected the study area. Physical weathering due to temperature fluctuations lead to the exfoliation of the granitic rocks in parts of the study area. Plants growth also caused the mechanical disintegration of rocks throughout the study area. Chemical weathering resulting from acid rain affected the volcanic rocks of the basement rocks. Sheet and gully erosion are observable in parts of the study area which resulted from the fast flowing surface water runoffs from higher elevation to lower elevation.

The soil types in the study area are products of insitu weathering and erosion of the underlying basement complex rocks. The soil types consist of both lateriric and vegetative soils. They can be classified into Litho soils and Luvi soils (Ray, 1999). The litho soils are shallow soils of less than 10 cm deep and are found around hills, mountain ranges and rock terrains as well as rocky terrains in inselbergs and intervening plains and valleys. The organic content, exchangeable cation and base saturation levels are low to moderate and thus strongly acidic to neutral (Ray 1999). The soils are ferrugunized with high iron oxide concentration as well as lateritic and hydromorphic with colours ranging from red to deep brown at B-horizons level. The texture is gravely to loamy-sand surface horizons with relatively low pH (5.1 to 6.1) and moderate to high organic matter. The vegetation is intertropical northern guinea savannah which is characterized by savannah plants/trees such as Afzella Africana, Vitellia paradoxa, Terminalia coxiplora whereas grass species include peniselum, andropogan, bracharia, hyparrheria and aristida.

The climate of the study area is typically tropical which is variable and dominated by two main seasons the dry season and the rainy season. The rainy season runs between April and October whereas the dry season lasts from Novermber to March. These seasonal climatic conditions are influenced by the North-South fluctuation of the zone of discontinuity called the inter-tropical convergence zone (ITCZ) which lies between the dry continental Saharan air mass and the humid maritime Atlantic air mass. At the surface it forms a boundary called a surface of discontinuity. Thus during the dry season the surface of discontinuity lies further south showing a southwards movement of wind and pressure from high pressure zone of the Sahara whereas during the rainy season the surface of discontinuity moves up north. The dry continental Saharan air mass causes the dry season which is accompanied by low humidity and intense aridity that makes the atmosphere very dusty whereas the moisture laden humid Atlantic air mass bring about the rainy season. The climate of the study area is often described in terms of the mean values of meteorological variables such as rainfall, temperature, wind, humidity and cloud cover (Hartmann, 1997). Rainfall is the most variable element of the tropical climate. All its characteristics such as amount, intensity and frequency vary with space and time and the variation has influence on the water resources (Adebayo 1999). In the study area, the rainy season begins in April and ends in October. The heaviest rains and the highest number of rainy days were recorded in the months of August and September whereas in some cases rainy season may extend up to the first week of November. The mean monthly rainfall range from 1.40 mm in November to 208 mm in August and from the year 1990 to 2000 the mean annual rainfall was 846 mm (Adebayo 1999). Temperature in the study area is typically of the West African Savannah Climate and is relatively high throughout the year due to high radiation. Temperatures are relatively high in the months of March, April, May and June when the daily maximum temperature may reach 45^{o}C whereas it is low in the months of December and January with temperature value of 20^{o}C. The relative humidity varies seasonally with values of about 90 % during the rainy season (Months of August and September) with values of 45 % to 59 % during the dry season (Months of January to March). This is largely due to the influence of tropical maritime air mass which covers the area (Adebayo 1999). The relative humidity starts to decline as from October following the cessation of rains and becomes extremely low during the harmattan sub-season. Hence, the mean relative humidity ranges from 32 % in December to 77 % in August (Adebayo 1999). The study area is dominated by two trade winds such as the northeast and the southwest trade winds. The northeast trade winds originate from the Sahara desert and occurs from November to April and characterized by thick haze of diatomaceous dust which obscures sun rays and make visibility poor. The southwest trade winds originate from the Atlantic Ocean and occurs from May to September and characterized by high moisture content. The northeast trade winds are associated with the dry season whereas the southwest trade wind are associated with the rainy season.

