AQUIFER CHARACTERISTICS AND GROUNDWATER POTENTIALS OF CRYSTALLINE BASEMENT COMPLEX OF (PARTS OF SHEETS 57 BICHI SE, 58 KUNYA SW, 80 KABO NE, AND 81 WUDIL NW) KANO, NORTH WESTERN NIGERIA

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BY

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FEBRUARY, 2015

DECLARATION

I declare that this thesis entitled "**Aquifer Characteristics and Groundwater Potentials of Crystalline Basement Complex of (Parts of Sheets 57 Bichi SE, 58 Kunya SW, 80 Kabo NE, and 81 Wudil NW) Kano, North Western Nigeria**" has been carried out by me. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other Institution.

Tahir Abubakar Garba		25/02/2015
....	....	....
Name of Student	Signature	Date

CERTIFICATION

This thesis titled "**Aquifer Characteristics and Groundwater Potentials in Crystalline Basement Complex of Parts of (Sheets 57 Bichi SE, 58 Kunya SW, 80 Kabo NE, And 81 Wudil NW) Kano, North Western Nigeria**" meets the regulations governing the award of the degree of Masters of Geology of Ahmadu Bello University Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to my Father Mal. Tahir Maigyada, and my children Muhammad Abubakar and Abdulmalik Abubakar for their prayers and support.

ABSTRACT

The work was carried out on the basement complex of Kano metropolis to investigate into the aquifer characteristics and groundwater potentials of the area, in order to reveal the nature, quality and occurrence of groundwater. The geological mapping was carried out using topographical map on a scale of 1:50,000. A vertical electrical sounding (VES) was conducted using Ohmega resistivity meter with Schlumberger configuration. Pump test data of boreholes from the area were used for the determination of aquifer characteristics, which includes; transmissivity (T), hydraulic conductivity (k), and storage coefficient (S). Field study have shown that the area is underlain by schists, granites (porphyritic & biotite granites), and diorites. There are also minor intrusions of quartz veins, and aplite dykes. The trends of these structures show a predominating NW-SE direction. Vertical electrical soundings (VES) reveals that four (4) geoelecric layers, which include; topsoil/laterite/clay, weathered layer, fractured/fresh basement exists. The weathered layer serves as an aquiferous zone; where it is extensively thick. Bedrock could also serves as an aquifer where it is extensively fractured. Pumping test data obtained indicates that aquifer properties in the study area are of low potentials, which could be related to depth of the boreholes drilled and/or design. The analysis and interpretation of groundwater chemistry of the area suggest concentration of Pb and Cd above WHO's maximum permissible limits of 0.01mg/l and 0.03mg/l respectively, in about 93% of the samples analysed. That is a dangerous proportion, as they are known to be very dangerous to human health. Therefore Government should provide waste management disposal systems and proper monitoring of waste discharges by industries in the area.

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Boreholes pumping test data

ABBREVIATIONS

masl- meter above sea level

mabgl- meter above ground level

GW- Groundwater

BH-Borehole

S-Storage coefficient

s-Draw down

t- Time

k-Hydraulic conductivity

T-Transmissivity

WHO-World Health Organization

NIS-Nigerian Industrial Standards

SON-Standard Organization of Nigeria

TDS-Total Dissolved Solids

Temp.-Temperature

ppt-Part per thousand

EC – Electrical conductivity

VES-Vertical Electrical sounding

ID-Identity

m-Meter

km-Kilometer

CHAPTER ONE:

INTRODUCTION

1.1 BACK GROUND

Groundwater is a vital resource, with a large fraction of the world's population relying on the resource directly or indirectly for livelihoods (Sanjay, 2010). Much of the groundwater can be said to be meteoric in origin. Also, a small percentage is known to enter the hydrologic cycle from subterranean sources and is described as juvenile water. This water includes water of magmatic and volcanic sources, while connate water is entrapped between the interstices of sedimentary formations.

However, in order to tap this resource, a hydraulic structure called borehole is sunk into the ground, which when properly drilled, designed, and developed, will permit economic withdrawal of water from an aquifer. According to this research, shallow boreholes are those drilled to a depth of <60m, while deep boreholes are drilled to a depth of >70m, because many believed that fractures closes within 70m depth.

Many boreholes are drilled into the crystalline basement, with the intention of constructing wells for rural and community water supplies. Some existing shallow porous and regolith aquifers have low yield, because of this; boreholes are now sunk into the hard rock in order to tap groundwater in deep fractures of ≥200m. However, some boreholes are unsuccessful, the reason being that, most of these unsuccessful boreholes do not encounter water-bearing fractures, or some of the fractures are not hydraulically interconnected to provide sufficient water to the boreholes.

1.2 AIM OF THE STUDY

The aim of this study is to:-

Examine the sustainability issue of the deep boreholes and how groundwater occur at depth of >200m in those boreholes; also to investigate the general hydrogeology of Kano metropolis using shallow and deep boreholes**.**

1.3 OBJECTIVES

I. Geological mapping of the area, which include the study of the rock types, and depth of weathering.

II. Determination of potability of the water obtained from these boreholes as well as their conformity with the standard for various uses.

1.4 SIGNIFICANCE OF THE STUDY

- This research will be relevant to hydrogeologists and other water managers, as it will reveal the nature, occurrence and quality of groundwater in the study area at depth.
- It will also resolve the sustainability issue of the deep boreholes.
- The study will produce a lineament map of the study area from a remotely sensed data.
- It will also be a good reference material for further research in the future.

1.5 LOCATION AND ACCESSIBILITY OF THE STUDY AREA

The study area is located in the Kano Municipal; it is bounded by latitudes 11°51´ to 12°06´N and longitudes 8°23´ to 8°38´ E covering an area of about 770.063 Km^2. (Fig. 1) shows the location of the study area in Kano State.

Fig 1: Location Map of Kano State Showing the Study Area (Obtained from http://www. mapsofworld .com/Kano)

It is accessible through the Kano-Zaria, Kano-Maiduguri, Kano-Katsina, Kano-Hadejia highway roads and numerous intraState roads, as well as footpaths.

1.6 RELIEF AND DRAINAGE

The area of study lies on the average altitude of 478m, and is generally undulating lowland. The highest point is about 681m (above sea level) (Goron Dutse hill) and the lowest point is 431m (above sea level) (Babban layi, Unguwa uku). The relief is greatly influenced by the geology; characterized by small and low laying outcrops in the study area.

The study area is drained by the River Challawa which flows from the west to the eastern part of the study area and its numerous seasonal tributaries, also by River Watari, which together with River Challawa join River Hadejia and empties into the Lake Chad. While Rivers Gari and Jakara flows from the study area and disappear into the sands of Chad formation further east.

1.7 CLIMATE, VEGETATION AND LAND USE

1.7.1 Climate

The climate of the study area is that of tropical wet-and dry type. The mean annual rainfall in the area is 800mm (Olofin, 1987). It extends from early May to late September, while dry season last for about seven months, October to April. According to Olofin (1987) the mean annual temperature is about 26°C. The highest temperatures are recorded between March and April.

Table 1: Annual weather of the Study Area

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C (°F)	30.1 (86.2)	33.1 (91.6)	36.9 (98.4)	38.2 (100.8)	36.7 (98.1)	34.0 (93.2)	31.0 (87.8)	29.0 (84.2)	31.0 (87.8)	34.0 (93.2)	33.2 (91.8)	31.1 (88)	33.19 (91.76)
Average low °C (°F)	13.0 (55.4)	15.0 (59)	19.0 (66.2)	23.6 (74.5)	24.0 (75.2)	22.8 (73)	21.8 (71.2)	20.9 (69.6)	20.9 (69.6)	18.9 (66)	15.8 (60.4)	13.0 (55.4)	19.06 (66.29)
Rainfall mm (inches)	0.0 (0)	0.3 (0.012)	1.6 (0.063)	11.6 (0.457)	49.6 (1.953)	118.2 (4.654)	173.8 (6.843)	228.0 (8.976)	103.1 (4.059)	10.2 (0.402)	0.0 (0)	0.0 (0)	696.4 (27.419)
Avg. rainy days (≥ 1.0 mm)	0.0	0.1	0.1	0.9	3.9	8.0	13.0	14.0	8.3	1.2	0.0	0.0	49.5
Mean monthly sunshine hours	244.9	234.5	238.7	234.0	263.5	261.0	229.4	220.1	240.0	266.6	264.0	260.4	2,957.1

(Source: Hong Kong Observatory,2012)

1.7.2 Vegetation

Generally, the Sudan Savanna can be said to be the vegetation of Kano region, (Olofin, 1987). It composed of a variety of trees scattered over an expense of land. Trees are hardly taller than 20m. Neem tree is the most common specie in the area. Most of the trees species are adapted to drought condition through long tap roots and tiny leaves. Most of the trees shed their leaves during the dry season, grasses dry off, but during the rainy season their underground stem develop new shoots.

1.7.3 Human Geography

The people in the area are dominantly Hausas, Fulanis, Kanuris, and some few tribes including Yorubas and Igbos. The use of the land is for agricultural, industrial and urban purposes. The second and third points are the most significant in the area, being urban and shortages of land for other purposes.

1.8 Statement of the Problem

The increased demand for water in many parts of crystalline basement complex areas (including the study area), has stimulated development of groundwater, leading to the expansion of means of groundwater abstraction. That call for this work; which intends to update the hydrogeology of the area by looking at why groundwater occurs at a depth of $\geq$ 200m into the fresh basement rocks despite the general understanding that fractures closes with depth. It will also look at the aquifer characteristics in order to determine ground water potentials of the area.

CHAPTER TWO:

LITERATURE REVIEW

2.1 PREVIOUS WORK

Many published and unpublished studies have been carried out in the area. They are mainly geological, geophysical and hydrogeological investigations. They studied distribution of rock types and aquifer characteristics in the study area.

Earlier works include Isa (1984). He investigated the hydraulic properties of the basement complex and Chad formation aquifers of Kano State based on pumping testing of selected boreholes. He obtained the average value of transmissivity (T) in basement complex of the study area to be $0.51m^2$/hr ($12.32m^2$/day). Coefficient of permeability (hydraulic conductivity) (k) is 0.0138m/hr (0.33m/day). Specific capacity is $0.36m^3$/1m of drawdown.

MacDonald and partner's (1986) work highlighted some hydrogeological characteristics of the aquifers in the area using borehole logs of drilling programme for Kano State Agricultural and Rural Development Authority (KNARDA), supervised by Wardrop Eng. Inc. These characteristics could be viewed in terms of the rock types, the structural development, as well as depth of weathering and products.

Hazell et. al., (1992), demonstrated the dependence of regolith aquifer characteristics on geology and environment, with particular emphasis on lithology, weathering pattern and fracturing. Specific capacity is shown to be related to both lithology and weathering grade; dry season water levels and frequency of occurrence of successful holes are related to lithology in the area, and concluded that borehole performance is dependent on the aquifer and not on small variations in small diameter and depth.

Olorunfemi and Fasuyi (1993) delineated the aquifer types in the study area. These aquifer types include; weathered layer aquifer, weathered/ fractured or partly weathered aquifer, and fractured aquifer.

Magdi (1999) has tried and studied the general geology of area in relation to the lateritic profiles around Kano metropolis.

Bala (2001) investigated the usefulness of Landsat-5 Thematic Mapper I imageries in groundwater exploration in basement complex rocks of Kano, and Zaria-Kaduna areas. He demonstrated that areas having high fracture density are considered to be of high groundwater potential. In another recent study carried out by Bala *et a*l., (2011), the regolith aquifers derived from different bedrock types in the basement complex of Kano were examined, using information on depth of borehole, static water level, yield and drawdown of 259 boreholes covering different rock types. Their result shows that mean depth of borehole vary from about 37m to 48m in rocks of the younger granites and in the migmatites-gneiss complex and schists, respectively.

Danjuma (2005) carried out a hydrogeological study of Sheet 80 Kabo NE where he related the petrology and hydrogeology of the area. This relationship could be viewed in terms of the rock types, the structural development and the depth of weathering.

Mukhtar (2011) analysed water from Kano River to determine the concentration of some selected metals; Cu, Fe, and Mn before and after treatment at Tamburawa Water Treatment Plant. The study was conducted where Challawa merges with Kano River. All the observed concentration of metals for raw water were above WHO standard before treatment, while the treated water concentration for Fe was above the international standard, that of Mn and Cu were within WHO limits. The treatment plant reduces the metal concentrations; it is still below the WHO standard.

2.2 GEOLOGY AND HYDROGEOLOGY OF CRYSTALLINE BASEMENT COMPLEX ROCKS OF NIGERIA

2.2.1 Geology of Crystalline Basement Complex Rocks

The crystalline basement rocks are composed of hard, crystallized or re-crystallized rocks of igneous and metamorphic origin. They occur as granites, gneisses, migmatites, schists, phyllites, pegmatites or quartzites.

In Nigeria, the basement complex is one of the major litho-petrological components that make up the Geology of Nigeria. According to Obaje (2009), it is part of the Pan-African mobile belt and lies between the West African and Congo cratons, and South of Toureg shield. It is intruded by the Mesozoic calc-alkaline ring complexes (Younger granites) of the Jos-Plateau and is uncomformably overlain by Cretaceous and Younger sediments. It was affected by the Pan African Orogeny (600ma). Within the basement complex of Nigeria four (4) major lithological units are found namely:-

- The migmatites-gneisses complex
- The schist belt (metasediments and metavolcanics rocks)
- The Older Granites (Pan African granitoids)
- Undeformed Acid and Basic dykes

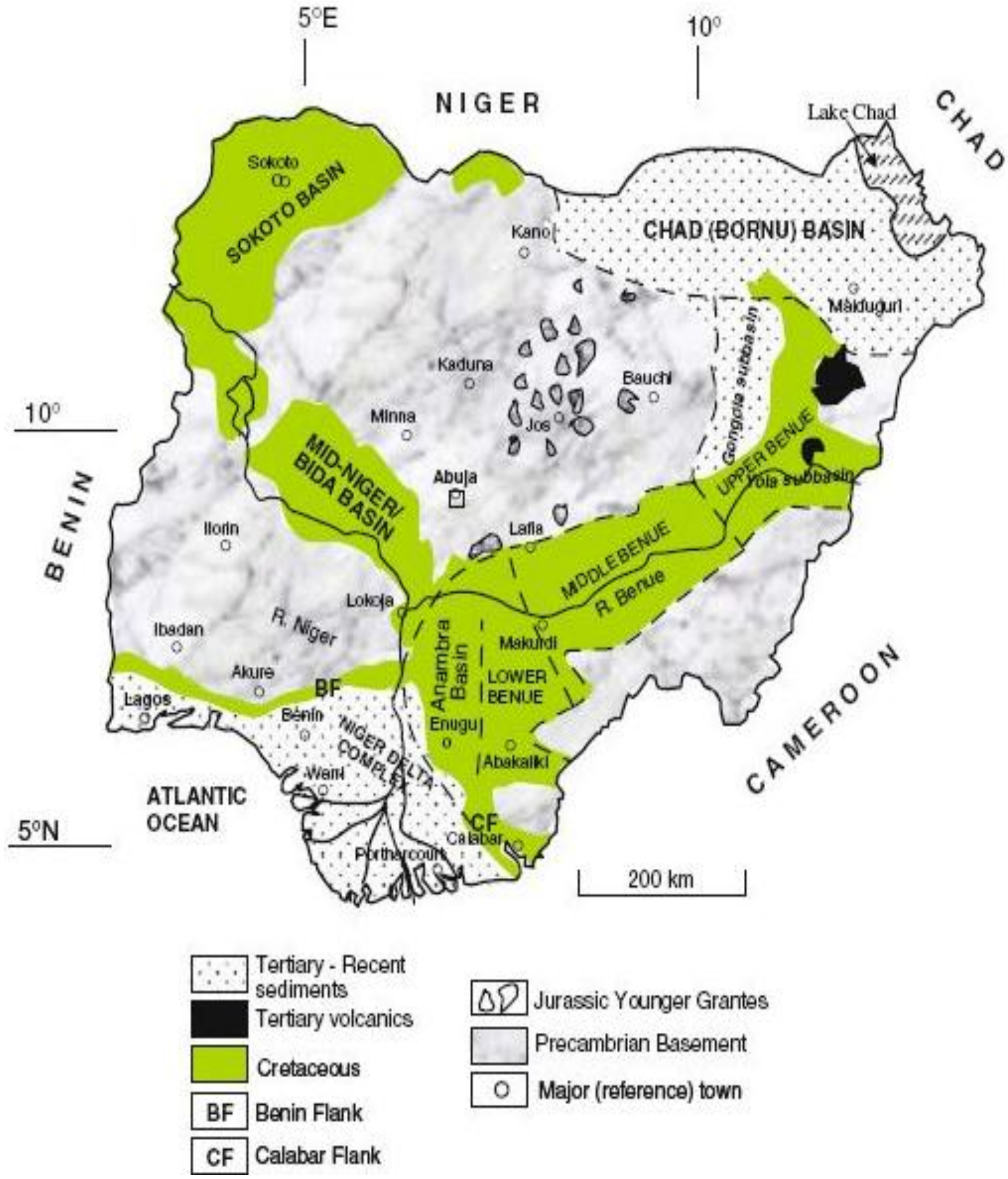

Figure 2: Geological map of Nigeria showing different rocks types (After Obaje, 2009)

2.2.2 Hydrogeology of Basement aquifers

Basement aquifers developed within the weathered overburden and fractured bedrock of crystalline rocks of intrusive and /or metamorphic origin that are mainly of Precambrian age (Wright and Burgess, 1992).

It is believed that, in weathered regolith groundwater is found in intergranular spaces between mineral grains, while in unweathered basement rocks it is stored in interconnected systems of fractures, joints and fissures that are associated with regional tectonism. However, poor connectivity of the bedrock fractures and low permeability, results in significant local variations in yield and this can cause local variation of the hydraulic conductivity within the same rock mass, over short distances.

The aquifer systems developed are:-

1) Alluvial aquifer; alluvial material overlies the weathered overburden and create a distinct intergranular aquifer type. These elongated aquifers follow rivers or drainage lines with limited width and depth, which vary according to the topography and the climate.
2) Composite aquifer; comprising of a variable thickness of regolith overlying bedrock.
3) Fractured aquifer; composed mainly of crystalline materials (i.e. igneous and metamorphic rocks) characterized by an intact and relatively unweathered matrix with a complex arrangement of interconnected fracture systems.