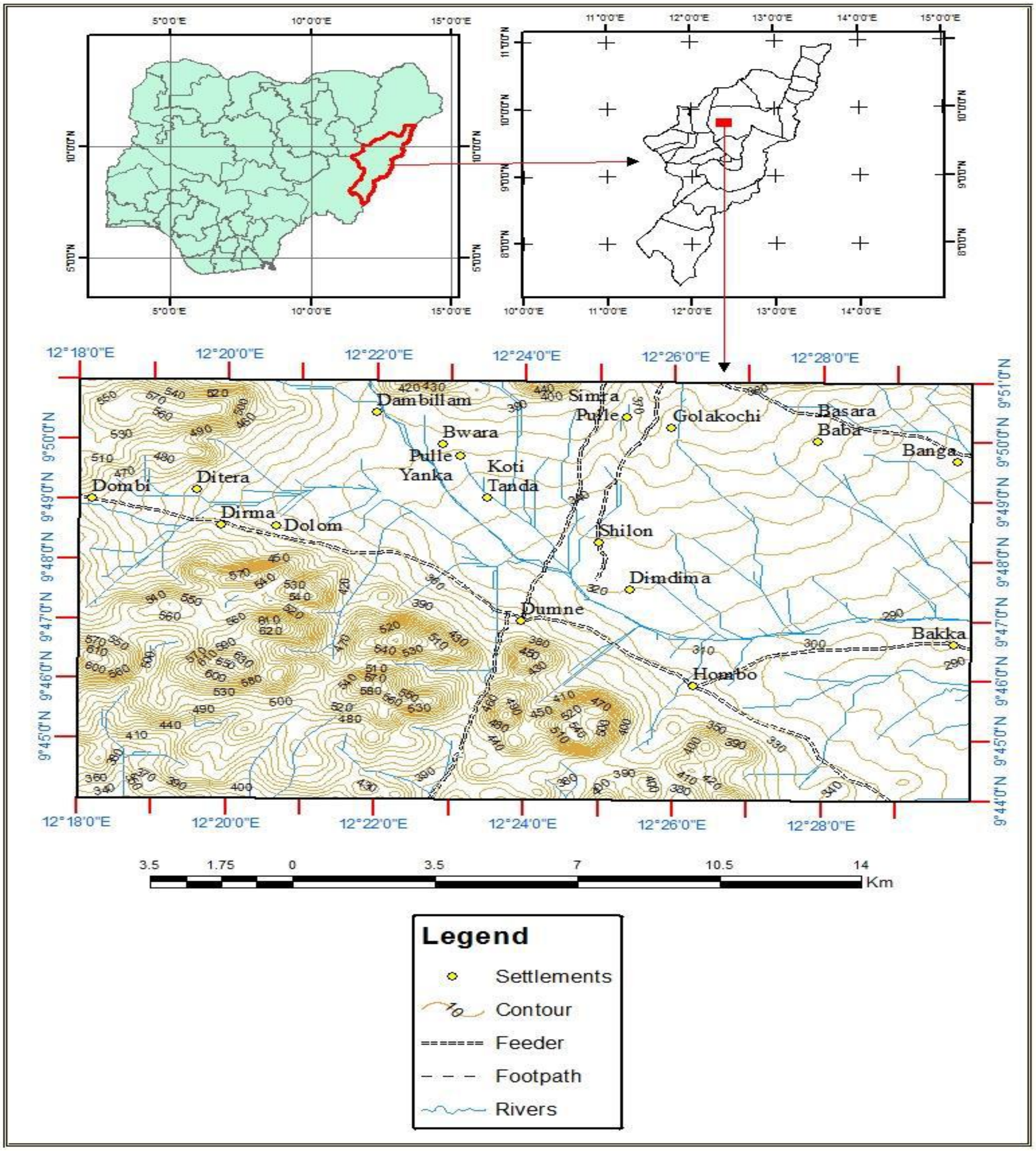

Fig.1: Topographic Map of the Study Area Showing Access Routes

III. LITERATURE REVIEW

Most of the previous works in the study area are mainly regional studies (Falconer, 1911; Dupreeze and Barber, 1965; Kiser, 1968) and discussed the geology and ground water Chemistry of the old northeastern Nigeria. These studies which were more or less outside the study area was

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only speculative of groundwater conditions in the study. Subsequently, Carter et al (1963) and Reyment (1965) published some details about the geology, stratigraphy, hydrology and water quality of most parts of the northern Nigeria and classified the water of northeastern Nigeria into Calcium and Sodium Bicarbonate types. Ekwueme (1993) gave details of the basement rocks of northeastern Nigeria in which he classified the rocks as consisting of migmatites, gneisses, diorites, porphyritic granites, volcanic rocks and young alluvial deposites. Ntekim (2001) in his work on groundwater characterization in Adamawa State classified groundwater into Ca-Mg-HCO_3 facies in the sedimentary areas and Ca-Mg-Na-Cl-SO_4 in the basement areas.

Recent works elsewhere (Nwaichi and James 2012, Hadian et al 2015, Khan and Jhariya 2017, Hazi et al 2018) gave a detailed account of the assessment of groundwater quality of parts Niger Delta Nigeria, jJava Indonesia and Yazd Iran.

Geology of the Study Area

The study area consist essentially of alluvium, basalt, porphyritic granite and coarse grained granite and gneisses and (Figure 2).

Alluvium

The alluvial deposits are mechanically weathered materials derived from bedrocks and surrounding hills which are found along stream and river channels. They consist essentially of sands, gravels, pebbles and cobbles and are exposed on the plains of the northeastern parts of the study area where intense farming activities takes place.

Basalts

Two types of basalts were encountered in the study area and consist essentially of the vesicular and non-vesicular basalts. They are fine grained with grain sizes ranging from 4 cm to about 8 cm and occur as boulders of different sizes. They are dark coloured and porphyritic with phenocrysts of olivine in a groundmass of calcic plagioclase feldspar and pyroxene with accessory minerals such as iron oxides, magnetite and ilmenite. The vesicular basalt occurs at the base of gneisses south of Dumne and ranges in size from 30 cm to about 60 cm. The vesicle ranges in size between 2 mm to 4 mm in diameter and are randomly distributed within the rock.

The non-vesicular basalts occur as ridges south of Dumne and Gban whereas relics of basaltic flows, represented by boulders and black soils are found in almost all the drainage channels and low-lying plains (Plates 1 and 2).