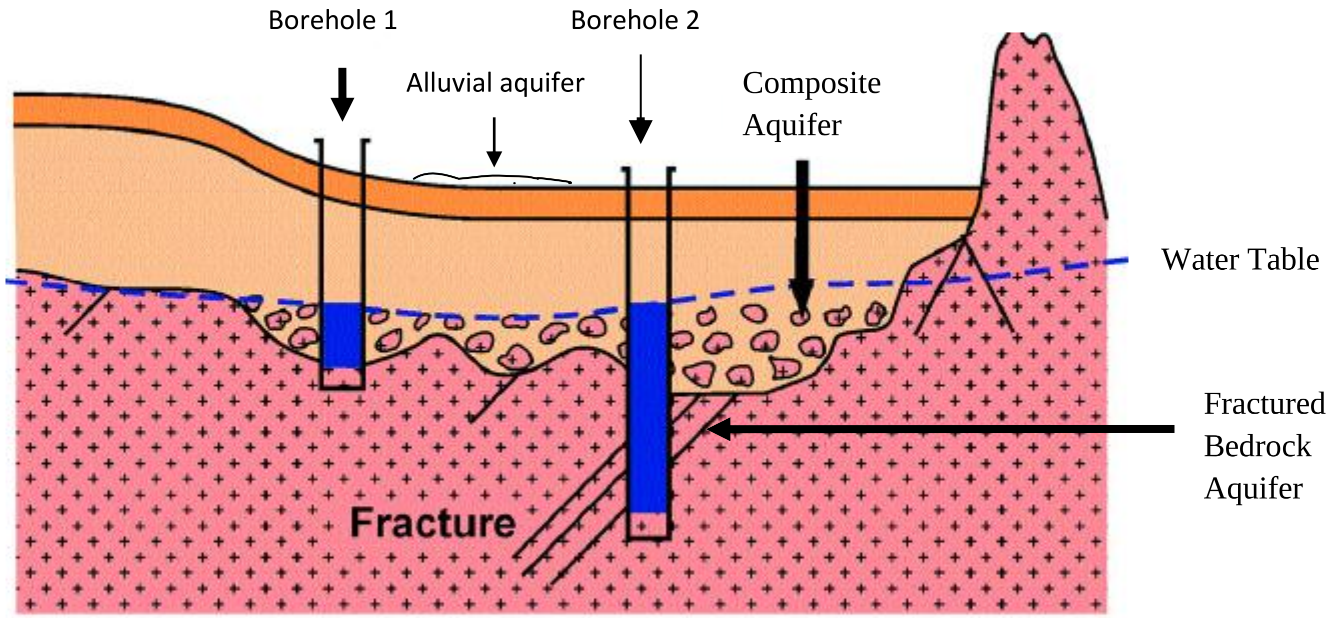

Fig. 3: Nature of Basement Aquifers (After Richard, 2004)

2.3 Development of Groundwater

Most studies on basement aquifers by different workers are on the development of groundwater resources in thick regolith (i.e. weathered overburden).They focuses mainly on establishing a relationship between the yield of a borehole and its depth, geology and weathering thickness. Using data from basement complex areas in some selected parts in Southwestern Nigeria and Abuja; Alao, (2000) put the average thickness of overburden from 6m to 15m, and average thickness of aquifers as 35m. In the study carried out by Bala *et a*l., (2011) in the basement complex of Kano, the regolith aquifers derived from different bedrock types were examined using information on depth of borehole, static water level, yield and drawdown of 259 boreholes covering different rock types. Their result shows that mean depth of borehole vary from about 37m to 48m in rocks of the younger granites and in the migmatites-gneiss complex and schists. Davis and Turk (1964) suggested the optimum depth of boreholes in crystalline rocks to range from 50m- 60m.

Permeability and porosity are some of the important properties that explain the characteristics of aquifers. According to MacDonald *et al*., (2008), these properties vary with depth. While permeability depends on the extent of fracturing and the clay content, porosity generally decreases with depth as shown in fig. 4 below:-

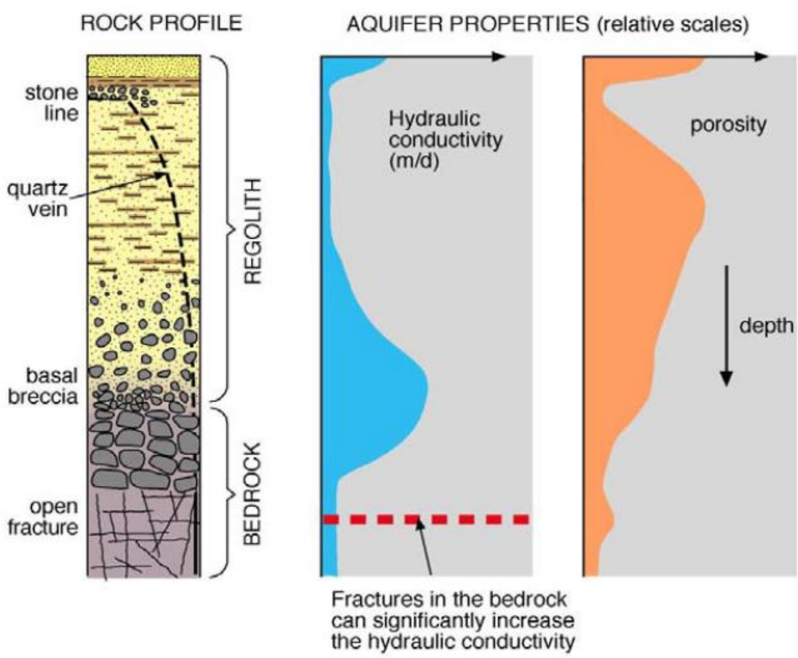

Fig. 4: Schematic diagram of the variation of permeability and porosity with depth in the crystalline basement (After Chilton and Foster, 1995)

In essence, Fig. 4 sows that regolith has a high storage capacity but low permeability, whereas bedrock has a low storage capacity but high permeability. However, that is not always the case.

Because there are cases where boreholes yield do not necessarily decline with depth. For example, Loiselle and Evans (1995) did not find any evidence of either decrease in fracture density or fracture yield up to a depth of about 180m in the crystalline rocks of Maine, USA. High yields from deep fracture horizons are reported from India and Sri Lanka. Data on borehole drilling in parts of the Indian shield also show an improvement in borehole productivity with an increase in depth up to 300m (Jagannathan 1993). Singhal and Gupta, (2010) observed that high discharge from deep gold mines in Karnataka, India, and Rand mines in South Africa also indicate high potentiality of deep fractured aquifer.

2.4 Exploration Approaches

Owing to the complexity of the geology and poor groundwater recharge; groundwater tends to be highly limited in extent in crystalline basement rocks. The finding of suitable target in complex terrain requires the use of local knowledge; geophysics, (magnetic surveys, vertical electrical sounding VES, and electromagnetic methods, etc); detailed structural and geological mapping (e.g. field mapping, aerial photography and satellite imagery analyses); exploratory drilling etc.

However, the conventional method applied in groundwater exploration in crystalline rocks area is by geophysical approach, where most boreholes are sited by 'anomaly hunting' using resistivity and electromagnetic methods, with little or no understanding of the structural geology of the target area. Sami (2009) demonstrated how the rate of drilling successful boreholes can be improved in the crystalline rocks area as shown below:-

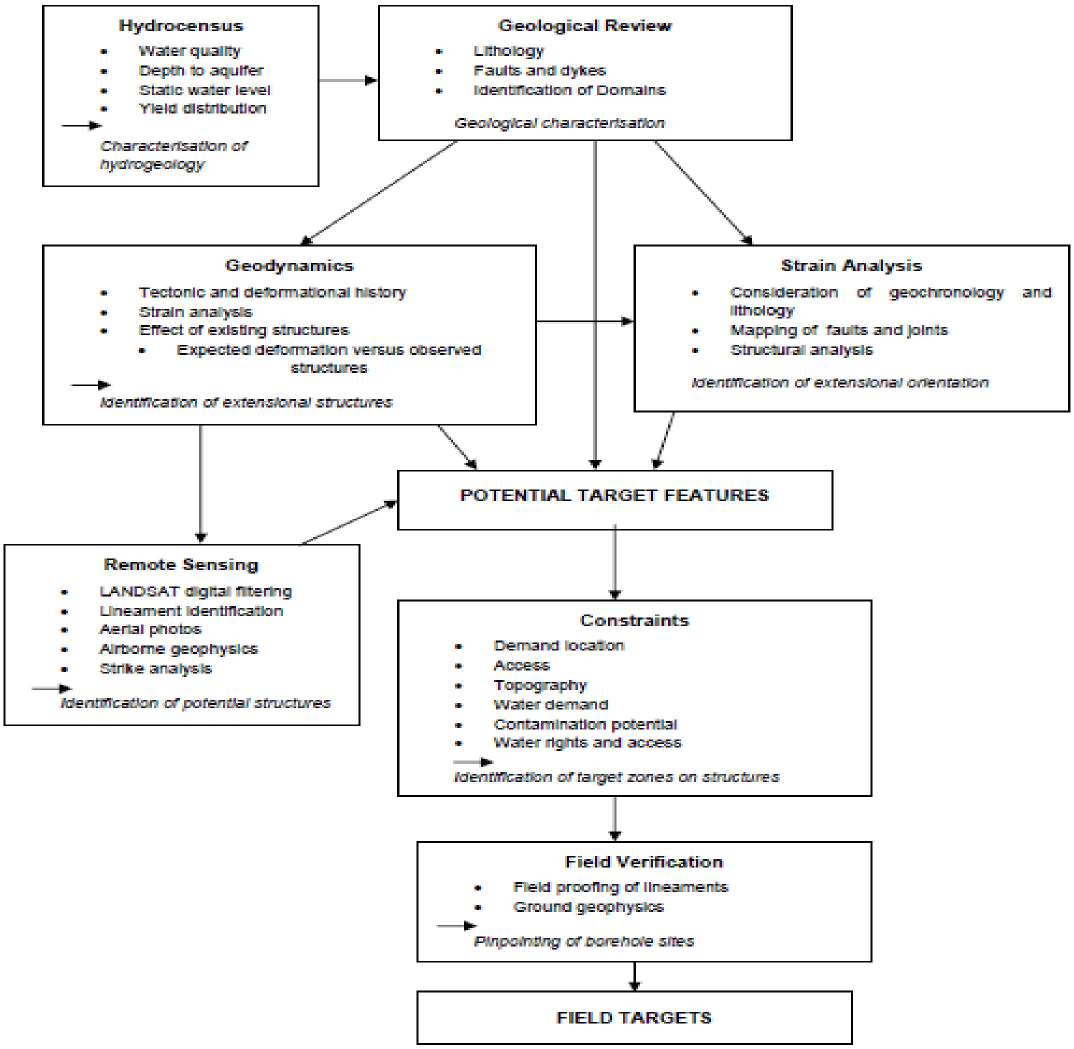

Figure 5: Flow chart of the Integrated Exploration Process (Adopted from Sami, 2009)

Sami (2009), placed emphasis on a comprehensive geodynamic and strain analyses, and how they are used to identify tectonic process and their expression, as well as identify compressional and extensional orientations by structural mapping of joints on an outcrop, respectively. These methods are very important and help in narrowing down the area of interest for ground geological and geophysical work. They prevent a situation whereby a large area is subjected to extensive geological and geophysical work for groundwater investigation.

Fracture-trace, or lineament analysis, is a powerful ground-water exploration tool. It depends on identifying faults and lineaments on aerial photographs or Landsat images and then locating them on the ground. They may be evident on high resolution satellite imagery and through geomorphic expression on topographic maps (Fetter, 2001).

Landsat 5-TM imagery of an area can be analyzed and interpreted in order to determine the lineament trends, lineament density and groundwater potential across the area (Anudu *et al*., 2011). Lineament density shows number of lineaments per unit area, or total length of lineaments per unit area. Areas having high lineament density could represent areas with high groundwater potentials.

However, in most cases, authors could not establish a direct relationship between borehole yield and lineament, due to lack of direct evidence that the structures responsible for the flow correlates with a mapped lineament. Sander, (2007) noted that, this may be attributed to local factors such as fracture infilling, fracture connectivity etc. It is recognized that lineament mapping is often not based on facts, but rather on personal beliefs or feelings, and also depends on factors such as data quality, extraction technique, and interpretation method. But when it is correctly interpreted, lineament in conjunction with knowledge of local geology, hydrogeology, tectonics, geomorphology etc; reveals setting and orientation of fractures for groundwater exploration at depth. These approaches to borehole siting will achieve a high success rate if properly applied.

2.5 Structural control of groundwater occurrence

In most geologic environments, there is a structural control which sometimes determines the availability of groundwater (Offodile, 2002). Structural patterns in geological formations arise mostly from the number of tectonic activities post dating the emplacement of rock formations. Groundwater is associated with these structures in various forms e.g. faults, fractures etc. These structural features are variable in nature with respect to frequency, spatial extent, and interconnectivity within the impervious crystalline rock mass.

Throughout the last decade, the optimization of the location of wells in tectonically fractured areas throughout Africa, India and Brazil focused mainly on assessing the relationship between bedrock structure and groundwater yield. This was achieved by analyzing the position of wells in relation to lineaments (aeromagnetic data or landsat images) (Greenbaun, 1992; Fernnandes and Rudolph, 2001; Owen *et al*., 2007). Fracture zones usually occur along lineaments and often correspond to the surface drainage patterns (Adams, 2009). Fracture systems are related to either decompression or tectonic forces. The former tend to be sub horizontal with a decreasing frequency with depth. The latter tend to be sub vertical and are often in zonal concentrations.

Therefore, flow in hard-rock aquifers is very complex and is governed by hydraulic conductivities in the regolith and underlying fractured bedrock. The flow could generally be local or regional flow systems. In local flow system, regolith zone acts as reservoir that slowly feeds the water from the surface into fractures of bedrock (where good hydraulic interconnection is present). Martin (2011) proposed that this flow is generally limited to 50m below ground level. However, in regional flow system, regional flow of ground water occurs within the major interconnected fracture systems.

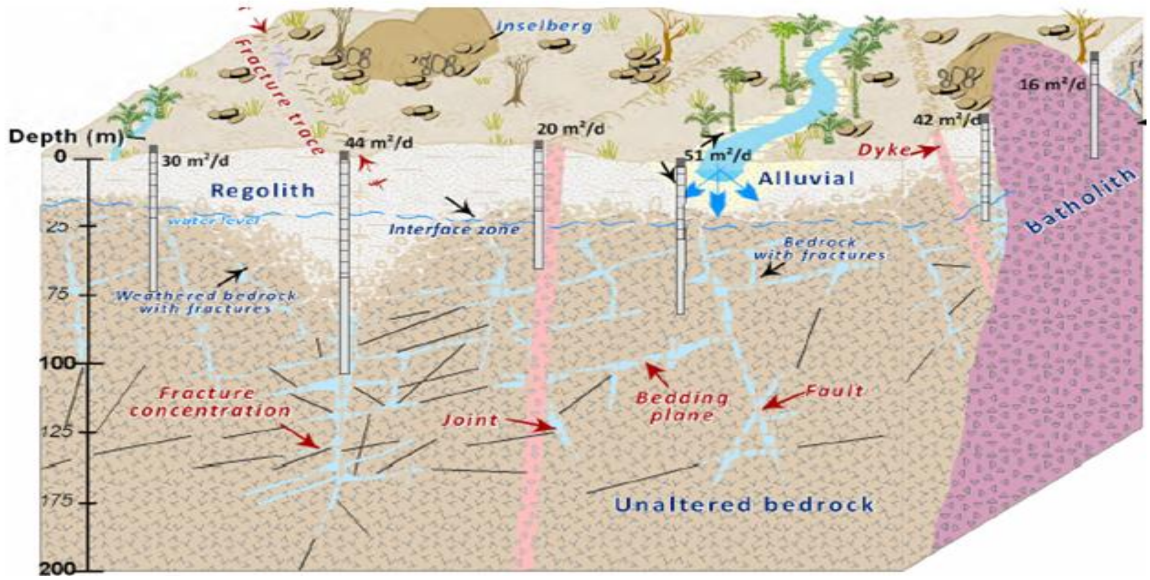

Fig 6: Groundwater flow in Basement Aquifers (After Martin, 2011)

The sustainability of such drilled wells is what has not been certified especially with the rate at which those wells are drilled in and around the study area. Adams, (2009) observed that not all fracture and fracture sets that are intercepted by drilling will yield water in hard rock terrain, but flow through rocks requires that a connected network of fractures be present.

2.6 Geology and Hydrogeology of the Study Area

Kano area is underlain by rocks of the Nigerian basement complex comprising migmatites-gneiss complex, younger metasediments, older and younger granites (Bala *et al*., 2011). MacDonald *et al*., (1986) established that, it is dominantly underlain by undifferentiated metamorphic suite, and older granite, (comprising of coarse pink granite and porphyritic biotite granite), with the older granite predominating over other rock types. The older granite is composed of coarse-grained granite, granodiorite, diorite and aplite. The lithological varieties are less common than in metamorphic suite. They were emplaced during the Pan African orogeny which was dated about 650±850 ma. The most abundant and typical member of the older granite suite is a coarse porphyritic granite (Oyawoye, 1972). It is typified by the abundant large feldspar set in a ground mass rich in biotite or hornblende. The feldspar may be white, purple, pink, yellowish brown and dark grey.

The schists are considered to be Upper Proterozoic supracrustal rocks which have been infolded into the migmatites-gneiss-quartzite complex (Obaje, 2009). According to Magdi (2009) schists occupy an area within the ‘’walled city’’ to the north central part of Kano. In hand specimen, the schists are fine to medium grained schistose rocks of pellitic to psamitic character. They are reddish to greenish grey in colour and highly weathered. They are found to be associated with diorite. This association indicates that schists have been intruded by small dioritic bodies, and are considered older than diorites in the area.