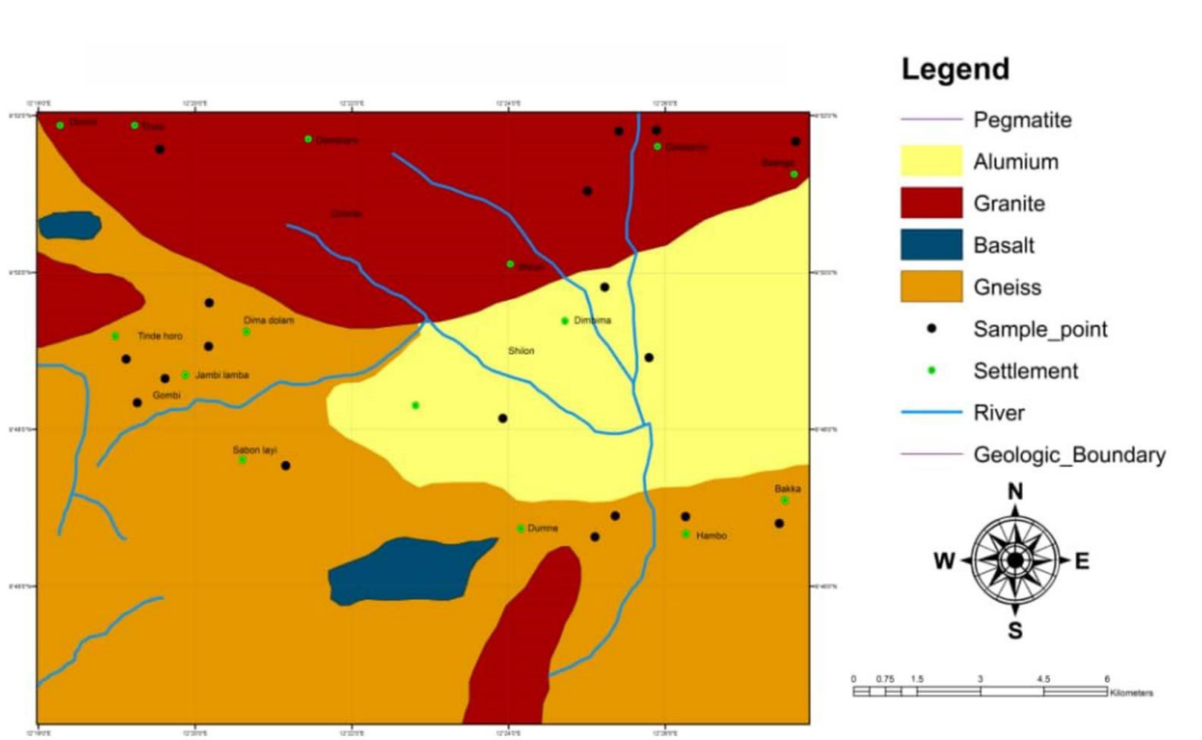

Figure 2: Geological Map of the Study Area

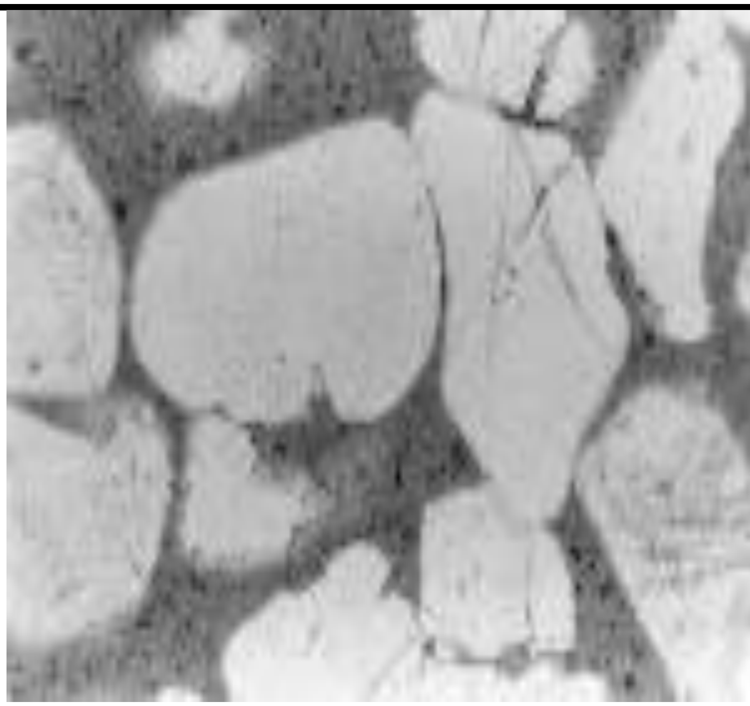

Plate 1 Photomicrograph showing Basalt under plain polarized light

(Magnification x 100)

Plate 2 Photomicrograph showing Basalt under cross polarized light (Magnification x 100)

Granites

Two types of granites namely porphyritic granites and the coarse grained granites occur in the study area. The porphyritic granites outcrop conspicuously at the base of slopes of small isolated hills of Laro, Biri Pintara, Old Prambe, Zamba, Dirma and east of Waltandi. Most of them occur as in-situ boulders of different sizes ranging from 50 cm to 20 m with gradational to sharp contact with the gneisses. The porphyritic granites are sometimes medium to coarse grained and are affected by extensive spheroidal weathered as seen at Dumne, Koti, Biri and Gbengere hills and occur as high reliefs in Gban areas (Plates 3 and 4). They consist of phenocrysts of biotite and hornblende set in a groundmass of of quartz and plagioclase.

The coarse grained granites occur in various locations closely associated with the migmatites and gneisses in low reliefs. They occur as plutons and show lithological variations with aplites with exposures of both types distinctly observed at Shure, Poma, Kubta, Bwara and north of Mopa areas. The rock is crystalline, coarse grained and compact with few distinct fractures of aplitic and pegmatitic composition crisscrossing the rock surface (Plates 5 and 6).

Plate 3 Photomicrograph showing porphyritic granite under cross polarized light (Magnification x 100)

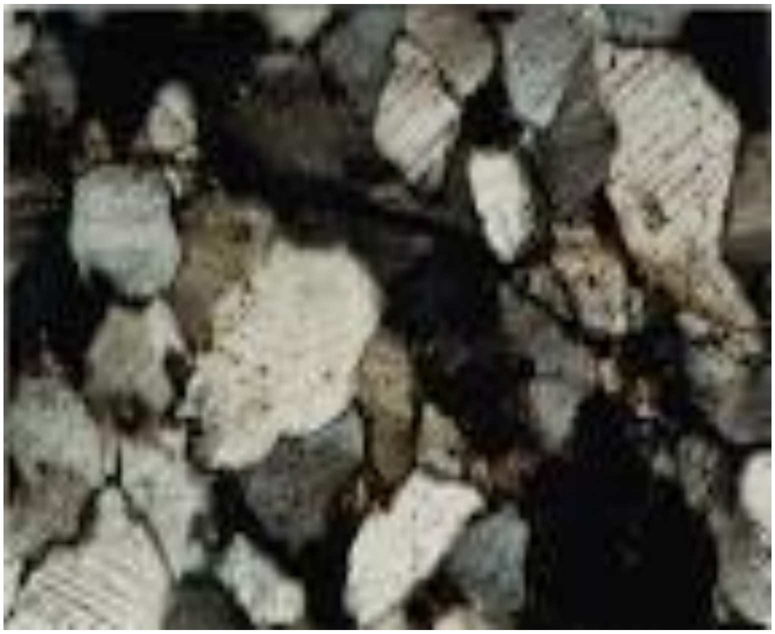

Plate 4 Photomicrograph showing porphyritic granite under cross polarized light (Magnification x 100)

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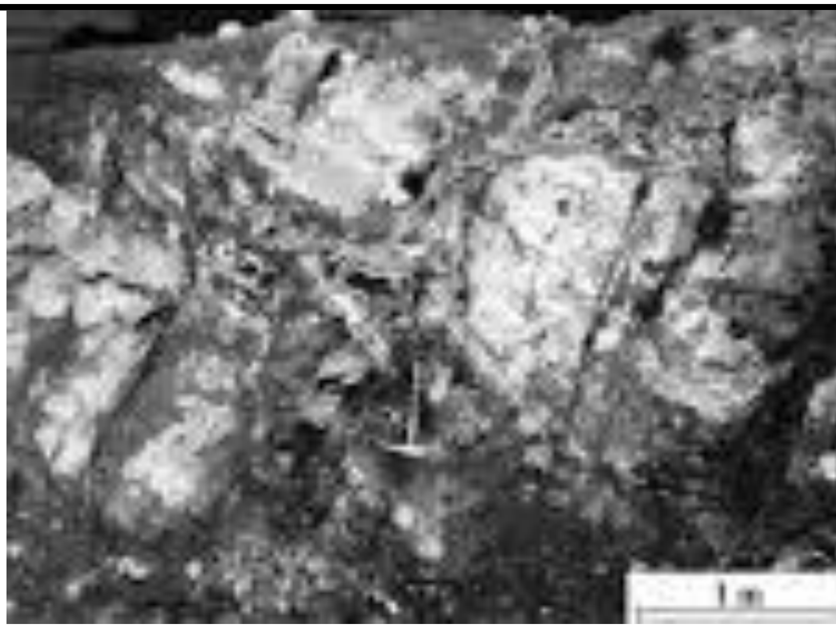

Plate 5 Photomicrograph showing coarse grained granite under cross polarized light (Magnification x 100)

Plate 6 Photomicrograph showing coarse grained granite under cross polarized light (Magnification x 100)

Gneisses

The rocks generally the most dominant gneissic rocks and outcrop sand witched between migmatites and granites in Dumne, Koti, Waltandi, Biri, Wuro Kitaku, Dombi and Dirma areas. Granite gneisses are the dominant gneissic rocks and were observed. They are granitic in nature which sometimes grade into dioritic composition with increasing mafic minerals especially biotite and hornblende as seen west and south of Dirma and Dombi-Simba and are called biotite-hornblende gneisses. They grade into migmatitic gneisses in some places especially towards the base of the hills. They also exhibit weak foliations marked by varied sizes, amounts and orientation of feldspar porphyroblasts. The porphyroblasts are sometimes numerous and moderately large (between 4 mm and 1 cm in width and 1 to 1.5 cm long), lineated, augen-shaped or may show small equidimentional rhombic grains with less pronounced lineation as observed in Dirma, Laro and Old Prambe. In some areas (Koti, Dirma and Waltandi), the rocks are banded and in others especially those with increased biotite

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content no distinctive banding is observed. They exhibit variable colours due largely to the nature and proportion of the feldspar and mafic minerals such as biotite and hornblende. They are coarse grained and consist of alternating bands of mafic and felsic minerals with abundant quartz and orthoclase feldspars. They are fractured and intruded by pegmatite dykes which are evidence of recrystallization especially around Gban areas. They are characterized by spheroidal weathering as observed south of Dumne, Zamba, Laro and Woro.

Geological Structure

Joints and Faults

The joints of the study are found in all the rock units with most of them trending WNW-ESE and ENE-WSW and are largely initiated by tectonic activities. This is consistent with the general trend of the Nigerian Basement Complex (Figures 3 and 4).

Faults are cracks in rocks caused by forces that compress or stretch a section of earth's crust. The earth's crust is divided up into several tectonic plates that essentially float on a mantle of plastic, partially mantled rocks. These plates slide under or slide past one another, stressing the rock along the edges of each plate. A new fault forms when the stress on the rock is great enough to cause a fracture, and one wall in the fracture moves relative to the other. Faults can also appear far from the boundaries between tectonic plates when stress caused by rising magma from the mantle overcomes the strength of rocks in the overlying crusts.

Faults in the study area are recognized based on the occurrence of mylonitess, slickensides, shear zones and rock breccia and occur mainly in Tinde, Dumne and Gwaraguda

Quartz Veins

The quartz veins and lenses occur by crisscrosses the granitic basement rocks of the study area. They vary from 10 cm to 40 cm in width and more than 100 m in length and are irregular in shape. They are found in Dumne, Mopa, Shure, Zamba and Dirma.

Pegmatite Veins

Pegmatite veins composed of microcline and quartz minerals were observed in all the rock units. They vary in size from lenses and vein lets of 20 cm to bodies up to 2 m wide and over 100 m long. They are widespread in the western part of the study area around Waltandi, southeast of Gban and Dombi.

Dolerite Dykes

They are the youngest member of the basement complex and occur as tabular and jointed unmetamorphosed bodies crosscutting the Gneisses and Older Granites in Waltandi, Gban, Shure and Dumne.They are generally dark in colour with some pale green spots of olivine when observed in hand specimen.. They range from 6 cm to 1.5 m wide and over 50 m long.

Mylonite

The mylonites are found in Gban and Dumne within the Gneisses and Older Granites. They are brecciated and sheared containing angular fragments produced by the fracturing, crushing and differential movement of the component grains of pre-existing rocks. They are fine to medium grained, creamy white in colour and trends ENE-WSW coinciding with the trend of the Benue Trough as found in Gban area. They exhibit some sreaky or banded structure which have been pulverized indicating faulting and accordingly large mylonitic zones or shear belts as observed in the study area are usually associated with faulting and fault zones.

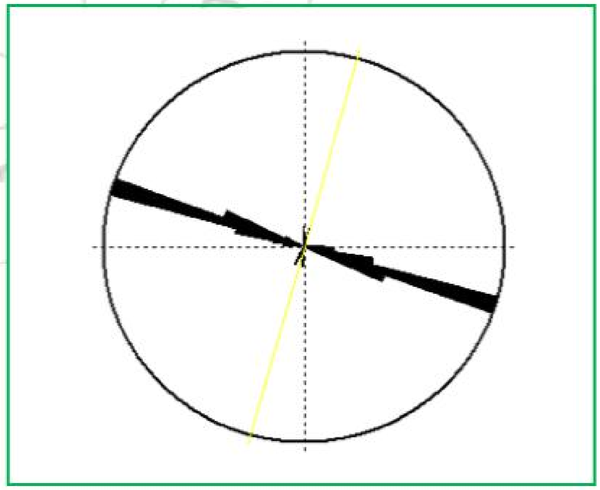

Fig.3: Rose Diagram of Lineaments in Granitic Rocks in Dumne Area (Total number of points = 25)