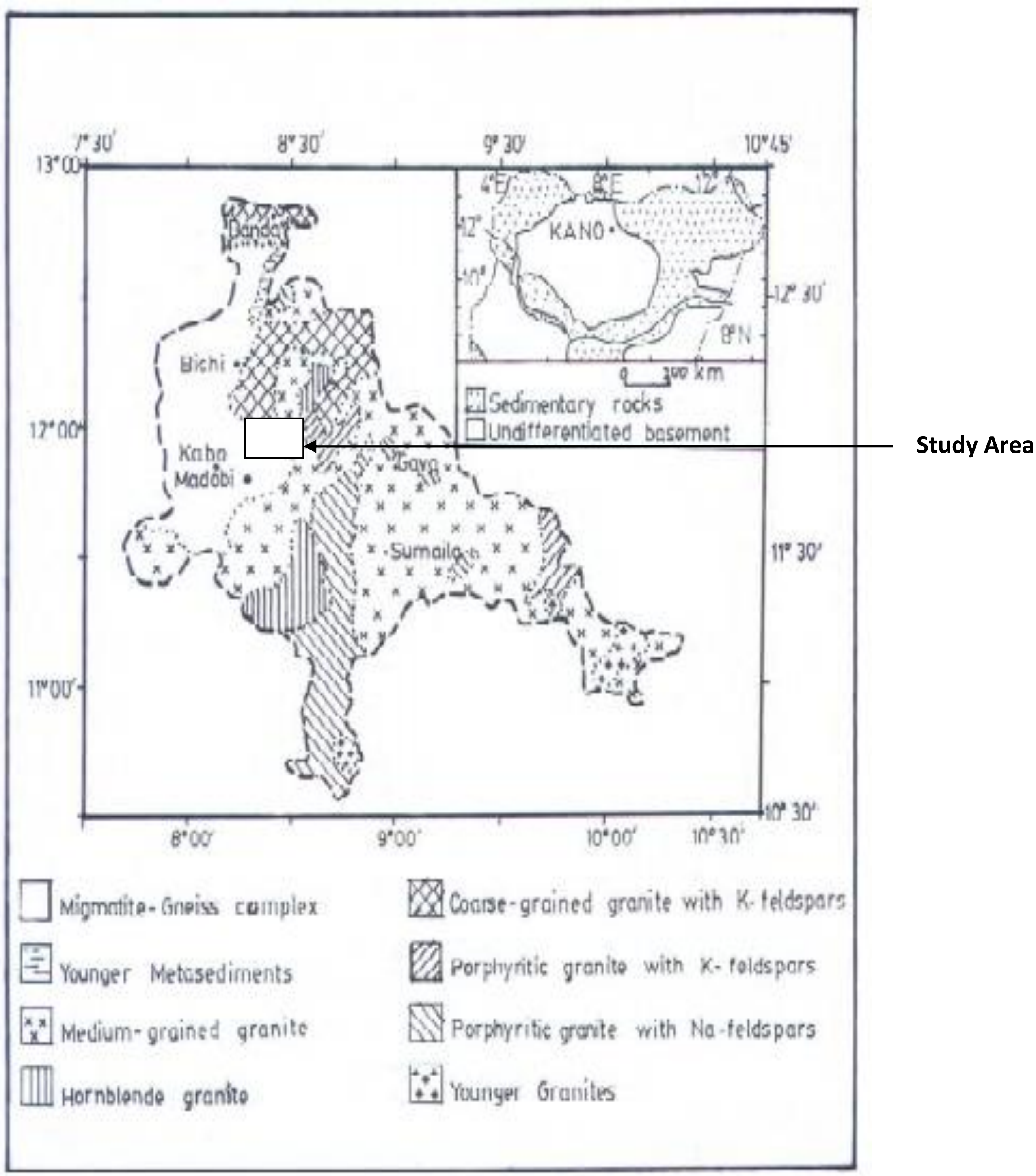

Figure 7: Geological map of Kano State Showing Study Area. (Inset) Location of Kano in the Geological Map of Nigeria (After Bala *et. al*., 2011).

In the study area, groundwater occurs within the weathered mantle or in the joint and fracture systems of the unweathered or partly weathered rocks (MacDonald *et al*., 1986). Dupreez and Barber, (1965) proposed that well should be located in the weathered mantle and fractured rock where permeability and porosity are sufficient to allow appreciable amount of water to accumulate in storage. The high groundwater yield in the area is found where thick overburden overlies fractured zones. The older granite has been subjected to many tectonic movements and pressure through geologic history such that they often have several fracture lines.

CHAPTER THREE:

METHODOLOGY

3.1 Introduction

This chapter describes the study design, sampling methods followed, and the techniques applied in data analysis.

3.2 Desk Studies

The study involved collection and reviewing of existing literatures including bulletins, journals, and textbooks, geological and topographical maps. This was helpful in understanding geological, geophysical and hydrogeological conditions of the study area.

3.3 Geological Mapping of the Study Area

Topographical maps on a scale of 1:50,000 covering the study area were obtained from Kano State Ministry of Land and Housing and Federal Survey Office in Kaduna, these maps were used as base map for this study. A reconnaissance Survey of the study area was conducted which allows the researcher to familiarize himself with the terrain and also aimed at identifying the existing rock exposure, and distribution of rock types.

An effort was made to study and appraise the geology of the area under investigation. The mapping was achieved using topographical map on a scale of 1:50,000, compass clinometer, satellite navigator (GPS), and a digital camera, which allows photographs of important structures and rocks to be snapped.

3.4 Geophysical Investigation

A vertical electrical sounding (VES) of electrical resistivity method was carried out using Ohmega resistivity meter with Schlumberger configuration. According to Macaulay (2008), the

VES principle is based on the fact that sub-strata is a resistor to the flow of electric current and that any sub-surface variation in conductivity will alter the current which affects the electrical resistivity of overburden and bedrock varies considerably in relation to moisture content.

Electric current is passed into the ground between two outer electrodes while the resultant potential difference is measured by two inner electrodes. The electric field produced is measured by the instrument in the form of Resistance which when multiplied by a constant (k) gives the apparent Resistivity value.

$P = K \Delta V/I$ …………… for Schlumberger array

The electrode spacing was progressively increased keeping the centre point of the electrode array fixed. The maximum half current electrode separation (AB⁄2) was between 1 and 80m while the half- potential electrode separation (MN⁄2) was maintained between 0.5 and 8m. The apparent resistivity measured at each point was plotted on a log-log paper. The plots gave a rough idea of position and forms of the interface.

A total of 20 VES points were sounded. The qualitative interpretation of the field data was done using a computer program known as Offix; to identify thickness and resistivity of different layers, so as to give information on deeply weathered and fractured zones as shown in appendix III.

3.5 Measurement of Hydrogeological Data

A depth to water table of a total of 50 hand dug wells were measured during the peak of dry season in April 2013, and peak of rainy season in September 2013. The results are presented in appendix II. The measurement was done before the water was agitated, using measuring tape.

This was achieved by tying to the tape a piece of small metal. When lowered into the well, it produced a ripple waves upon touching the water surface. The depth to water table was then read directly from the tape after compensating for the height of the well above ground surface.

3.6 Aquifer Properties

Pump test data of twenty (20) deep and shallow boreholes were used for the determination of aquifer characteristics. These properties includes: - transmissivity (T), hydraulic conductivity/ coefficient of permeability (k), and storage coefficient/ storativity (S), and are also known as aquifer constants. These constants are determined from pump test, because during pump tests a large sample of aquifer present in a well is tested under field conditions.

Parts of the data obtained from the measurements were plotted on semi-log graph in order to observe the changes in drawdown for a period of pumping of the borehole. The drawdown (s) in meters on the ordinate is plotted against time (t) in minutes (fig. 12). When there is significant change in drawdown during the period of pumping, the flow is considered unsteady, but if the change in drawdown is not significant (nearly horizontal line on the graph), the flow is regarded as steady flow. However, all the pump test data used for this study are of unsteady flow.

The Theis equation is used to determine aquifer hydraulic characteristics. The time drawdown is then interpreted to yield the aquifer parameters. Theis equation is as follows:-

$$s = \frac{Q}{4\pi T} W(u) \quad \text{……………………………………………….(1)}$$

The equation above is also known as the non equilibrium equation,

Where W (u) is the well function which represents the exponential integral,

s is the drawdown, and Q = is the constant well discharge,

$u = r^2S/4Tt$

where r = radial distance from the pumped well,

T= Transmissivity,

t=time since pumping began

S= storage coefficient

The non-equilibrium or Theis equation permits determination of the aquifer constants (S and T). The equation is widely used in practice and is preferable to the equilibrium equation because:-

1. A value of S can be determined,
2. Only one observation well is required,
3. A shorter period of pumping is necessary, and
4. No assumption of steady state is required.

   However, as a derivative of Theis non equilibrium equation; Jacob's equation introduced a simplified equation for one observation well for small value of u (i.e. for small r and / or large t) less than 0.01 so that from the drawdown time graph plotted on a semi-logarithmic paper, we have:-

   Drawdown $s = \frac{2.3\,Q}{4\pi T} \log 2.25Tt/r^2S$………………………………… (2)

   This is the equation of a straight line whose slope is equal to $\frac{2.3\,Q}{4\pi T}$ and is found as the vertical projection of the intercept of the straight line between two number on the time scale that have logarithmic one unit apart say 1000 and 100. T may be found from the slope and S may be found from equation (2) for pump testing above.

   When however, one observation well is used $\log 2.25Tt/r^2S$ in equation (2) above is equal to 1. Hence the equation becomes;

Drawdown $s = \frac{2.3\ Q}{4\pi T}$ …………………………………………………… (3)

Q is known from the pumping test,

s is found from the slope,

Hence T can be calculated by substitution in equation (3).

Having calculated T, the hydraulic conductivity (permeability) of the aquifer could be computed empirically using the equation:

T= kb

i.e. $k= \frac{T}{b}$ …………………………………………..(4).

Where k= hydraulic conductivity,

T= Transmissivity, and

b= Thickness of the aquifer.

From the borehole log, the value of b can be known.

Specific capacity can be calculated using the following equation:

$S= \frac{Q}{s}$ ……………………………………… (5)

Where Q= discharge

s= maximum drawdown.

3.7 Lineament mapping

LANDSAT ETM+ imagery of the area was downloaded from global land cover facility site. The automatic lineament extraction was carried out with the aid of the Line module of the PCI Geomatica software. The calculation of lineament related values with script files was done using Arc GIS 9.3 software. The extracted lineaments were taken to Rockworks 15 software where rose-diagram (azimuth-frequency) generated lineaments trends (Fig. 14).

3.8 Collection of Water Samples

The bottles for sampling were obtained, and at each sampling point the bottle was rinsed with the deionized water before the sample was collected. Then p^H, Temperature, Total Dissolved Solids (TDS), and Conductivity were measured directly in the field using Mi 806 (4 in 1) combined meter. This allows an initial, rapid assessment of water quality at the site of sampling. This was followed by the acidification with some few drops of Nitric acid (HNO_3) to prevent adsorption of ions on the walls of the containers, similarly to prevent bacterial activities. The sample was labeled and stored in container containing ice blocks before taken to the laboratory for analysis.

Equipment used:- Polyethylene bottles (for acidified and non acidified samples), disposable syringes, washing bottles, permanent drawing ink markers, ice blocks, and two 500ml polyethylene beakers for sample water to measure p^H and EC, p^H meter. At each of the sampling points, the following procedures were followed;

1. Writing the sample number on sample bottles;
2. Marking location and sample number on the map;
3. Temperature/p^H/EC meter and polyethylene beaker were rinsed in deionized water and then with water to be sampled, to remove any trace of previous sample or storage solution;
4. Measurements of temperature, p^H, TDS, and electrical conductivity (EC) of water using Mi 806 (4 in 1) combined meter;
5. Recording the temp/p^H/EC/TDS readings on the field record sheet, the meter and beaker were rinse with deionized water and meter kept in its cap;

6. Two samples were collected at each sampling points with some drops of nitric acid (HNO_3) added to one of the bottles for cation analysis and closed tightly;
7. The filled samples bottles were placed in the cool box;
8. Transportation of samples to the laboratory for analysis.

3.8.1 Laboratory Work

The water quality of the acidified and non acidified samples from deep and shallow boreholes were analysed at the Multi-user laboratory, Department of Water Resources and Environmental Engineering, Multi-purpose laboratory in the Department of soil Science, ABU Zaria, in order to determine the concentrations of major and some trace elements in the water. This was achieved using Atomic Absorption Spectrometer (AAS-Varian AA240Fs), Water kit, Direct reading Photometer (Hanna model), titrimetric method, and Flame photometer (FPF9 Jenwy model).

3.8.2 Interpretation of groundwater chemistry

The chemical parameters of water samples from the 20 deep and shallow boreholes were plotted using AquaChem; a software package developed specifically for graphical and numerical analysis and modeling of water quality data. The plot types used in this work includes:

- Correlation plot: Wilcox
- Summary plot: Schoeller
- Trilinear plot: Piper.

Each of these plots provides a unique interpretation of the many complex interactions between the groundwater and aquifer materials, and identifies important data trends and groupings.

In Piper plots, major ions are plotted as cation and anion percentages of milliequivalents in two base triangles. The total cations in meq/l, and the total anions in meq/l, are set equal to 100%. The data points in the two triangles are then projected onto the diamond grid. The projection reveals certain useful properties of the total ion relationships. Every sample is represented by three data points; one in each triangle and one in the diamond grid. In Schoeller plot, semi-logarithmic plots represent major ion analyses in milliequivalents per liter, and demonstrate different hydrochemical water types on the same plot. The Wilcox plot is a simple scatter plot of **Sodium Hazard** (**SAR**) on the **Y-axis** vs. **Salinity Hazard** (**Cond**) on the **X-axis**. The Conductivity (**COND**) is plotted in a log scale.

CHAPTER FOUR:

RESULTS AND DISCUSSIONS

4.1 Geology

The study area is believed to be a typical basement complex. The major rock units mapped in the study area are:-

- Schists;
- Diorites;
- Granites; and
- Minor Intrusions.

They are shown on the geological map of the area (Fig.8).

Geological mapping of the area was done by making of observations of geology in the field and recording them, so that a geological map of the study area can be produced.

4.1.1 Schists

This rock type is generally believed to have developed in separate basin during a sedimentary cycle preceding the Pan-African orogeny (Ajibade and Fitches, 1988). The rock contains abundant particles of mica, characterized by strong foliation, and originating from a metamorphism. They are fine to medium grained, and reddish (rusty) to greenish grey in colour. They are highly weathered. The schists occupy a larger area within the ‘’old Kano city’’ to the north central part of the area.

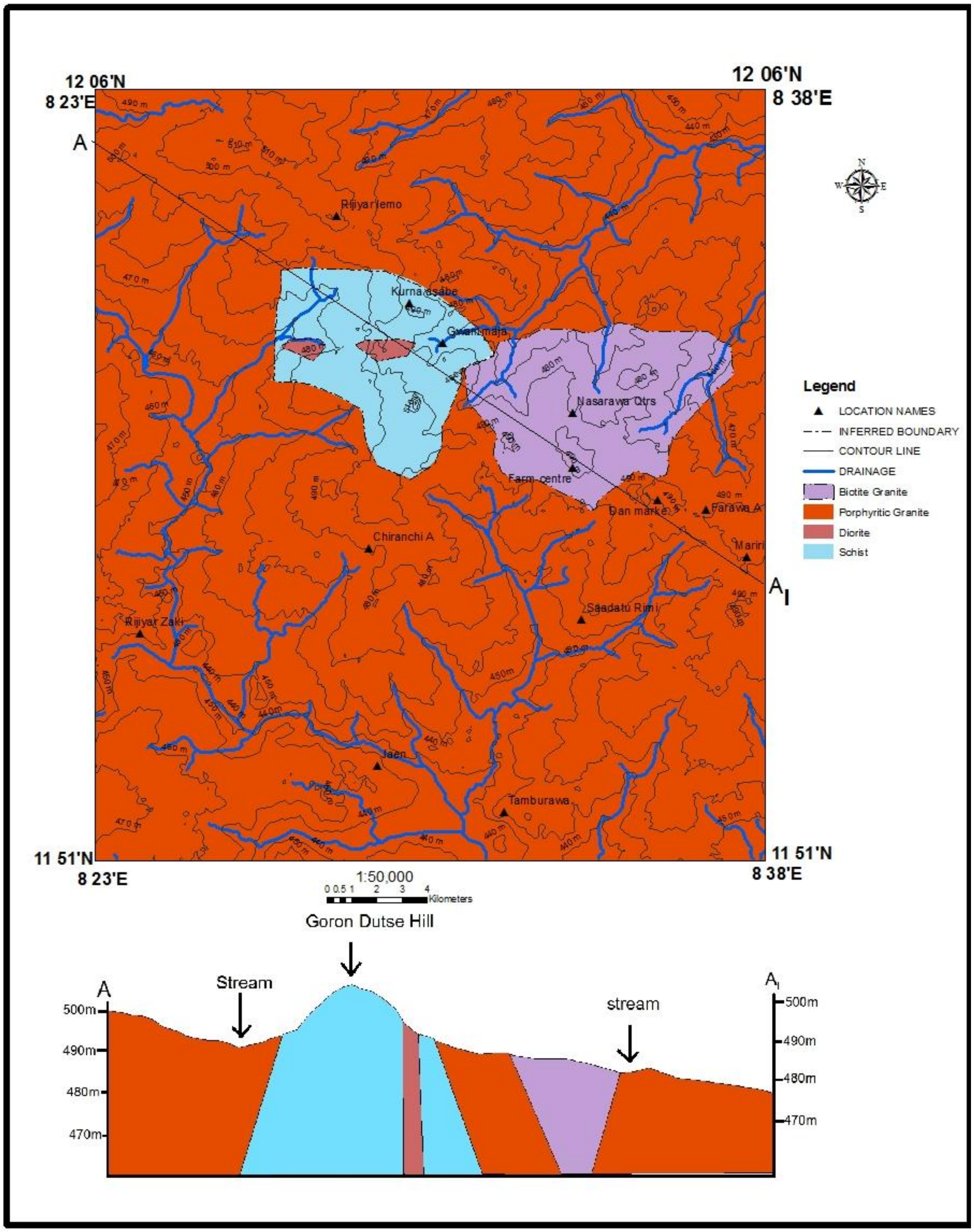

Fig. 8: Geological map and cross sectional view of A-A_1 of the Study area

4.1.2 Diorite

They are medium to fine grained in texture. The colour of these rocks is dark greenish-grey. They were emplaced within the schists, and outcropping as rounded to sub rounded boulders.

4.1.3 Granites

The granites constitute more than three-quarter of the total area mapped. The granites outcrop as distinct plutons often of batholitic dimensions, and date back to Pre-Cambrian time. These rocks are the most obvious manifestation of the Pan-African Orogeny. They are of two (2) varieties; porphyritic granites and biotite granites.

I. Porphyritic granites

These are the most dominant rock type in the study area. They vary in colour from pink to light. The proportion of milky or pink phenocrysts of feldspar is responsible for the variation in colour. These rocks were seen highly weathered and extensively fractured with major and minor fractures criss – cutting the rocks.

Plate I: Highly weathered porphyritic granite (Naibawa bye-pass) (11° 54′ 59″ N 08° 33′ 26″ E)

Plate II: Fractured Porphyritic granite (Near Tamburawa bridge) (11° 50′ 23″ N 08° 30′ 58″ E)

II. Biotite granite

They are medium-grained and vary in colour from light to pink. Minerals observed in hand specimens are quartz, feldspar, and biotite. They occupy small part of the area mapped. These granites have a different crystallization history with the porphyritic types. At Locality 9 they form a small hill known as ‘’Magwan’’. The rocks here appear massive in nature. Blocks of some of these rocks were seen detached from the main rock by weathering which was facilitated by the orthogonal nature of the rock fractures and are found as boulders.