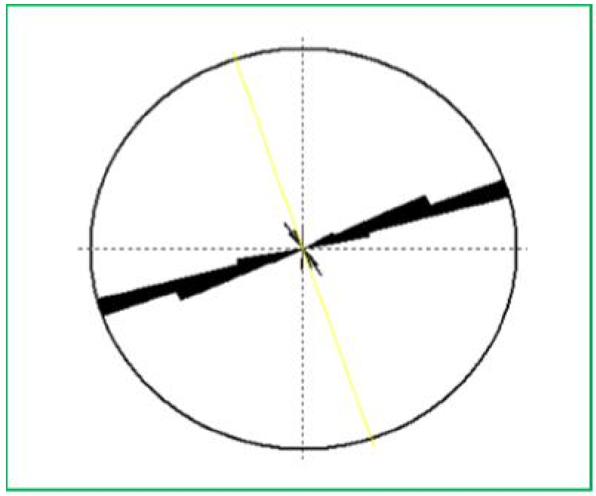

Fig.4: Rose Diagram of Lineaments in Granitic Rocks in Tinde Area (Total number of points = 20)

Hydrogeology of the Study Area

The study area is underlain by the Precambrain Basement rocks consisting essentially of alluvial deposites, basalt, porphyritic granites, coarse grained granites, gneisses and migmatites. These rocks has been subjected to tectonism leading to fracturing and as a result the occurrence of joints, faults, dykes and veins as well as intrusion of basaltic rocks. Furthermore these rocks have subsequently undergone complete weathering and lateritization resulting in the occurrence of unconsolidated weathered overburden materials such as gravels, clays, laterites and sands. Subsequently, two aquifer units have been identified in the study area based on geological reconnaissance namely; the unconsolidated weathered overburden and the fractured basement aquifer units (Obiefuna et al 1997).

This study is confined to shallow groundwater hosted within the unconsolidated weathered overburden aquifer unit that are tapped mainly by hand-dug wells and shallow boreholes. These wells are considered to be vulnerable to pollution by largely anthropogenic activities that is tapping place regularly in the study area.

IV. MATERIALS AND METHODS

The first step involve the use of topographic map of the study area in the identification of the rock formations as well as their structural and stratigraphic 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 dykes were also recorded, Sources and causes of groundwater pollution were located and plotted on a map. This was followed by detailed surface and subsurface geologic and hydrogeological studies during which geological boundaries were demarcated and hydraulic parameters measured. An inventory of wells in the area were performed which included location with Global Positioning System (GPS) and documentation of each well site, including land-use, soil type, geology,

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. The site of sampling was selected randomly taking cognizance of the geology and soil characteristics, geographical distribution of wells as well as density, method and place of storage of samples prior to analyses, effects of human activities and environmental constituents such as surface scums and leachate contaminations.

A total of twenty shallow ground water samples consisting of hand-dug wells and shallow boreholes were collected from different locations between the months of August and September 2017.

The samples were filtered through a thin polycarbonate membrane with 0.45µm pore size and collected in polyethylene bottles of four litre capacity with stopper. Each bottle was washed with 2% Nitric acid and then rinsed several times with distilled water and preserved in a cool, clean place prior to analysis.

The water samples were analyzed for various parameters in the 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 have been measured.

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;

Physicochemical parameters such as Temperature, pH, Turbidity, Dissolved Oxygen (DO), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were measured using water analysis kit model (Merk, DR Spectrophotometer 2400). All multi-probes of the kit were calibrated together using the same standards and procedures.

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 was calibrated with standard solution of 400 NTU using Hydrazine Sulphate and Hexamethylenetetramine. Dissolved Oxygen was also measured by modified Winkler's method at the site.

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

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determined by calculation method using the formular (APHA, AWWA, WPCF 1998).

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

The Total Alkalinity was measured by titrating the sample against N/50 solution of sulphuric acid using methyl orange and phenalthalein 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 fall within the acceptable range of ±5.

V. RESULTS AND DISCUSSION

Assessment of physicochemical qualities of groundwater

The summary of the groundwater parameters and composition with the World Health Organization standards (WHO 2013) and Nigerian Standard for Drinking Water Quality (NSDWQ 2007) for drinking suitability is indicated in Tables 1. The table revealed that all other parameters with the exception of pH, Mn^{2+} phosphate, Fe^{2+}, potassium, total hardness and Zinc falls below the guidelines established by the world Health Organization (WHO 2013) and (NSDWQ 2007) for potable water.

The pH values in more than 78% of the groundwater samples fall above the (WHO 2013) and (NSDWQ 2007) recommended limit of 6.5 to 8.5 whereas that of surface water samples falls within the recommended limit with a value of 7.11. This indicate largely alkaline groundwater but nearly neutral surface water which could be attributed to the precipitation and dissolution of carbonate or calcite minerals within the underlying basaltic rocks. The generally high alkaline groundwater however does not impact human health but can alter and affect the taste of the groundwater.

The groundwater samples of the study area revealed elevated Mn^{2+} values ranging from 5.00 mg/l to 7.10 mg/l with a mean value of 6.00 mg/l whereas those of Fe^{2+} values varies from 0.17 mg/l to 8.57 mg/l with a mean value of 0.85 mg/l. These values are largely above the WHO (2013) and NSDWQ (2007) limits of 0.50 mg/l for Mn^{2+} and 0.30 mg/l for Fe^{2+}. The elevated values of manganese and iron in groundwater samples could be attributed to the weathering of manganese and iron bearing minerals that make up the underlying igneous rocks in the study area. Other possible sources include leakages from poorly constructed sewage facilities and/or organic rich soil materials.

The values of phosphate ranges from 0.10 mg/l 0.92 mg/l with a mean value of 0.69 mg/l whereas those of potassium varies from 458 mg/l to 522 mg/l with a mean value of 493.22 mg/l. These are largely above the WHO (2013) and (NSDWQ 2007) recommended limit of 0.30 mg/l for phosphate and 50 mg/l for potassium respectively. The relatively high values could be attributed to anthropogenic activities such as application of fertilizer and animal wastes in farming as well as leaching and dissolution of phosphate and potassium from minerals that make up the underlying igneous rocks in the study area. Phosphates and potassium as important fertilizers are strongly held by clay particles in soils and is also soluble in water and increases in concentration with time. Therefore leaching of phosphate and potassium through the soil profile and into groundwater is important particularly in coarse-textured soils (Groundwater Monitoring and Assessment Programme (1999).

The zinc concentration in the sampled water varies from 33.44 mg/l to 41 mg/l with a mean value of 38.17 mg/l is by far above the WHO (2013) and (NSDWQ 2007) recommended limit of 3 mg/l. The primary source of zinc are the underlying igneous rocks where they can occur in significant quantities whereas the anthropogenic sources include industrial wastes and sewage sludges. They however do not represent drinking water concerns in ambient groundwater but proper disposal of industrial wastes remains the best management strategy for reducing the potential impacts of this metal on groundwater quality.