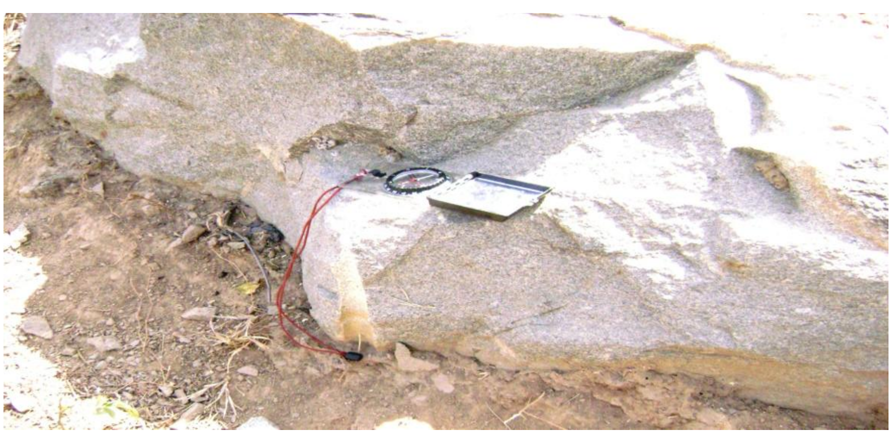

Plate III: Biotite granite exposure (Magwan) ($11^{\circ}\ 50'\ 23''$ N $08^{\circ}\ 30'\ 58''$ E).

4.2 Structures

The basement complex is believed to have responded to various tectonic events during the Pan-African orogeny and even earlier. Major structural elements identified in the field are the joints and fractures. The regional strike of the joints and fractures are dominantly N-S, representing the final imprint of the pan-African orogeny. Other trends are NE-SW and NW-SE. Major rivers are structurally controlled by these main strike directions of structures, an example is River Hadejia.

4.2.1 Joints and fractures

These are the majo r structural elements identified. A characteristic feature of the basement complex is the widespread occurrence of fractures. Strike of Joints and fractures trends was taken. Two sets of joints set were observed; a predominant NNE-SSW trending joint set and a less predominant joint set trending E-W.

4.2.2 Foliations

Foliation is almost associated only with granitic and schistose rocks of the area. In granites, the predominant foliation trend observed is N-S. In the schist, schistosity is well developed and trend predominantly NE-SW.

4.2.3 Minor Intrusions

Some dykes and veins of aplite have been found intruding the major rocks of the study area.

I. Quartz veins

They are tabular or sheet-like bodies of quartz which have been introduced into joint or system of joints or fissures in rocks. They are light coloured composed basically of quartz. They range in thickness from few millimeters to several centimeters. Some veins observed tend to cross cut each other forming a network. However, only few of them form mappable units. At locality 4

(Ring Road Bye-pass, Naibawa) a quartz vein cutting through a biotite granite exposure is seen as shown in (plate IV).

Plate IV: A quartz vein (Block Industry, Naibawa) (11°54´59´´N, 08°33´26´´E)

II. Aplite dykes

A major aplite dyke was found intruding porphyritic granite at locality 2 (Near Tamburawa Water Treatment Plant).The dyke trends N38°E. Aplite is a light-coloured, fine-grained, equigranular intrusion, composed of subhedral to anhedral grains of quartz and alkali feldspar, and found as late-stage veins in granite bodies. The quartz–alkali feldspar composition corresponds to the lowest temperature melts in granite magma systems, suggesting that they are residual melts formed by the differentiation of granite magma. In the aplite observed; individual crystals cannot be identified with a naked eye. In some localities is stained and appear dark brown due to weathering.

4.3 Geophysical Results

Twenty (20) VES soundings data were analysed. Table 2 below shows the values of resistivity, and thickness of each layer.

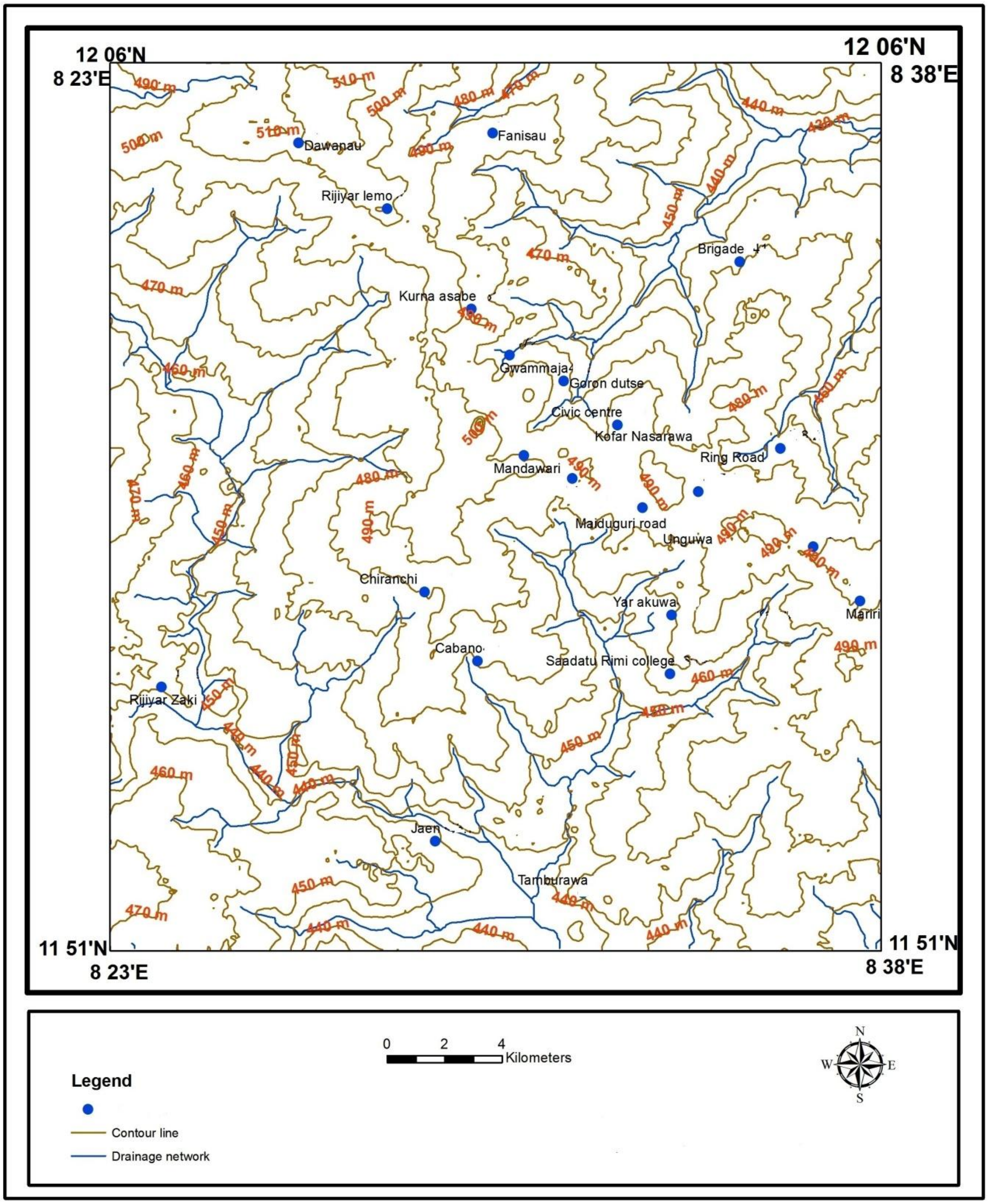

Fig. 9: Topographical map of the area showing VES points

Table 2: Summary of VES Results

S/N	Location ID	1st layer			2nd layer			3rd layer			4th layer			Type of Curve
		Resistivity (Ωm)	Depth (m)	Thickness (m)	Resistivity (Ωm)	Depth (m)	Thickness (m)	Resistivity (Ωm)	Depth (m)	Thickness (m)	Resistivity (Ωm)	Depth (m)	Thickness (m)	
1	BUK 1	197.7	2.86	2.86	52.84	11.89	9.02	503.5	60.84	48.95	206.4	60.85	-	QH
2	UBA 1	2783.2	1.12	1.12	48.82	18.12	16.99	9779.3	43.32	25.20	31.67	43.32	-	QH
3	ASH 1	78.63	9.18	9.18	116.0	17.43	8.24	333.2	72.05	54.62	231.4	72.05	-	HA
4	ALI 1	375.3	1.81	1.81	28.48	56.16	54.34	76.91	84.89	28.73	209.6	84.89	-	QH
5	GPL 1	119.8	1.75	1.75	43.74	26.75	24.99	79.04	73.44	46.69	64.99	73.44	-	QH
6	RAS 1	26.60	1.72	1.72	67.89	8.91	7.18	26.13	42.64	33.72	64.07	42.64	-	KA
7	KZR 1	22.09	4.93	4.93	36.22	18 .71	13.77	176.6	62.31	43.60	62.85	62.31	-	A
8	ABK 1	303.2	1.92	1.92	93.69	28.04	26.12	129.1	67.55	39.50	115.9	67.55	-	QH
9	RLM 2	12.93	2.73	2.73	103.0	26.76	24.03	339.9	73.06	46.30	269.4	73.06	-	A
10	RLM 1	147.3	6.74	6.74	119.7	15.45	8.70	262.6	56.90	41.45	150.5	56.90	-	HA
11	FCT 3	115.7	11.57	11.57	119.8	28.45	16.87	262.4	85.10	56.64	161.2	85.10	-	HA
12	BDW 2	55.62	2.87	2.87	136.9	10.14	7.27	48.81	61.01	50.87	57.07	61.01	-	K
13	KWU 1	126.1	1.50	1.50	39.84	17.30	15.79	90.18	52.26	34.96	257	52.26	-	QH
14	PAV 1	35.71	6.70	6.70	88.45	27.18	20.48	101.9	74.09	46.90	107.2	74.09	-	HA
15	BHT	78.45	2.42	2.42	32.19	8.19	5.76	77.27	61.71	53.52	124.5	61.71	-	H
16	MHB 1	273.6	4.20	4.20	62.01	25.48	21.28	145.4	68.09	42.60	92.19	68.09	-	QH
17	GWD 1	26.36	7.85	7.85	216.3	21.04	13.19	138.5	44.23	23.18	597.9	44.23	-	HA
18	SK9 1	147.5	1.47	1.47	48.72	6.77	5.29	87.15	48.89	42.12	257.8	48.89	-	QH
19	AHL 1	208.4	2.20	2.20	108.1	18.29	16.08	87.27	86.90	68.60	53.66	86.90	-	Q
20	IDR 1	141.0	3.84	3.84	95.49	16.02	12.18	236.9	48.81	64.83	245.5	64.83	-	H

4.3.1 Discussions of Geophysical Results

The aim of Vertical electrical Sounding is to determine the different geoelectric layers in the subsurface, the aquifer units and their characteristics, as well as general hydrogeological condition. Four layered-type curves were obtained from the VES points in the study area. They have varying geologic characteristics, showing different degree of weathering and other second porosity in form of fracturing of the bedrock. Plots of calculated apparent resistivity in ohm-m against electrode spacing with geoelectric sections showing resistivity and depth of the subsurface layer are presented in appendix y. These layers could be grouped as follows:-

1st layer - Top soil/laterite/clay

2nd layer – Weathered layer

3rd layer – Fractured layer

4th layer – Bedrock.

I. Top soil

This is a surface dry layer of high resistivity that ranges from 12.93 ohm m to 2783.2 ohm m. Its thickness varies from 1.12m to 11.5m. The low resistivity end is diagnostic of sandy clay and clay while a high resistivity end indicates laterite. However, very high resistivity could be a fresh basement.

II. Weathered layer

This layer is thought to be highly decomposed crystalline rock. The resistivity value ranges from 28.48ohm m to 216.3 ohm m. The thickness varies from 5.29m to 54.34m. According to Dan Hassan and Olurenfemi (1994), it consists of clayey sand/ sandy clay layer. The layer is highly decomposed by weathering to form sand and clayey sand depending on the local variation of the mineralogy. However, this layer is believed to be the regolith. Hazell *et. al*., (1992) made it clear in the geophysical assessment of Kano crystalline aquifers that, resistivity values reflects the preferred lithological range, high value indicates a granular regolith, and intermediates values indicating silty clayey regolith. See Table 3 for the Resistivity ranges and weathering grades.

Dan Hassan and Olurenfemi (1994) identified this layer to be the major aquifer unit. If the depth of weathering is sufficiently thick as exhibited by most of the VES points in the study area; the weathered mantle could contain water in storage large enough to produce a successful borehole. Therefore, the following VES points are identified as good potentials for groundwater development; BUK 1, SOK 1, FCT1, BRJ 2, BMP1, CLB 1, DKT 1 and BDW 2.

III. Fractured layer

The resistivity value ranges from 26.13 ohm m to 9779.3 ohm m. The thickness varies from 23.18 m to 68.60 m. In some places, fractured zones occur immediately beneath the weathered horizon. The fractured zones are difficult to detect geophysically, unless it is of greater thickness. Where the fractured zone is saturated, a high groundwater yield can be obtained from borehole penetrating such a sequence.

IV. Bedrock

This has a very high resistivity with infinite thickness. But where it is fractured and saturated; the resistivity reduces. It is not a source of groundwater unless fractured. However, when the shape of the VES curves approaches a very steep gradient of about 45□ (steady increase in resistivity), it may indicate a fresh basement rock without fractures.

Therefore the geophysical result shows that, generally the area has a good potential for groundwater development, especially in places underlain by porphyritic granite because of its thick regolith and extensive fractures.

Table 3: Resistivity and conductivity ranges for weathering grades (Source: Hazell *et. al.*, 1992)

Type of regolith/rock	Provisional grade	Resistivity (ohm m)	Conductivity (mmhos/m)	Lithology
Silty-clayey regolith	III/IV	<50	>20	Mica rich biotite gneiss
Fine/medium-coarse regolith	III	50-100	20-10	Granite gneiss migmatites
Granular regolith	IIA	100-170	10-6	Older Granite coarsed grained
Slightly weathered regolith/fractured rock	II	170-270	6-4	All
Fractured rock	II/I	>270	<4	All

4.4 Groundwater configuration maps

The elevation of water levels (Appendix II) above sea level measured at the field was used in constructing groundwater configuration maps for both the peak of dry and wet seasons. Fig10 and 11 shows the peak of dry and wet season's groundwater elevation maps. In the maps, hand dug wells were located on the topographical map of the study area with their respective values of water level elevations above sea level plotted against each of the well measured. This was followed by manual plotting of groundwater contours lines on the map. Directions of groundwater movement were drawn, usually from higher elevations to lower elevations and perpendicular to groundwater contours, thereby joining the second order streams of the area on the map. The last stage was digitization of the maps using global mapper software.

4.4.1 Static water level at peak of Dry Season

The measured water level in hand dug wells at peak of dry season range from 3.20 to 19.00 mbgl. The maximum water levels elevation was 500 masl and minimum was 425.6 masl, this gave a range of 74.4m with the mean water level elevation at 467.44 masl.

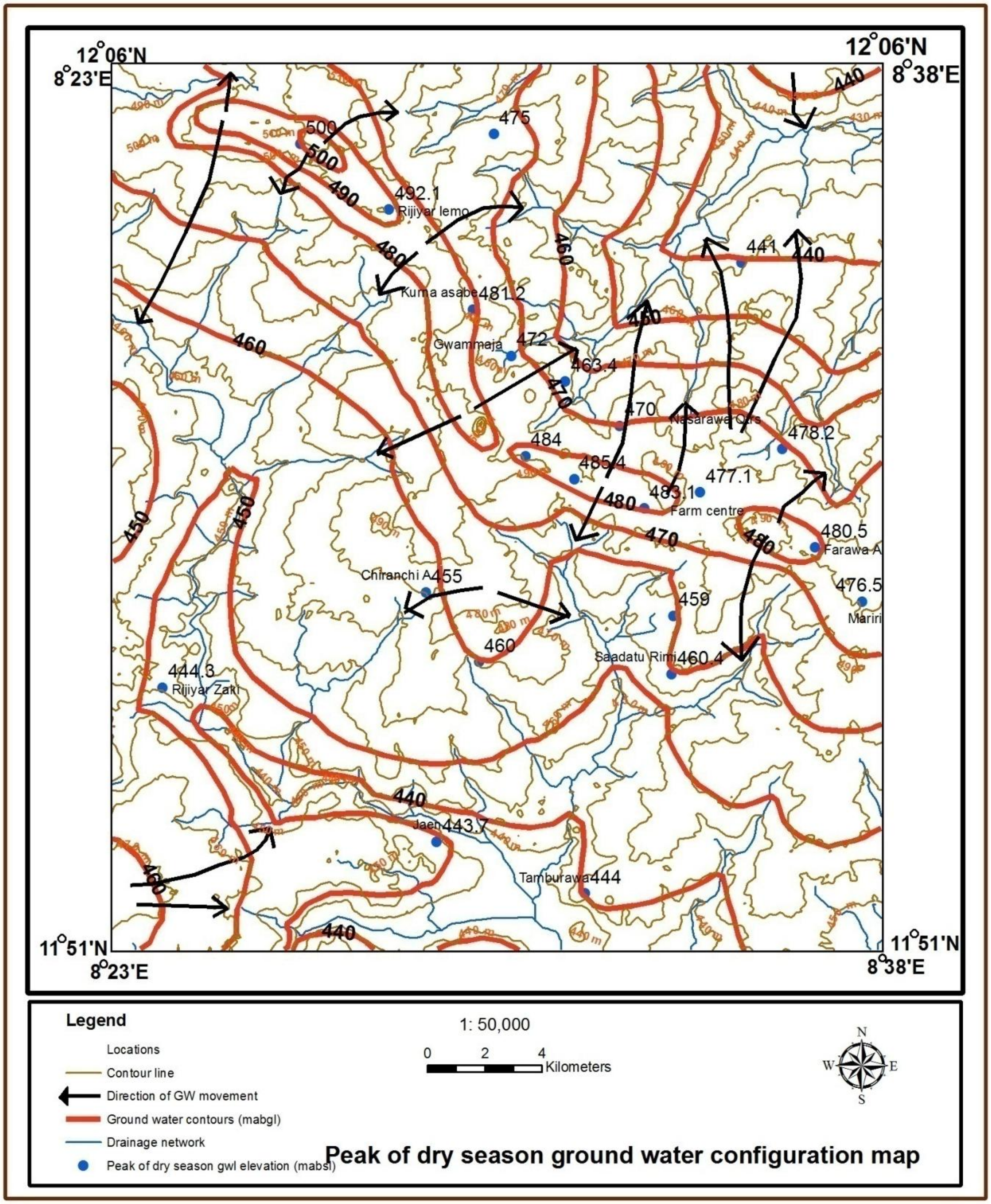

Fig. 10: Peak of dry season groundwater configuration map

4.4.2 Static water level at peak of Wet Season

The water level measurements in hand dug wells at peak of wet season range from 0.50 to 12.0 mbgl. The maximum water levels elevation was 508 masl and minimum was 444.60 masl, this gave a range of 63.4m and with a mean water level elevation of 470.68 masl.

4.4.3 Discussion of Groundwater Configuration maps

Analysis of the water level configuration indicated that the maximum and minimum water level elevations at the peak of rainy season were 8.00m and 1.6m higher than those of the peak of dry season. The flow in the area is from areas of recharge to those of discharge. Along rivers or streams; the static water level is found to be shallow (i.e. within few meters from the surface) as observed in the south eastern and south western parts of the study area. In areas of higher elevations e.g. north western part of the study area the static water level is deeper. The depth to water table is thicker at the recharge area (watersheds) and thinner at the discharge areas (river or stream channels). Groundwater recharge is a function of rainfall, vegetation, relief and characteristics of regolith. The aquifer are usually recharged by infiltration directly from rainfall or by fractures directly connected to a major river or stream.

The flow direction is generally from topographically higher areas toward low-laying areas. It indicates flows that are parallel to the hydraulic gradient and perpendicular to the water table contours. The directions of groundwater flow are shown by arrows on the maps of water table configuration and directions of groundwater flow at the peaks of the rainy and dry seasons.

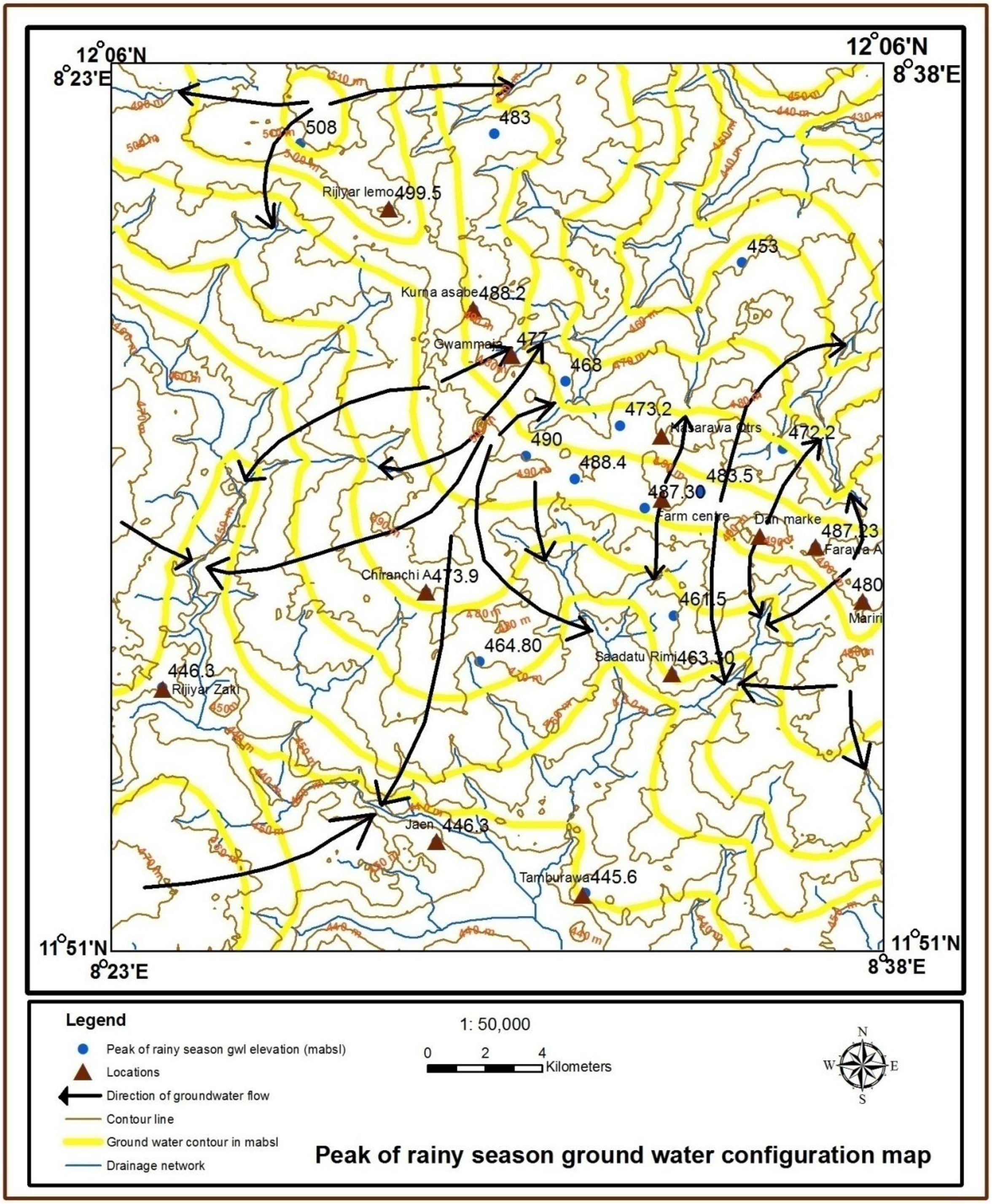

Fig. 11: Peak of rainy season groundwater configuration map

4.5 Hydraulic properties of the Aquifers

Twenty (20) boreholes were pump tested in the study area. Appendix III shows pump test data for constant discharge and recovery period phases. Table 4 and 5 shows their calculated aquifer properties. The aquifer properties of the boreholes were derived using the following procedure:-

(BH 1: Farm centre)

Data: - Q=0.90l/s=0.90×$10^{-3}$$m^3$/s s=50.26m Δs= 3.08m b=50m

1. Transmissivity,

   $T=\frac{2.3Q}{4\pi\Delta s}$

   $T=\frac{2.3\times0.90\times10-3}{4\times3.142857\times3.08}$

   $=\frac{0.00207}{38.72}$

   T= $5.35x10^{-5}$ m^2/s

2. Hydraulic conductivity,

   $k=\frac{T}{b}$, where b= aquifer thickness

   $=\frac{0.0000535}{50}$ = $1.07x10^{-6}$

   k = $1.07x10^{-6}$m/s

3. Specific capacity = $\frac{Q}{s}$

   where s= maximum drawdown

   $=\frac{0.90\times10-3}{50.26}$

$= \underline{1.79 \times 10^{-5} m^2/s}$

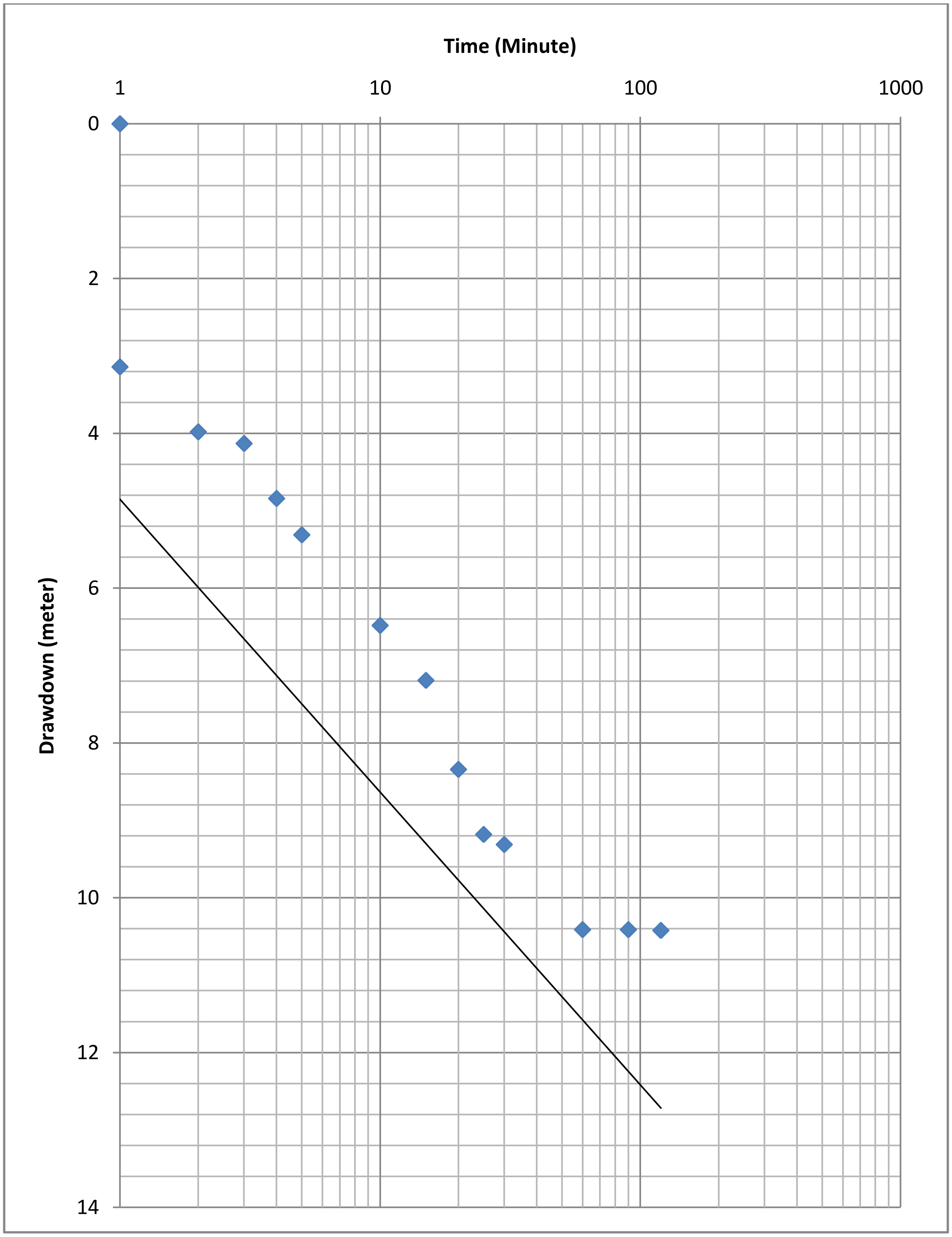

Fig. 12: A graph of draw down versus time of GGASS Panshekara

Table 4: Aquifer Properties of Pump tested Deep Boreholes in the Study Area

S/N	BH ID	Coordinates	Location	Depth (m)	Discharge Q(l/s)	Transmissivity (T)		Hydraulic Conductivity (k)		Specific capacity (m^2/s)	Drawdown per log cycle (Δs)
						(m^2/s)	(m^2/day)	(m/s)	(m/day)		
1	BH 1	N11°58′78′′ E8°33′21′′	Farm centre	300	0.90	$5.35x10^{-5}$	4.62	$1.07x10^{-6}$	0.09	$1.79x10^{-5}$	3.08m
2	BH 2	N11°58′73′′ E8°32′30′′	Farm centre	250	0.75	$5.30x10^{-5}$	4.58	$1.06x10^{-6}$	0.09	$1.30x10^{-5}$	2.59m
3	BH 3	N11°58′05′′ E8°33′30′′	Farm centre	120	0.79	$6.02x10^{-5}$	5.20	$2.00x10^{-6}$	0.17	$1.29x10^{-5}$	2.4m
4	BH 4	N12°01′13′′ E8°33′07′′	Nasarawa GRA	125	0.82	$5.64\ x10^{-5}$	4.87	$2.26x10^{-6}$	0.20	$1.51x10^{-5}$	2.66m

Table 5: Aquifer Properties of Pump tested Shallow Boreholes in the Study Area

S/N	BH ID	Location Name	Depth (m)	Discharge Q(l/s)	Transmissivity (T)		Hydraulic Conductivity (k)		Specific capacity (m^2/s)	Drawdown per log cycle (Δs) (m)
					(m^2/s)	(m^2/day)	(m/s)	(m/day)		
1	BH5	GGSS Panshekara	36	1.11	$1.78x10^{-5}$	1.54	$1.49x10^{-6}$	0.13	$1.07x10^{-4}$	4.95
2	BH6	Dan gauro Pri. Sch	37	1.17	$6.12x10^{-5}$	5.29	$5.10x10^{-6}$	0.44	$1.97x10^{-4}$	3.5
3	BH7	Liman M. Idi	29	1.14	$2.43x10^{-5}$	2.10	$2.69x10^{-6}$	0.23	$8.90x10^{-5}$	8.6
4	BH8	Majema	31	0.31	$8.86x10^{-6}$	0.79	$7.39x10^{-7}$	0.06	$3.78x10^{-5}$	6.4
5	BH9	D/kowa Pri. Sch.	54	0.45	$7.84x10^{-6}$	0.68	$4.36x10^{-7}$	0.04	$1.95x10^{-5}$	10.5
6	BH10	Dabo Pri. Sch.	44	0.35	$5.12x10^{-6}$	0.44	$3.42x10^{-7}$	0.03	$1.34x10^{-5}$	12.5
7	BH11	Masaka	34	0.32	$1.45x10^{-5}$	1.25	$1.21x10^{-6}$	0.10	$4.81x10^{-5}$	4.05
8	BH12	Nababa	28	0.30	$1.74x10^{-5}$	1.50	$1.45x10^{-6}$	0.13	$4.08x10^{-5}$	3.15
9	BH13	Masallacin Lawal	43	1.17	$9.31x10^{-5}$	8.04	$5.82x10^{-6}$	0.50	$4.13x10^{-4}$	2.3
10	BH14	Ayagi	52	0.38	$1.74x10^{-5}$	1.50	$1.93x10^{-6}$	0.17	$3.8x10^{-5}$	4.0
11	BH15	Barnoma	50	1.17	$2.49x10^{-4}$	21.51	$3.11x10^{-5}$	2.69	$7.96x10^{-4}$	0.86
12	BH16	Rimin Auzunawa	46	0.50	$5.63x10^{-6}$	0.49	$3.75x10^{-7}$	0.03	$1.83x10^{-5}$	16.25
13	BH17	Fegin Liman	36	0.85	$2.16x10^{-5}$	1.87	$1.20x10^{-6}$	0.10	$7.60x10^{-5}$	7.2
14	BH18	Masallacin J. Tukwane	41	0.60	$1.93x10^{-5}$	1.67	$1.48x10^{-6}$	0.13	$5.64x10^{-5}$	5.7
15	BH19	Mil Tara	52	0.80	$3.57x10^{-5}$	3.08	$2.23x10^{-6}$	0.19	$1.06x10^{-4}$	4.1

16	BH20	Kofar Yamma	33	0.50	$8.71x10^{-6}$	0.75	$3.96x10^{-7}$	0.03	$2.06x10^{-5}$	10.5

The Transmissivity values for the deep boreholes pump tested in the area have a range between $6.02x10^{-5}$ m^2/s and $5.30x10^{-5}$ m^2/s (5.20 m^2/day and 4.58 m^2/day), while the shallow boreholes have a range between $2.49x10^{-4}$ m^2/s and $5.12x10^{-6}$ m^2/s (21.51 m^2/day and 0.44 m^2/day) as shown in table 4 and 5 above.

Table 6: Gheorghe Standards for Transmissivity

Transmissivity Range (m^2/day)	Transmissivity Potentials
>500	High potential
50-500	Moderate potential
5-50	Low potential
0.5-5	Very low potential
<0.5	Negligible potential

Table 7: Standard for Transmissivity by Krasny (1993)

T(m^2/day)	Designation of Transmissivity	Groundwater supply potential
1000	Very high	Withdrawal of great regional importance
100	High	Withdrawal of lesser regional importance
10	Intermediate	Withdrawal for local water supply (small community's plants etc.)
1	Low	Small withdrawal for local water supply (Private consumption etc)
0.1	Very low	Withdrawal for local water supply with limited consumption
	Impermeable	Sources for local water supply are difficult if possible to ensure.

The hydraulic conductivity values are between $2.26x10^{-6}$m/s and $1.06x10^{-6}$m/s or 0.20 m/day and 0.09 m/day for the deep boreholes, while that of shallow boreholes have a range of $3.11x10^{-5}$ m/s and $3.42x10^{-7}$ m/s (2.69 m/day and 0.03 m/day) .

Table 8: Hydraulic conductivity of Crystalline rocks Domenico and Schwartz (1997)

Materials	**Hydraulic conductivity (m/sec)**
Permeable basalt	$4x10^{-7}$ to $2x10^{-2}$
Fractured igneous and metamorphic rock	$8x10^{-9}$ to $3x10^{-4}$
Weathered granite	$3.3x10^{-6}$ to $5.2x10^{-5}$
Weathered gabbro	$5.5x10^{-7}$ to $3.8x10^{-6}$
Basalt	$2x10^{-11}$ to $4.2x10^{-7}$
Unfractured igneous and metamorphic	$3x10^{-14}$ to $2x10^{-10}$

The specific capacity values in the study area ranges between $1.79x10^{-5}$ and $1.29x10^{-5}$ m^2 /s for deep boreholes. For shallow ones; it ranges between $7.96x10^{-4}$ m^2 /s and $1.34x10^{-5}$ m^2 /s.

4.5.1 Discussions of the Hydraulic Properties

Using the Gheorghe's classification in table 6, the Transmissivity values of the aquifers in the study area are within the low potentials. But using the classification by Krasny (1993) in Table 7, Transmissivity values of some of the aquifers have intermediate value e.g. BH13(Masallacin Lawal) and BH 14 (Ayagi), indicating low potentials of groundwater withdrawals for local water supply(small community's plants etc.), while some have low transmissivity; small withdrawal for local water supply (Private consumption).

Therefore, the high values of Transmissivity and hydraulic conductivity in some boreholes are associated with boreholes drilled within fracture zones, or with fractures connected to a river or stream. For example, BH 1-4 (deep boreholes) has high transmissivity of 4.62, 4.58, 5.20, and 4.87 m^2/day respectively. They could have deeper fractures connected to a major river or stream, because the areas they are located have a thin regolith, and regolith zone acts as a reservoir that slowly feeds the water from the surface into fractures of bedrock, but in this case good hydraulic interconnection could not be good enough to warrant movement of substantial quantity of water through the regolith into fractured bedrock. While BH 6, BH 13, BH 15 and probably BH 19 has transmissivity of 5.29, 8.04, 21.51, and 3.08 m^2/day respectively, and likely associated with boreholes drilled within fracture zones.

Low values of transmissivity and hydraulic conductivity are associated with boreholes drilled within clayey weathered aquifer, or crystalline rock with limited fractures.

Hydraulic conductivity based on aquifers material composition, when compared with Bouwers (1978) Standards for Hydraulic conductivity, and hydraulic conductivity of crystalline rocks by Domenico and Schwartz (1997) indicates that aquifers are derived from deep weathering and fracturing of the bedrock.