The dataset of groundwater samples in the study area revealed total hardness values ranging from 85 mg/l to 93.42 mg/l with a mean value of 88.16 mg/l whereas surface water displayed a value of 63.98 mg/l. Thus while the total hardness values of both groundwater and surface water samples fall below the WHO (2013) and (NSDWQ 2007) permissible limit of 500 mg/l the Sawyer and McCarty (1967) classification indicate that they are largely moderately hard water. Water hardness in most groundwater naturally occur from weathering of limestone, as well as from calcium bearing minerals in the underlying rocks. They can also occur locally in groundwater from chemical and mining industrial effluent or from excessive application of lime to the soils in agricultural areas. The relatively high hardness values recorded in the groundwater samples are largely due to anthropogenic activities such as the excessive application of lime to the soils in farming activities in the study area.

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Table 1 Summary of Physicochemical parameters of the shallow groundwater in the Study Area.

PARAMETER	RANGE	MEAN	WHO (2013)	NSDWQ (2007)
pH (unit)	8.10-9.00	8.66	6-5 – 8.5	6.5-8.5
Temperature (ºC)	27-29	27.98	-	
EC (µS/cm)	400-473	445.11	1400	1400
TDS (mg/l)	278.10-346	304.43	500	500
Turbidity (NTU)	0.002-1.101	0.301	5	5
Calcium (mg/l)	41.66-57.12	48.53	75	75
Magnesium (mg/l)	7.00-9.10	7.97	50	50
Sodium (mg/l)	0-1.20	0.23	200	200
Potassium (mg/l)	458-522	493.22	50	50
Zinc (mg/l)	33.44-41.00	38.17	3.0	3.0
Manganese (mg/l)	5.00-7.10	6.00	0.50	0.50
Total Hardness (mg/l)	84.99-93.42	88.16	500	500
Bicarbonate (mg/l)	35.92-47.81	39.91	1000	1000
Carbonate (mg/l)	0.001-0.550	0.38	500	500
Sulphate (mg/l)	39.82-69.98	62.55	400	400
Chloride (mg/l)	0.001-0.004	0.002	250	250
Fluoride (mg/l)	0.001-0.012	0.008	1.50	1.50
Phosphate (mg/l)	0.100-0.918	0.69	0.30	0.30
Nitrate-N	0.937-2.100	1.24	10	10
Iron (mg/l)	**0.167-8.568**	**0.85**	**0.30**	**0.30**

Hydrogeochemical Facies

The Piper trilinear diagram is used to categorize the water facies on the basis of dominant ions (Piper 1944). In Piper diagram, major ions are plotted in two base triangles as major cations and major anions. It shows the relatively concentrations of the different ions from the individual samples based on average values for each location The Piper trilinear Diagrams are plotted to illustrate chemical differences between water samples collected from different boreholes and hand-dug wells (Figures 5 and 6).

The results revealed that both the hand-well and borehole samples indicate Na^{+}+ K^{+} as the major cations and SO_4^{2-} as the major anions with the Na^{+}+ K^{+} facies as the major hydrogeochemical facies. The similarity in major cation and major anion types as well as hydrogeochemical facies indicate significant groundwater mixing, water-rock interaction and a common source for both water sources. It further reveals relatively old groundwater samples and the preponderance of alkali metals (Na^{+}+ K^{+}) over the alkaline earth metals (Ca^{2+}+Mg^{2+}) as well as strong acids (SO_4^{2-}+Cl^{-}) over weak acids (CO_3^{2-}+HCO_3^{-}) in both hand-well and borehole samples in the study area.

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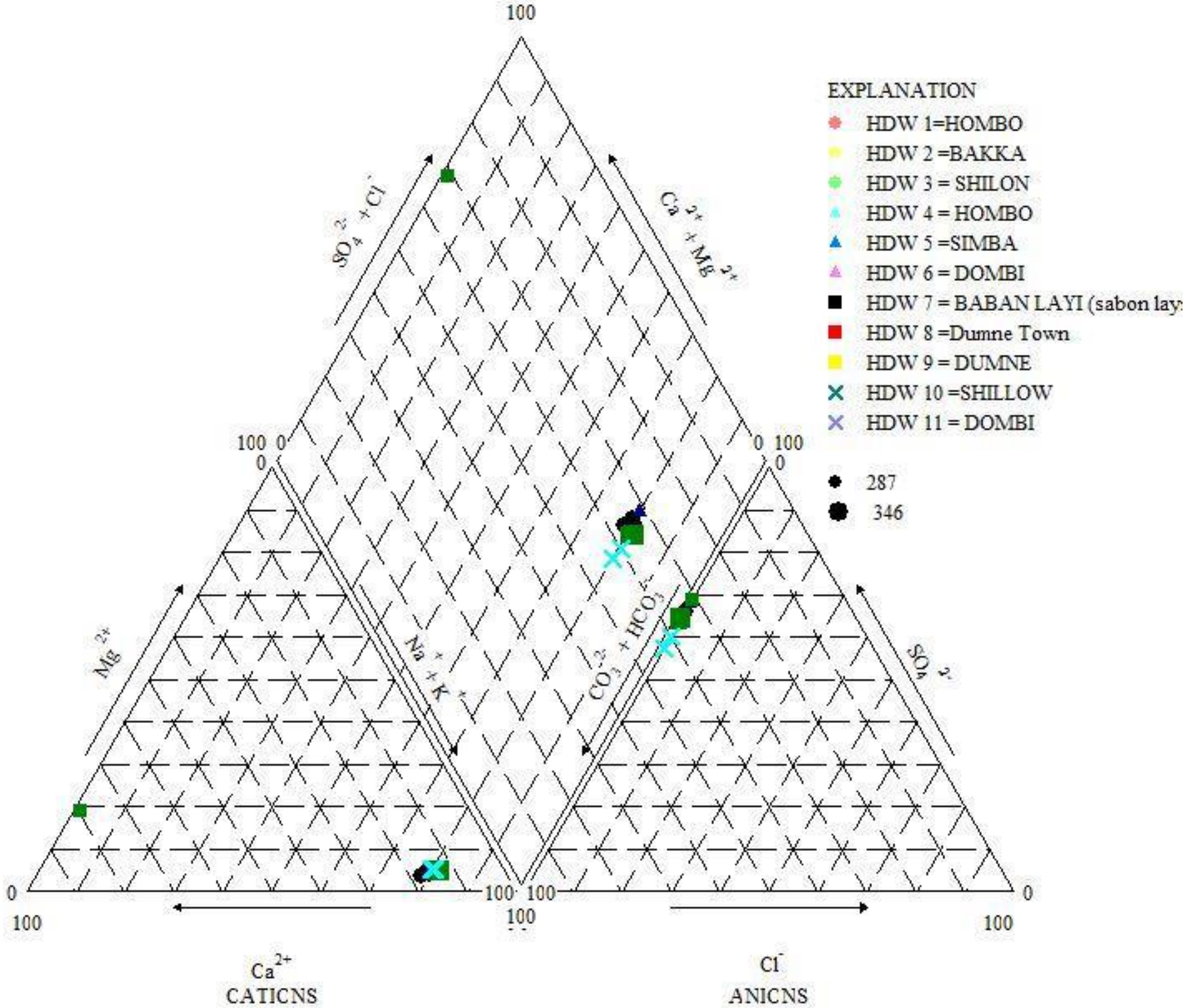

Fig.5: Piper Trilinear Diagrams for Hand-dug Wells in the Study Area

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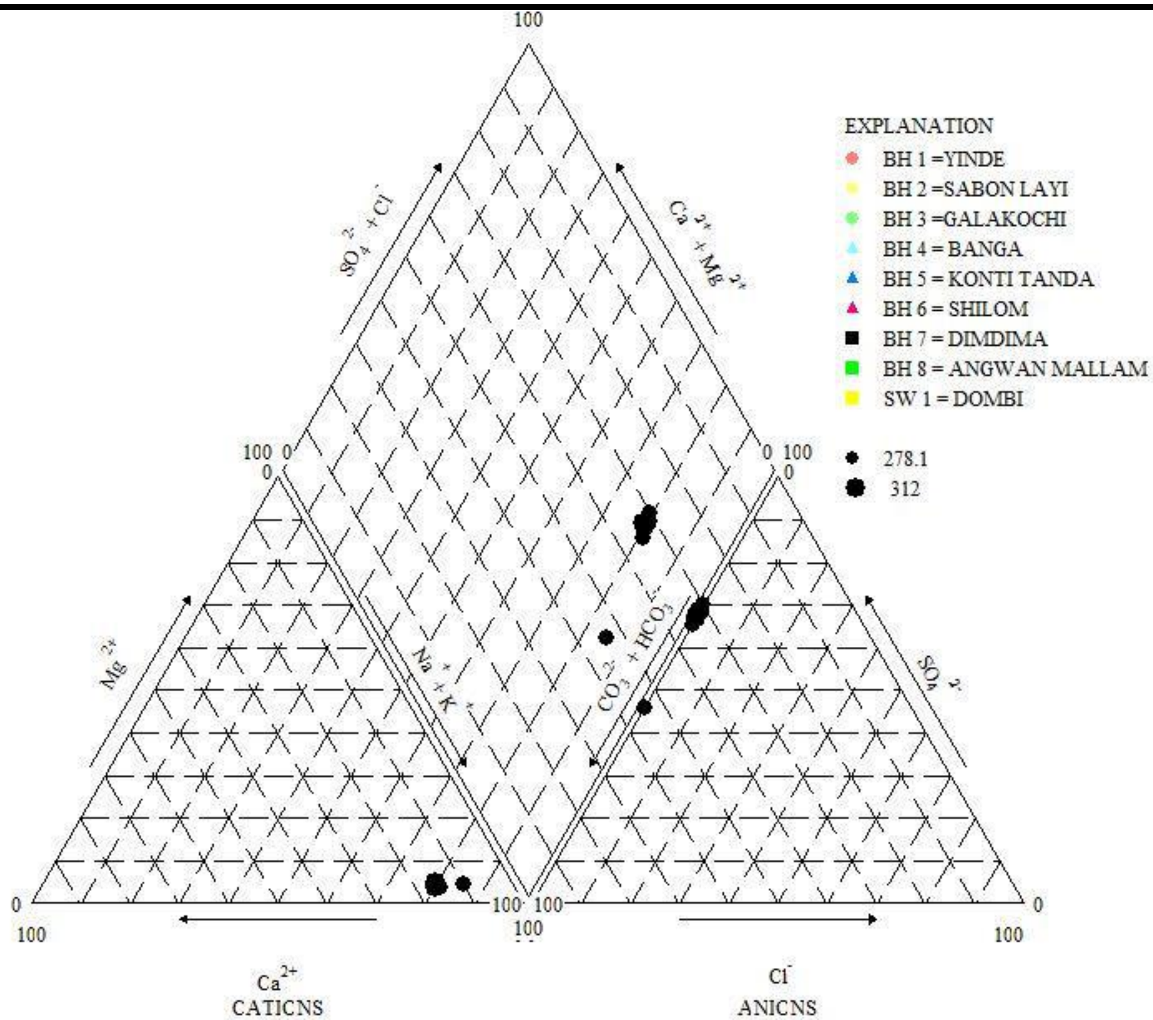

Fig.6: Piper Trilinear Diagrams for Boreholes and Surface Water in the Study Area

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/litre against TDS in mg/litre as well as the ratio of anions ($CI/CI+HCO_3$) in milliequivalent/litre against TDS in mg/litre. The Gibbs plot of both the groundwater and surface water samples revealed that the datasets plot within the rock dominance portion indicating that the groundwater and surface water chemistry are strongly controlled by the water-rock interactions (Figures 7 and 8). Thus rock-water interaction is the key factor that controls the chemistry of groundwater in the study area (Alam 2013; Raju et al 2011).