For Specific capacity, the time of pumping during the constant discharge phase of pump test was not enough to make meaningful conclusion. This is because, under normal circumstances, period of pump test should not be less than 24 hrs. In some pump test data used for this work; the time of pumping was not up to 3 hrs, therefore the duration was too short, and consequently the aquifer was not stressed sufficiently to know its actual specific capacity.

From analysis of transmissivity, hydraulic conductivity, and specific capacity, their values are small; because aquifers of the study area are believed to be much better than they were evaluated. However, low values of hydraulic conductivity compared to transmissivity values might be due to lack of interconnection between the fractures, or was affected by the depth of boreholes drilled and/or design.

4.6 Lineament Analysis and Groundwater Potential

Structural trends such as discontinuity can be detected in many forms, such as faults, joints, bedding planes or foliation (Mogaji et. al.,2011), and may be detected in the form of a lineament using remotely sensed data such as conventional aerial photographs and satellite imagery.

According to Anudu et. al., (2011) the commonest method used to calculate lineament density is based on the number of lineaments per unit area (number/km^2), or the total length of lineaments per unit area (km/km^2) or combining both.

The NW-SE is the major trend of lineaments in the area, as observed from Rose diagram of Fig.14. The zones of high lineaments density shown in (Fig. 15) could probably be feasible zones for groundwater prospecting in the study area.

To study the relationship between the deep groundwater productivity and lineament in the area; the positions of deep boreholes are plotted on superimposed lineament map (Fig. 16), and are located at northeastern part of the area, and by looking at the proximity of these boreholes to lineaments; it was evident that the deep boreholes may not be tapping the suspected deep seated fractures. Therefore, their exploitation potential is poor, signifying low potential.

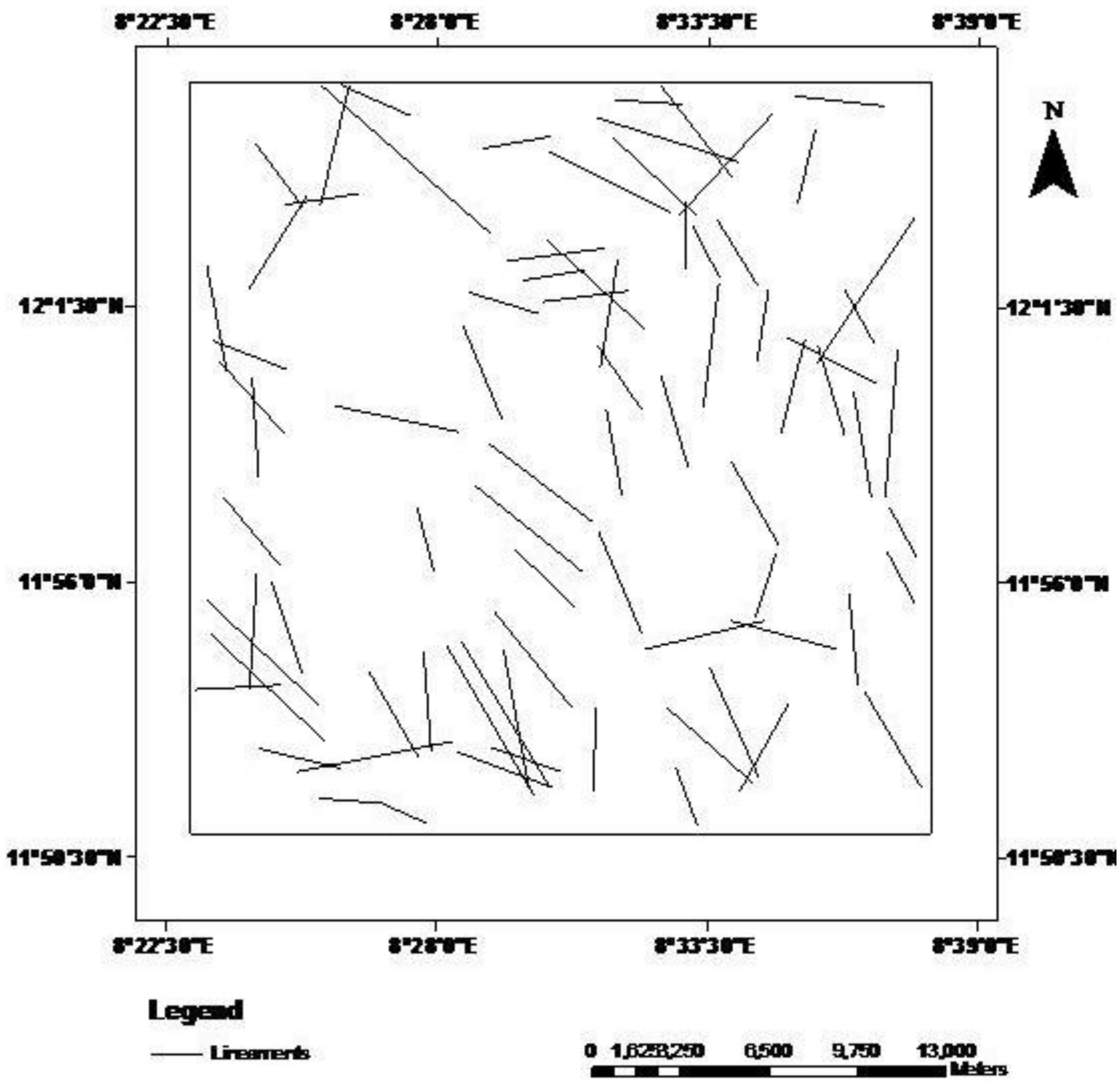

Fig. 13: Lineament Map of the Study Area

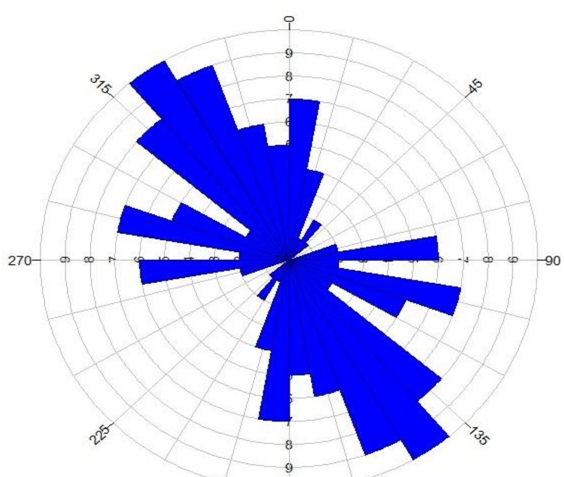

Fig. 14: Rose diagram (Azimuth-frequency) showing Lineaments trends in the Study Area

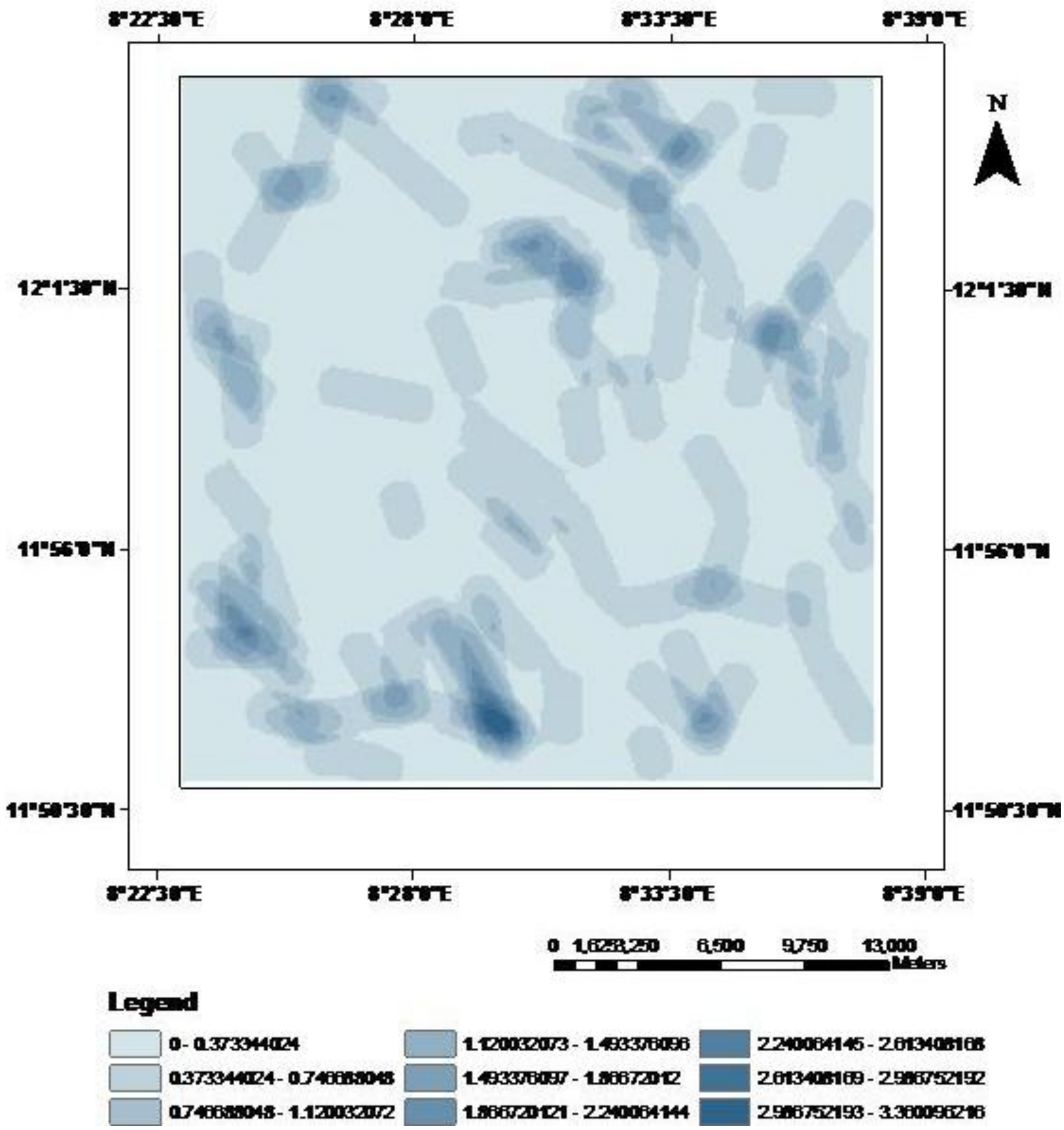

Fig. 15: Lineament density map of the study area

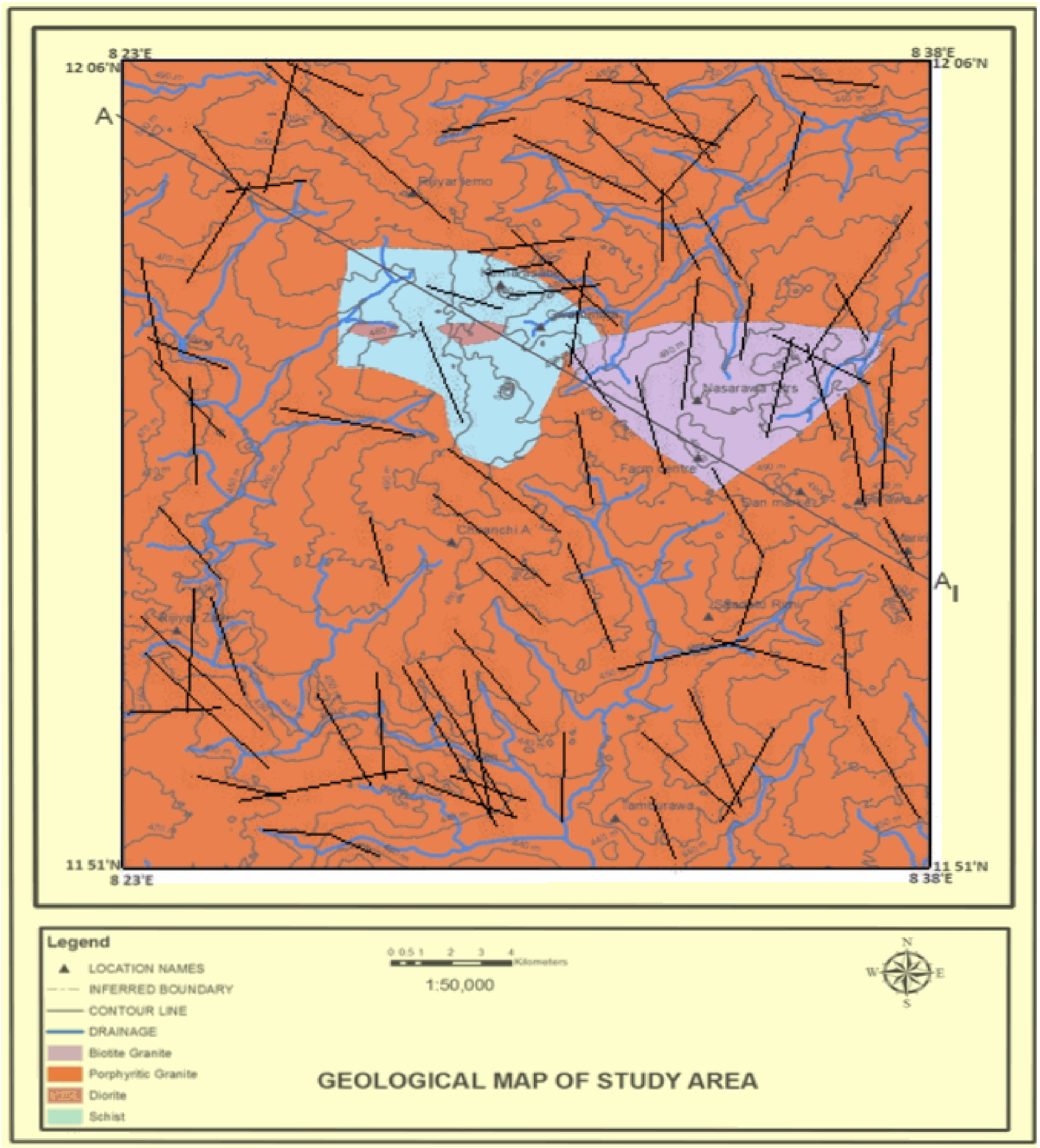

Fig. 16: Lineament Map superimposed on the Geological map of the Study Area

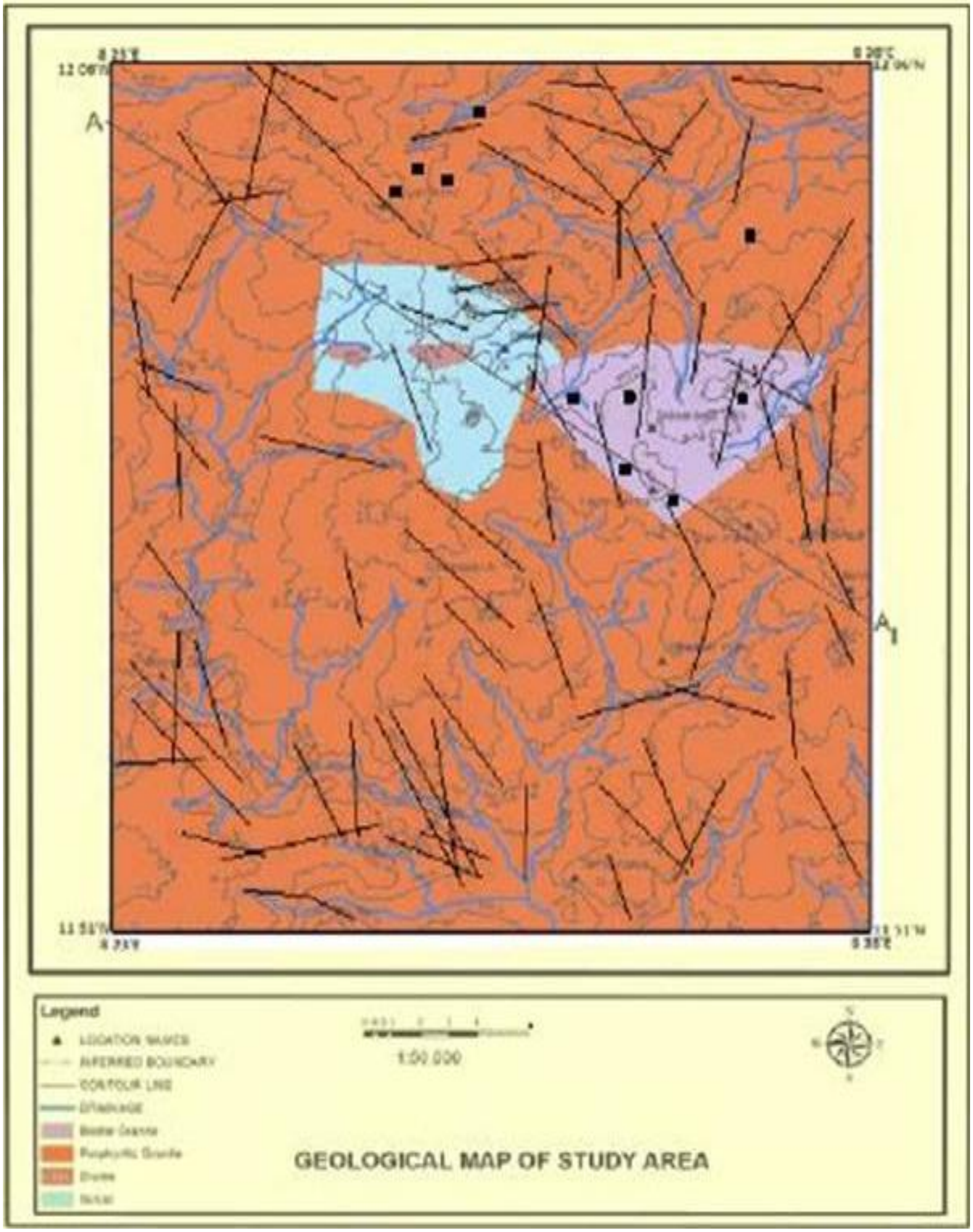

Fig. 17: Lineament map superimposed on geological map showing location of deep boreholes

4.7 Ground Water Chemistry

The goal of evaluating ground water quality is to determine if the resource meets the requirements for its many different uses. Ground water quality can be adversely affected or degraded as a result of human activities that introduce contaminants into the environment.

It can also be affected by natural processes that result in elevated concentrations of certain constituents in the groundwater. For example, despite that soil provides a protective “filter” or “barrier” that immobilized the downward migration of contaminants released on the land surface; elevated metal concentrations can result when metals are leached into the groundwater from minerals present in the earth

4.7.1 Physical Parameters

4.7.1.1 Conductivity

Conductivity is a numerical expression of the ability of an aqueous solution to carry an electric current, or a measure of how well water can pass an electrical current. It is an indirect measure of the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, iron and aluminum. This ability depends on the presence of ions, their total concentration, and mobility and on temperature of measurement. The term is reported in micromhos per cm (umhos/cm). In the SI units; the reciprocal of the ohm is the Siemens (S).

The electrical conductivity measured from the deep boreholes in the study area ranges from 140-1700 uS/cm, with an average of 550 uS/c m (Table 11). The range falls within the maximum permissible limit of the Nigerian Standards for Drinking Water; except two samples KN 5(A.M.Bindawa) and KN 9 (Brigade) that have values above maximum permissible limit. For shallow boreholes sampled, they ranges from 220-1320 uS/cm, with an average of 566 uS/c m, here one sample KN13 (Karkasara) is above the maximum permissible unit.

According to Schoeinich (2001), conductivity can be used as an index of salinity hazard in assessment of water quality for irrigation. When conductivity is less than 250 uS/cm, the water is excellent for irrigation, when it is 250-750 uS/cm, water is good for irrigation. Values from 750-2250 uS/cm is moderately good for irrigation. Many deep and shallow boreholes sampled, fall within category of excellent, and good for irrigation.

4.7.1.2 p^H

P^H is a measure of the acidity or alkalinity of water. p^H is expressed in a scale with ranges from 1 to 14. A solution with a p^H less than 7 has more H^+ activity than OH^-, and is considered acidic. A solution with a pH value greater than 7 has more OH^- activity than H^+, and is considered basic. The p^H scale is logarithmic, meaning that as you go up and down the scale, the values change in factors of ten. A one-point pH change indicates the strength of the acid or base has increased or decreased tenfold.

Changes in p^H can change the aspects of water chemistry. For example, as p^H decreases, the concentration of metal may increase because higher acidity increases their ability to be dissolved from rocks into the water. Water with a pH value less than 7 may dissolve metals to an extent which, if not causing deterioration of storage tanks or distribution mains, may give rise to undesirable metal concentrations. According to (WHO 2003 and 2011), the desirable limit for P^H of water for drinking and domestic use is 7.0-8.5, while the permissible limit 6.5-9.2. Most of the deep boreholes have P^H within the permissible limit, except KN 5(A.M. Bindawa), KN 8 (Gidan wanka), KN 9Brigade) and KN 10 (Alfurqan) with weakly acidic P^H . For shallow boreholes, only two (2) i.e. KN 13 Karkasara) and KN 14 (Gandun albasa) have a P^H within the permissible limit of WHO, the remaining eight (8) are weakly acidic, and therefore not within the permissible limit.

4.7.1.3 Temperature

Temperature is one of the most important chemical parameter of water. It is significant because it affects the amount of dissolved oxygen in the water. The amount of oxygen that will dissolve in water increases as temperature decreases. Water at 0^0C will hold up to 14.6 mg of oxygen per litre, while at 30^0C it will hold only up to 7.6 mg/L.

Most of the boreholes sampled have a temperature typical of ambient condition. However, four (4) deep boreholes shows a slightly high temperature; KN 2(Farm centre) (36.5^0C), KN 5 (A.M.Bindawa) (37.4^0C), KN 6 (FTZ Fanisau) (41^0C) and KN 7 (Nasiru Ahali) (37.4^0C). It could be due to their depth; 175m, 200m, 190m, and 180m respectively.

4.7.1.4 Total Dissolved Solids

The *total dissolved solids* (*TDS)*, includes ionised and non ionized matter, but only the former is reflected in the conductivity. Where TDS are high the water may be "saline" and the applicable parameter "Salinity”.

Total dissolved solids (TDS), is a measure of salinity that can have an important effect on the taste of drinking-water. The palatability of water with a TDS level of less than 600 mg/L is generally considered to be good; drinking water becomes significantly unpalatable at TDS levels greater than 1000 mg/L (Unicef, 2008).

The mineralisation (TDS) of groundwater in the boreholes sampled from the study area range from 70 mg/l to 960 mg/l with an average of 307 mg/l for deep boreholes. For shallow boreholes the TDS values range from 120 mg/l to 750 mg/l to with an average of 317 mg/l. Therefore, the water sampled from the boreholes within the study area are good for drinking, as they are within the maximum permissible limit.

Table 9: WHO 2003 and 2011 Standard Permissible Limit for Physical and Chemical Parameters of Water for Drinking and Domestic Use

Water Quality Standard	**Unit Measurement**	**2003 WHO STANDARD**		**2011 WHO Recommended Values**
		Desirable Limit	**Permissible Limit**	
Turbidity	NUT	< 5	< 25	
Colour	Pt/Co	< 5	< 50	
Hydrogen ion Potential, p^H	-	7.0-8.5	6.5-9.2	6.5-8.5
Hardness, Total	Mg/l $CaCO_3$	< 100	< 500	
Oxygen, O_2	Mg/l	>5	-	
Total Dissolve Solid, TDS	Mg/l	< 500	< 2000	

Table 10: physical / Organoleptic Parameters (NIS, 2007)

Parameter	Unite	Maximum permitted levels	Health impact	Note
Colour	TCU	15	None	
Odour	-	Unobjectionable	None	
Taste	-	Unobjectionable	None	
Temperature	^{o} Celsius	Ambient	None	
Turbidity	NTU	5	None	

Table 11: Physical parameters of the Boreholes from the Study Area (Source: Field Data, 2014)

Date of sampling: 17/04/2014

S/N	Location	Coordinates	Elevation (m)	Bh depth (m)	p^H	Temp. (^{0}C)	EC mS/(uS/cm)	TDS ppt/ (mg/l)	Sample ID
1	Fortia	11^{0}58′38″N 08^{0}33′01″E	493	148	6.56	33.8	0.59/590	0.34/340	KN 1
2	Farm Centre	11^{0}57′56″N 08^{0}34′51″E	492	175	7.25	36.5	0.17/170	0.09/ 90	KN 2
3	Capital Road	11^{0}51′40″N 08^{0}30′53″E		180	6.94	34	0.14/140	0.07/70	KN 3
4	Magwan	11^{0}51′40″N 08^{0}30′53″E	496	170	6.50	32.7	0.27/270	0.15/150	KN 4
5	A.M. Bindawa, R/lemo	12^{0}04′10″N 08^{0}28′06″E	492	200	5.75	37.4	1.04/1040	0.58/580	KN 5
6	FTZ, Fanisau	12^{0}04′31″N 08^{0}30′06″E	475	190	6.55	41	0.27/270	0.15/150	KN 6
7	Nasiru Ahali	12^{0}02′44″N 08^{0}28′49″E	493	180	7.45	37.4	0.21/210	0.11/110	KN 7
8	G/w R/lemo	12^{0}02′31″N 08^{0}29′02″E	491	160	5.89	33.1	0.24/240	0.13/130	KN 8
9	Brigade	12^{0}03′05″N 08^{0}34′31″E	459	170	5.90	33.1	1.70/1700	0.96/960	KN 9
10	Al-furqan	11^{0}50′35″N 08^{0}29′51″E		130	6.20	33.4	0.87/870	0.49/490	KN 10
11	Filin cashew	11^{0}57′38″N 08^{0}34′02″E	442	36	5.87	30.9	0.76/760	0.42/420	KN 11
12	Naibawa	11^{0}55′39″N 08^{0}33′06″E	475	27	6.13	31.9	0.31/310	0.17/170	KN 12
13	Karkasara	11^{0}57′02″N 08^{0}32′52″E	470	32	6.80	31	1.32/1320	0.75/750	KN 13
14	Gandun Albasa	11^{0}58′33″N 08^{0}31′02″E	484	36	7.02	30.8	0.59/590	0.33/330	KN 14
15	Kabuga	11^{0}58′59″N 08^{0}28′37″E	467	40	5.93	31.3	0.66/660	0.37/370	KN 15
16	Goron Dutse	12^{0}00′18″N 08^{0}29′51″E	493	50	5.72	34.3	0.44/440	0.25/250	KN 16
17	Dakata	12^{0}01′41″N 08^{0}34′26″E	473	56	5.79	31.9	0.34/340	0.19/190	KN 17
18	Yankaba	12^{0}00′04″N 08^{0}35′09″E	475	55	6.11	33.9	0.53/530	0.30/300	KN 18
19	GGSS Mariri	11^{0}56′53″N 08^{0}36′48″E	483	36	5.95	32.7	0.22/220	0.12/120	KN 19
20	NNPC Hotoro	11^{0}57′49″N 08^{0}34′43″E	486	34	5.91	31.1	0.49/490	0.27/270	KN 20

4.7.2 Chemical Parameters

4.7.2.1 Cations

Potassium

It can occur naturally in minerals and from soils. High levels in surface water, especially in areas where there are agricultural activities as indicative of introduction of Potassium due to application of fertilisers. The concentration of Potassium in groundwater in the study area ranges from 1.3 mg/l to 46 mg/l with an average of 12.835 mg/l. Most of the samples analysed are within the maximum permissible limit (15 mg/l) in respect to the WHO (2004) standard. However, some samples have a concentration above the maximum permissible limit. For deep borehole; KN5 (A.M.Bindawa) (18 mg/l), KN6 (FTZ Fanisau) (19mg/l), and KN9 (Brigade) (16mg/l). For shallow borehole; KN11 (Filin cashew) (20mg/l), KN15 (Kabuga) (28mg/l), KN16 (Goron dutse) (46mg/l), and KN19 (GGSS Mariri) (18mg/l).

Copper

Copper in a drinking-water supply usually arises from the corrosive action of water on copper pipes. High concentrations can interfere with the intended domestic uses of the water. Copper in drinking-water may increase the corrosion of galvanized iron and steel fittings. Staining of laundry and sanitary ware occurs at copper concentrations above 1 mg/litre. At levels above 5 mg/litre, copper also imparts a colour and an undesirable bitter taste to water. Although copper can give rise to taste, it should be acceptable at the health-based guideline value. In the study area, the concentration of Cupper ranges from -0.005mg/l to 0.051mg/l with an average of 0.00615 mg/l. The highest value of 0.051 mg/l is not above the maximum permissible limit of WHO 2003 and 2005 with permissible limits of <0.05mg/l and 0.1mg/l respectively. This makes the water suitable for human consumptions. However, according to Nigerian Standards (NIS

2007), if the concentration of Cupper is above maximum permissible limit (1 mg/l); gastro-intestinal disorder results as the health hazard.

Iron

Iron is one of the most abundant metals in the Earth's crust. It is found in natural fresh waters at levels ranging from 0.5 to 50 mg/litre (WHO, 2004). Anaerobic groundwater may contain ferrous iron at concentrations of up to several milligrams per litre, without discoloration or turbidity in the water when directly pumped from a well. On exposure to the atmosphere, however, the ferrous iron oxidizes to ferric iron, giving an objectionable reddish-brown colour to the water. At levels above 0.3 mg/litre, iron stains laundry and plumbing fixtures. There is usually no noticeable taste at iron concentrations below 0.3 mg/litre, although turbidity and colour may develop. Iron concentration in the study area ranges from 0.014 mg/l to 4.697 mg/l with an average of 0.2971 mg/l. Comparing the values obtained from the water analysis with the standards (WHO and SON in Appendix I) shows that, only one sample i.e. KN4 (Magwan) 4.697mg/l have concentration above the maximum permissible limits (0.3 mg/l) of those Standards. Low iron concentration in the boreholes of the study area could be due to instability of the Iron.

Manganese

At levels exceeding 0.5 mg/litre, manganese in water supplies causes an undesirable taste and stains sanitary ware and laundry(WHO, 2003). The presence of manganese in drinking-water, like that of iron, may lead to the accumulation of deposits in the distribution system. Concentrations below 0.1 mg/litre are usually acceptable to consumers.

Even at a concentration of 0.2 mg/litre, manganese will often form a coating on pipes, which may slough off as a black precipitate. White clothes turn yellowish when washed in water containing manganese. The water analysis carried out indicates a concentration of Manganese in groundwater of the study area to range from 0.007 mg/l to 0.321mg/l with an average of 0.02485 mg/l, even though only four (4) samples detected Manganese. These are KN4 (Magwan) 0.321mg/l, KN5 (A.A. Bindawa) 0.038mg/l, KN9 (Brigade) 0.131 mg/l and KN13 (Karkasara) 0.007 mg/l. They are below the maximum permissible limits of WHO 2003 and 2005 (<0.5mg/l and 0.5 mg/l) respectively. However, NIS 2007 indicates that any concentration above their maximum permissible limit of 0.2mg/l could lead to neurological disorder. Therefore, KN4 (Magwan) is considered unsuitable for drinking.

Zinc

Zinc is an essential trace element found in virtually all food and potable water in the form of salts or organic complexes. It gives an undesirable taste to water at a taste threshold concentration of about 4 mg/litre (as zinc sulfate). Water containing zinc at concentrations in excess of 3–5 mg/litre may appear opalescent and develop a greasy film on boiling. Drinking-water seldom contains zinc at concentrations above 0.1 mg/litre. The concentration of zinc in groundwater of the study area ranges from 0.0003 mg/l to 19.2001 mg/l with an average of 0.989 mg/l. The permissible limits of WHO 2003 and 2005 are <5.0mg/l and 5mg/l respectively. The maximum permissible limits of WHO 2005 and SON 2007 are; 5mg/l and 3mg/l respectively. In addition to that, SON 2007 did not reported any health hazard associated with concentration of >3mg/l. However, only one sample KN4 (Magwan) 19.2005mg/l have a concentration above the maximum permissible limit.

Cadmium

Cadmium is released to the environment in wastewater and diffuse pollution is caused by contamination from fertilizers and local air pollution. The concentration of cadmium in the study area ranges from 0.001 mg/l to 0.011mg/l with an average of 0.0054 mg/l. All the samples analysed are within the desirable limit of 0.01mg/l. But NIS 2007 reported that concentration above a maximum permissible limit of 0.003 could be toxic to kidney.

Chromium

Chromium is a trace metal that is widely distributed in the Earth's crust. The 2003 WHO *International Standards for Drinking-water recommended* a maximum allowable concentration of 0.05 mg/litre for chromium (hexavalent). The guideline value was first proposed in 1958 for hexavalent chromium, based on health concerns, but was later changed to a guideline for total chromium because of difficulties in analyzing for the hexavalent form only. The concentration of chromium in groundwater of the study area ranges from 0.025 mg/l to 0.122 mg/l with an average of 0.0418mg/l. The following deep boreholes samples are above the maximum permissible limit (0.05mg/l) of WHO (2003 and 2011); KN 7 (Nasiru Ahali) 0.072 mg/l, KN 8 (Gidan wanka) 0.079 mg/l KN 10 (Al furqan) 0.062 mg/l. For shallow borehole, 1 sample is above maximum permissible limit; KN 13 (Karkasara) 0.091 mg/l. NIS 2007 maintained the same value of 0.05mg/l, and added that, concentration above that could lead to cancer.

Hardness (calcium and magnesium)

Hardness is the sum of polyvalent metallic ions in water. Calcium and magnesium are the principal components, and hard waters are most common in groundwater, especially when derived from limestone, dolomite or chalk aquifers.

Hardness is expressed in terms of milligrams of calcium carbonate equivalents per litre.

A general hardness scale is (mg/L $CaCO_3$);

soft (0-60), moderately hard (61-120), hard (121-180), very hard (> 180).

Hard water can be unacceptable to consumers. Hard water requires more soap to produce lather, and can form scale deposits on pipes, basins, pots and hot water heaters (scale formation increases at higher temperatures). In contrast, soft water can lead to corrosion of metal pipes and elevated levels of heavy metals such as cadmium, copper, lead and zinc in drinking water. The taste threshold for the calcium ion is in the range of 100–300 mg/L and the taste threshold for magnesium is probably lower. In some instances, consumers tolerate water hardness in excess of 500 mg/L. Soft water may also have a salty taste.

The concentration of calcium in groundwater in the study area ranges from 2.868mg/l to 212.911mg/l with an average of 38.914 mg/l. All the samples have values below the maximum permissible limits of 200 mg/l of both International Standards for Drinking Water (WHO, 2004 ,2005 and 2011) , as well as Nigerian Standards for Drinking Water (SON 2007) as shown in Appendix I. The only exception is KN9 (Brigade) with 212.911 mg/l.

The concentration of Magnesium ranges from 0.864 mg/l to 19.972 mg/l with an average of 6.818 mg/l. Even the highest concentration at KN10 (19.972 mg/l) is below the recommended and maximum permissible limits of International Standards of WHO (2003, 2004, 2005 and 2011) and Nigerian Standards (SON 2007); with >125mg/l, 39 mg/l and 150 mg/l, 50mg/l and 150 mg/l, 50mg/l, 39 and 150 mg/l respectively.

Lead

Lead is rarely present in water as a result of its dissolution from natural sources; rather, its presence is primarily from household plumbing systems containing lead in pipes, solder, fittings or the service connections to homes. The amount of lead dissolved from the plumbing system depends on several factors, including; pH, temperature, and hardness and standing time of the water, with soft, acidic water being the most plumbosolvent. Lead is a toxicant that accumulates in the skeleton. Infants, children up to 6 years of age and pregnant women are most susceptible to its adverse health effects. Lead is toxic to both the central and peripheral nervous systems, inducing neurological and behavioural effects.

The 2011 WHO *International Standards for Drinking-water* recommended a maximum allowable concentration of 0.01 mg/litre for lead, based on health concerns. The concentration of Lead in groundwater of the study area ranges from 0.07 mg/l to 0.18 mg/l with an average of 0.105 mg/l. All the boreholes samples analysed are above the maximum permissible limit of 0.01; certainly the source could not be plumbing fixtures.

Nickel

The concentration of nickel in drinking-water is normally less than 0.02 mg/litre, although nickel released from taps and fittings may contribute up to 1 mg/litre. In special cases of release from natural or industrial nickel deposits in the ground, the nickel concentrations in drinking-water may be even higher. The concentration of nickel in the area ranges from 0.001 mg/l to 0.035 mg/l with an average of 0.011 mg/l. Most of the samples analysed have shown nickel concentration below the maximum permissible limit (0.02 mg/l) of NIS 2007. The only exceptions are four samples of shallow boreholes; KN13 (Karkasara) 0.022mg/l, KN15 (Kabuga) 0.021, KN18 (Yankaba) 0.035mg/l and KN19 (Mariri) 0.022mg/l. NIS 2007 indicates that concentration above maximum permissible limit of 0.02mg/l may lead to possible carcinogenic effect.