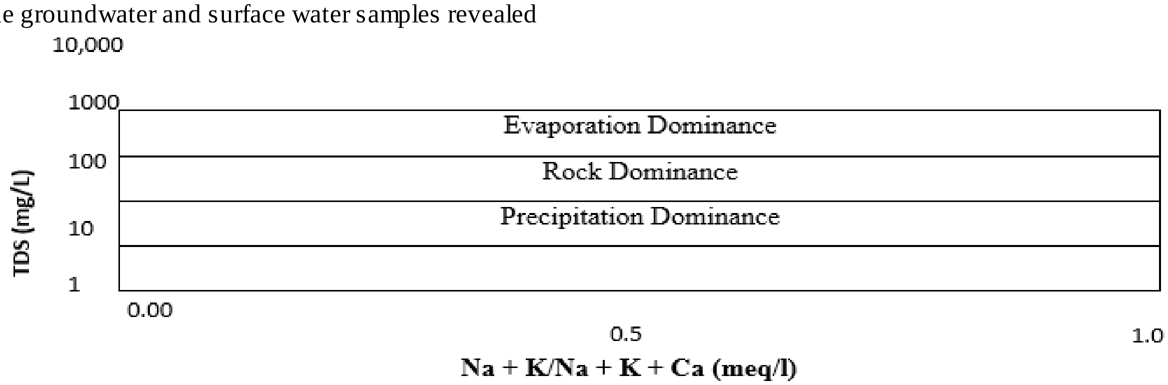

Fig.7: Mechanism controlling groundwater chemistry (Gibbs I).

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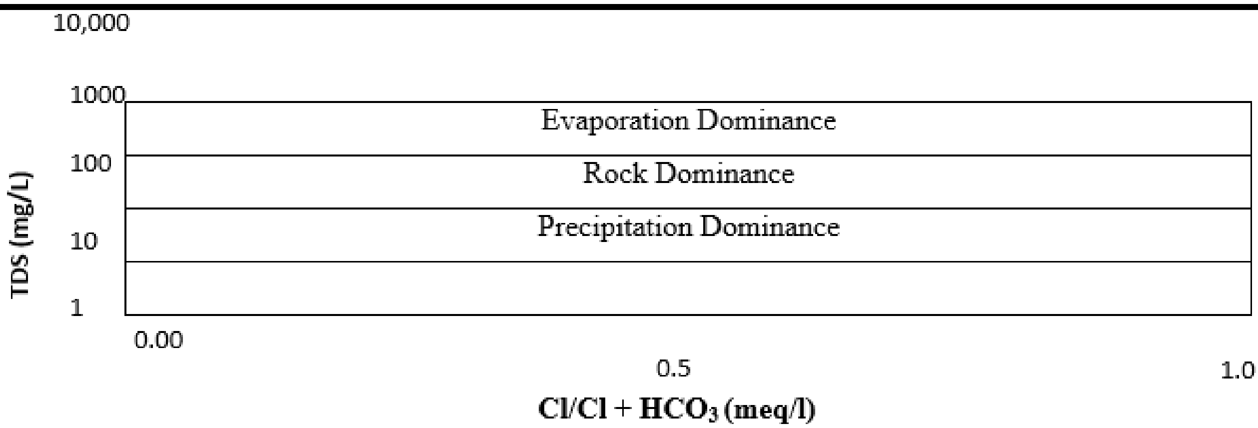

Fig.8: Mechanism controlling groundwater chemistry (Gibbs II).

VI. CONCLUSIONS

This study revealed that all other parameters with the exception of pH, potassium, total hardness and Zinc exceeded the guidelines established by the world Health Organization (WHO 2013) for potable water.

The pH values in more than 78% of the groundwater samples fall above the (WHO 2013) recommended limit of 6.5 to 8.5 whereas that of surface water samples falls within the recommended limit with a value of 7.11. This indicate largely alkaline groundwater but nearly neutral surface water which could be attributed to the precipitation and dissolution of carbonate or calcite minerals within the underlying basaltic rocks. The generally high alkaline groundwater however does not impact human health but can alter and affect the taste of the groundwater.

All the groundwater and surface water samples in the study area display potassium values above the WHO (2013) recommended limit of 250 mg/l with values ranging from 458 mg/l to 522 mg/l and a mean value of 4.87 mg/l. The relatively high values could be attributed to anthropogenic activities such as application of fertilizer and animal wastes in farming as well as leaching and dissolution of potassium from minerals that make up the underlying igneous rocks in the study area. Potassium as an important fertilizer is strongly held by clay particles in soils and is also soluble in water and increases in concentration with time. Therefore leaching of potassium through the soil profile and into groundwater is important particularly in coarse-textured soils (Groundwater Monitoring and Assessment Programme 1999).

The zinc concentration in the sampled water varies from 33.44 mg/l to 41 mg/l with a mean value of 38.17 mg/l is by far above the WHO (2013) recommended limit of 3 mg/l. The primary source of zinc are the underlying igneous rocks where they can occur in significant quantities whereas the anthropogenic sources include industrial wastes and sewage sludges. They however do not represent drinking water concerns in ambient groundwater but proper disposal of industrial wastes remains the best management strategy for reducing the potential impacts of this metal on groundwater quality.

The dataset of groundwater samples in the study area revealed total hardness values ranging from 85 mg/l to 93.42 mg/l with a mean value of 88.16 mg/l whereas surface water displayed a value of 63.98 mg/l. Thus while the total hardness values of both groundwater and surface water samples fall below the WHO (2013) permissible limit of 500 mg/l the Sawyer and McCarty (1967) classification indicate that they are largely moderately hard water. Water hardness in most groundwater naturally occur from weathering of limestone, as well as from calcium bearing minerals in the underlying rocks. They can also occur locally in groundwater from chemical and mining industrial effluent or from excessive application of lime to the soils in agricultural areas. The relatively high hardness values recorded in the groundwater samples are largely due to anthropogenic activities such as the excessive application of lime to the soils in farming activities in the study area.

The Piper trilinear diagram is used to categorize the water facies on the basis of dominant ions (Piper 1944). In Piper diagram, major ions are plotted in two base triangles as major cations and major anions. It shows the relatively concentrations of the different ions from the individual samples based on average values for each location The Piper trilinear Diagrams are plotted to illustrate chemical differences between water samples collected from different boreholes and hand-dug wells.

The results revealed that both the hand-well and borehole samples indicate $Na^{+}+ K^{+}$ as the major cations and SO_4^{2-} as the major anions with the $Na^{+}+ K^{+}$ facies as the major hydrogeochemical facies. The similarity in major cation and major anion types as well as hydrogeochemical facies indicate significant groundwater mixing, water-rock interaction and a common source for both water sources. It further reveals relatively old groundwater samples and the preponderance of alkali metals (Na^{+}+ K^{+}) over the alkaline earth metals (Ca^{2+}+Mg^{2+}) as well as strong acids (SO_4^{2-}+Cl^{-}) over weak acids (CO_3^{2-}+HCO_3^{-}) in both hand-well and borehole samples in the study area.

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