Sodium

Sodium salts (e.g., sodium chloride) are found in drinking-water. Although concentrations of sodium in potable water are typically less than 20 mg/litre, they can greatly exceed this in some localities. Concentrations in excess of 200 mg/litre may give rise to unacceptable taste. The water analysis indicates a sodium concentration in groundwater of the study area to range from 6.6 mg/l to 126 mg/l with an average of 34.53 mg/l. The samples have values which are far below those of the Drinking Water Standards (WHO 2003 and 2004), as well as Nigerian Standards for Drinking Water (SON 2007), with recommended and maximum permissible limits of 150 mg/l and 200 mg/l respectively (Appendix I).

4.7.2.2 Anions

Bicarbonate (HCO^{-2}_3)

Bicarbonate usually originate or have its sources from atmospheric carbon dioxide dissolved by rain water and carbon dioxide present in the humus soil, absorbed by water during percolation. The concentration of bicarbonate ranges from 0.6 mg/l to 6.8 mg/l with an average of 1.9mg/l. All the water samples analysed have bicarbonate concentration far below the recommended limit of WHO (2004) and maximum permissible limit of WHO (2005) put at 500 mg/l and 200mg/l respectively.

Sulphate (SO_4)

The source of sulphate in water is decaying organic matter through hydrogen sulphide. Sulphate is an indicator of organic pollution in water especially in shallow aquifers and hand dug wells. The concentration of sulphate in groundwater of the study area ranges from 12.2mg/l to 60 mg/l with an average of 22.9 mg/l. Even the highest concentration at KN13 (Karkasara) 60mg/l, is below the recommended limits (<200 mg/l, 150 mg/l, 200 mg/l, 250 mg/l, 100mg/l and 100mg/l) of WHO (2003, 2004, 2005 &2011), SON 2007 and NIS 2007 standards for drinking water, respectively.

Carbonate (CO_3)

It occur in water occasionally; even in the study area in very few (precisely 3 out of 20 samples), in concentration from 0.00 mg/l to 0.04 mg/l with an average of 0.04 mg/l.

Nitrate and nitrite

Nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle. Nitrate is used mainly in inorganic fertilizers, and sodium nitrite is used as a food preservative, especially in cured meats. The nitrate concentration in groundwater and surface water is normally low but can reach high levels as a result of leaching or runoff from agricultural land or contamination from human or animal wastes as a consequence of the oxidation of ammonia and similar sources. Anaerobic conditions may result in the formation and persistence of nitrite. The formation of nitrite is as a consequence of microbial activity and may be intermittent. Nitrification in distribution systems can increase nitrite levels, usually by 0.2–1.5 mg/litre. The concentration of Nitrate ranges from 7.4 mg/l to 49.4mg/l with an average of 15.635 mg/l. Most of the samples are below the maximum permissible limits of WHO 2003, 2004, 2005 and SON & NIS 2007 (<45 mg/l, 45 mg/l, 100mg/l, 50 mg/l, 50mg/l respectively. However, only one sample shallow borehole sample i.e. KN13 (Karkasara) 49.4 mg/l have concentration higher than the maximum permissible limits of WHO 2004 and 2005. The primary health concern regarding nitrate and nitrite is the formation of methaemoglobinaemia, so-called "blue-baby syndrome." Nitrate is reduced to nitrite in the stomach of infants, and nitrite is able to oxidize haemoglobin (Hb) to methaemoglobin (metHb), which is unable to transport oxygen around the body. Generally the water is suitable for drinking and other domestic uses.

Chloride

High concentrations of chloride give a salty taste to water. Taste thresholds for the chloride anion depend on the associated cation, and are in the range of 200–300 mg/litre for sodium, potassium and calcium chloride. Concentrations in excess of 250 mg/litre are increasingly likely to be detected by taste. The concentration of chloride in groundwater of the study area ranges from 0.00 mg/l to 0.04 mg/l with an average of 0.0155 mg/l. The concentration is far below the WHO 2004, 2005 and 2011, as well as SON and NIS 2007 recommended limits of 250 mg/l. This indicates the water in the area to be suitable for drinking and other domestic uses. The chloride content or concentration shows that the water samples analysed are of meteoric in origin.

Table 12: Results of Water Quality Analyses (Cations)

S/N	Sample ID	Location	Coordinates	Depth (m)	Ca^{+} mg/l	Na^{+} mg/l	K^{+} mg/l	Fe^{3+} mg/l	Mg^{2+} mg/l	Cu^{2+} mg/l	Zn^{2+} mg/l	Cr mg/l	Ni mg/l	Cd mg/l	Mn^{+} mg/l	Pb mg/l
1	KN 1	Fortia	11°58′38″N 08°33′01″E	148	30.978	42	4.2	**0.178**	7.855	0.003	**0.0997**	0.000	0.009	**0.004**	0.000	**0.133**
2	KN 2	Farm Centre	11°57′56″N 08°34′51″E	175	9.511	13	5.4	**0.238**	2.565	-0.005	**0.0725**	0.000	0.006	0.001	0.000	**0.094**
3	KN 3	Capital Road	11°51′40″N 08°30′53″E	180	8.969	6.6	4.4	**0.151**	2.659	0.000	**0.0924**	0.028	0.012	0.001	0.000	**0.093**
4	KN 4	Magwan	11°51′40″N 08°30′53″E	170	14.918	20	3.2	**4.697**	2.706	0.006	**19.2005**	0.025	0.005	**0.004**	0.321	**0.180**
5	KN 5	A.M. Bindawa	12°04′10″N 08°28′06″E	200	**106.964**	38	**18**	0.074	11.240	0.007	0.0128	0.000	0.002	**0.005**	0.038	**0.137**
6	KN 6	FTZ, Fanisau	12°04′31″N 08°30′06″E	190	9.670	14	**19**	0.116	3.170	0.008	**0.0326**	0.036	0.006	**0.004**	0.000	**0.103**
7	KN 7	Nasiru Ahali	12°02′44″N 08°28′49″E	180	4.545	12	7.4	0.055	3.048	0.005	0.0003	**0.072**	0.011	**0.004**	0.000	**0.110**
8	KN 8	G/w, R/lemo	12°02′31″N 08°29′02″E	160	6.041	15	8.5	0.080	3.629	0.008	0.0000	**0.079**	0.0000	**0.005**	0.000	**0.097**
9	KN 9	Brigade	12°03′05″N 08°34′31″E	170	**212.911**	**78**	**16**	0.024	18.376	0.012	0.0673	0.031	0.001	**0.004**	0.131	**0.089**
10	KN 10	Al-furqan	11°50′35″N 08°29′51″E	130	91.726	43	6.0	0.035	19.972	0.005	0.0103	**0.062**	0.000	**0.006**	0.000	**0.123**
11	KN 11	Filin cashew	11°57′38″N 08°34′02″E	36	47.634	40	20	0.032	9.042	0.000	0.0206	0.047	0.012	**0.007**	0.000	**0.104**
12	KN 12	Naibawa	11°55′39″N 08°33′06″E	27	9.168	24	14	0.031	3.688	0.009	0.0261	0.063	0.011	**0.006**	0.000	**0.116**
13	KN 13	Karkasara	11°57′02″N 08°32′52″E	32	87.898	126	1.3	0.028	14.356	0.000	0.0199	**0.091**	**0.022**	**0.007**	0.007	**0.112**
14	KN 14	Gandun Albasa	11°58′33″N 08°31′02″E	36	27.170	44	7.6	0.036	7.004	0.009	0.0072	0.027	0.003	**0.005**	0.000	**0.121**
15	KN 15	Kabuga	11°58′59″N 08°28′37″E	40	31.647	53	**28**	0.061	6.016	0.051	0.0286	0.000	0.021	**0.005**	0.000	**0.092**
16	KN 16	Goron Dutse	12°00′18″N 08°29′51″E	50	12.256	24	**46**	0.015	4.819	0.000	0.0239	0.044	0.012	**0.007**	0.000	**0.078**
17	KN 17	Dakata	12°01′41″N 08°34′26″E	56	9.524	25	14	0.036	2.910	0.000	0.0082	0.000	0.006	**0.005**	0.000	**0.070**
18	KN 18	Yankaba	12°00′04″N 08°35′09″E	55	31.946	20	7.2	0.016	6.698	0.005	0.0324	0.000	**0.035**	**0.008**	0.000	**0.089**
19	KN 19	GGSS Mariri	11°56′53″N 08°36′48″E	36	2.868	26	18	0.025	0.864	0.000	0.0111	0.122	**0.022**	**0.009**	0.000	**0.091**
20	KN 20	NNPC Hotoro	11°57′49″N 08°34′43″E	34	21.937	27	8.5	0.014	5.738	0.000	0.0126	0.109	0.019	0.011	0.000	**0.073**

WHO std. mg/l	100	50	15	0.1	50	2.0	0.01	0.05	0.02	0.003	0.4	0.01

Table 13: Results of Water quality analyses of deep borehole's samples in the Study Area (Anions)

S/N	Sample ID	Location	Coordinates	Depth (m)	HCO_3^{2-} mg/l	SO_4^{2-} mg/l	NO_3^- mg/l	CO_3^- mg/l	Cl^- mg/l
1	KN 1	Fortia	$11^0$58′38″N $08^0$33′01″E	148	1.0	20.5	11.0	0.00	0.02
2	KN 2	Farm Centre	$11^0$57′56″N $08^0$34′51″E	175	1.2	21.2	12.3	0.00	0.02
3	KN 3	Capital Road	$11^0$51′40″N $08^0$30′53″E	180	0.6	18.5	10.7	0.00	0.00
4	KN 4	Magwan	$11^0$51′40″N $08^0$30′53″E	170	1.5	22.4	13.2	0.2	0.04
5	KN 5	A.M. Bindawa	$12^0$04′10″N $08^0$28′06″E	200	2.1	20.5	10.2	0.4	0.02
6	KN 6	FTZ, Fanisau	$12^0$04′31″N $08^0$30′06″E	190	3.2	18.2	12.6	0.00	0.04
7	KN 7	Nasiru Ahali	$12^0$02′44″N $08^0$28′49″E	180	2.5	22.5	18.3	0.00	0.03
8	KN 8	G/w R/lemo	$12^0$02′31″N $08^0$29′02″E	160	1.7	30.5	26.2	0.00	0.00
9	KN 9	Brigade Mkt	$12^0$03′05″N $08^0$34′31″E	170	2.6	19.5	16.8	0.00	0.02
10	KN 10	Al-furqan	$11^0$50′35″N $08^0$29′51″E	130	3.5	20.2	14.3	0.00	0.00
11	KN 11	Filin cashew	$11^0$57′38″N $08^0$34′02″E	36	1.2	15.0	9.8	0.00	0.00
12	KN 12	Naibawa	$11^0$55′39″N $08^0$33′06″E	27	0.9	15.5	11.8	0.00	0.00
13	KN 13	Karkasara	$11^0$57′02″N $08^0$32′52″E	32	0.9	60.0	**49.4**	0.00	0.00
14	KN 14	Gandun Albasa	$11^0$58′33″N $08^0$31′02″E	36	6.8	19.5	16.6	0.00	0.02
15	KN 15	Kabuga	$11^0$58′59″N $08^0$28′37″E	40	2.2	12.2	7.4	0.00	0.00
16	KN 16	Goron Dutse	$12^0$00′18″N $08^0$29′51″E	50	1.4	20.4	11.8	0.00	0.03
17	KN 17	Dakata	$12^0$01′41″N $08^0$34′26″E	56	1.0	20.2	11.9	0.00	0.00
18	KN 18	Yankaba	$12^0$00′04″N $08^0$35′09″E	55	1.3	21.5	14.5	0.00	0.00
19	KN 19	GGSS Mariri	$11^0$56′53″N $08^0$36′48″E	36	1.2	25.0	18.6	0.00	0.04
20	KN 20	NNPC Hotoro	$11^0$57′49″N $08^0$34′43″E	34	1.2	20.5	15.3	0.2	0.03
				WHO std.	100	250	45		250

4.9.3 Discussion of Groundwater Chemistry

The high concentrations of some metals could be due to weathering of rocks in the area. High concentrations of Pb and Cd may results from discharge of wastes from industries. The analysis of eleven (11) groundwater samples from the area by Iliyasu (2014), indicates a concentration above permissible limits of heavy metals (As, Cr, Pb, U, Co, Ni, Mn, and V) in at least five (5) samples. He attributed it to discharge of wastes from industries into Kano and Challawa Rivers. The low values of Cl ion from the study area could be due to the indirect method of analysis used for Cl^- during the analysis. According to Fetter (2001), indirect method of analysis tends to produce low values of mineralization. Direct method does not includes pre-dilution of the samples, while in indirect method samples are diluted before analysis, which sometimes interfere with the results. The water types are shown in table 18 and 19 below:-

Table 14: Water types (facies) of Boreholes in the Study Area

S/N	Sample ID	Location	Coordinates	Water type
1.	KN1	Fortia	$11^0$58′38″N $08^0$33′01″E	Na-Ca-Mg- SO_4
2.	KN2	Farm Centre	$11^0$57′56″N $08^0$34′51″E	Na-Ca-Mg-SO_4
3.	KN3	Capital Road	$11^0$51′40″N $08^0$30′53″E	Na-Ca-K-SO_4
4.	KN4	Magwan	$12^0$04′10″N $08^0$28′06″E	Na-Ca-SO_4
5.	KN5	A.M. Bindawa, R/lemo	$12^0$04′31″N $08^0$30′06″E	Ca-Na-Mg- SO_4
6.	KN6	FTZ, Fanisau	$12^0$02′44″N $08^0$28′49″E	Na-Ca-Mg-SO_4
7.	KN7	Nasiru Ahali	$12^0$02′31″N $08^0$29′02″E	Ca-Na-SO_4
8.	KN8	Gidan wanka, R/lemo	$12^0$03′05″N $08^0$34′31″E	Na-Ca-Mg-SO_4
9.	KN9	Brigade Mkt	$11^0$57′38″N	Ca-Na-

			$08^0 34'02''$E	
10.	KN10	Al-furqan, Aliyu avenue	$11^0 50'35''$N $08^0 29'51''$E	Ca-Na-Mg- SO_4
11.	KN11	Filin cashew	$11^0 55'39''$N $08^0 33'06''$E	Ca-Na-Mg- SO_4
12.	KN12	Naibawa	$11^0 57'02''$N $08^0 32'52''$E	Na-Ca-K-Mg-SO_4
13.	KN13	Karkasara	$11^0 58'33''$N $08^0 31'02''$E	Na-Ca
14.	KN14	Gandun Albasa	$11^0 58'59''$N $08^0 28'37''$E	Na-Ca-Mg SO_4
15.	KN15	Kabuga	$12^0 00'18''$N $08^0 29'51''$E	Na-Ca-K SO_4
16.	KN16	Goron Dutse	$12^0 01'41''$N $08^0 34'26''$E	K-Na-Ca-Mg-SO_4
17.	KN17	Dakata	$12^0 00'04''$N $08^0 35'09''$E	Na-Ca-K-SO_4
18.	KN18	Yankaba	$11^0 56'53''$N $08^0 36'48''$E	Ca-Na-Mg-SO_4
19.	KN19	GGSS Mariri	$11^0 57'49''$N $08^0 34'43''$E	Ca-Na-K-SO_4
20.	KN20	NNPC Hotoro	$11^0 57'56''$N $08^0 34'51''$E	Na-Ca-Mg-SO_4

To determine the variation in the groundwater chemistry based on the lithology of the area where the boreholes were sampled; three groups of water facies were identified. Each member in a group is similar to each other, but distinct from other groups. Water types are used to understand the controlling factors of the water Chemistry. The water types in the area are as follows:-

1. Na-Ca-Mg-SO_4 (Biotite granite)
2. Ca-Na-Mg-SO_4 (Porphyritic granite)
3. K-Na-Ca-Mg-SO_4 (Schist)

The three (3) groups shown above represent trends between the water facies observed in the study area. For deep boreholes, two (2) groups were observed, i.e. group 1 and 2, while groups 2 and 3 are for shallow boreholes.

Group 1 is characterized by enrichment in Na and Ca. The Na is believed to have been released into the water by weathering of plagioclase feldspars. Group 2 is rich in Ca and Na. The rock type is affected by intense weathering and fracturing, hence groundwater is actively being mixed. Group 3 is distinguished by higher K. It could be released by weathering of orthoclase and microcline feldspars. The change in water chemistry in the study area is as a result of increasing rock-water interactions along hydrological flow paths.

Piper Plot

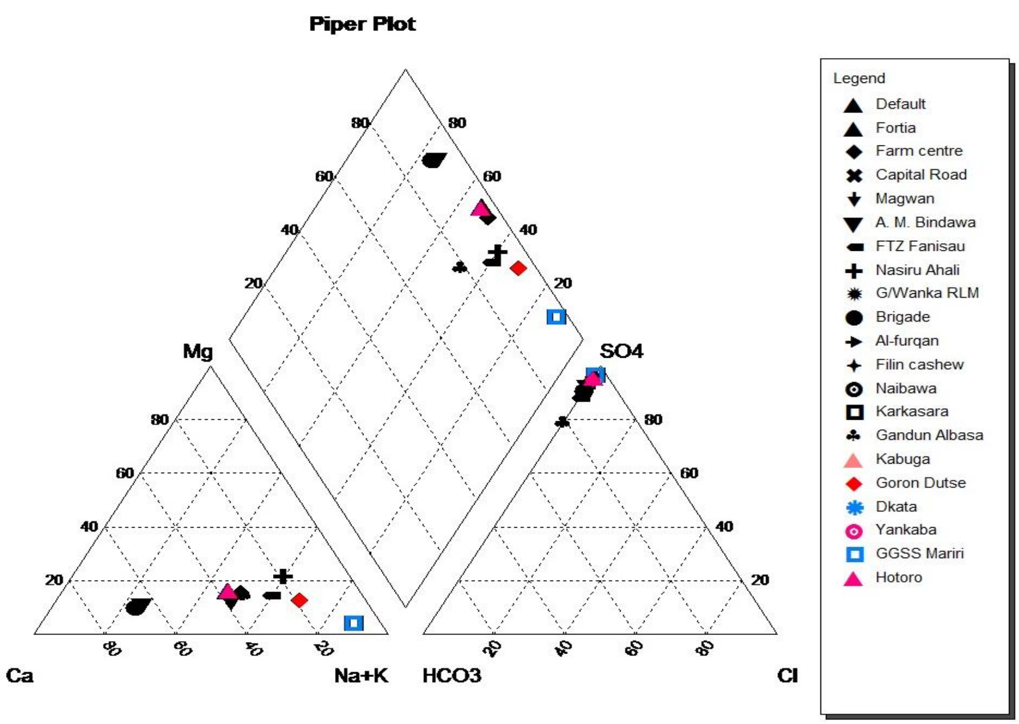

Figure 18: Piper Trilinear Plot showing different water facies in the study area.

In the above plot, trends in major ions were observed; major cations are Na, and Ca, while the major anions are SO4, and HCO3. All the seven stations of the twenty samples analysed fit into the Piper diagram.

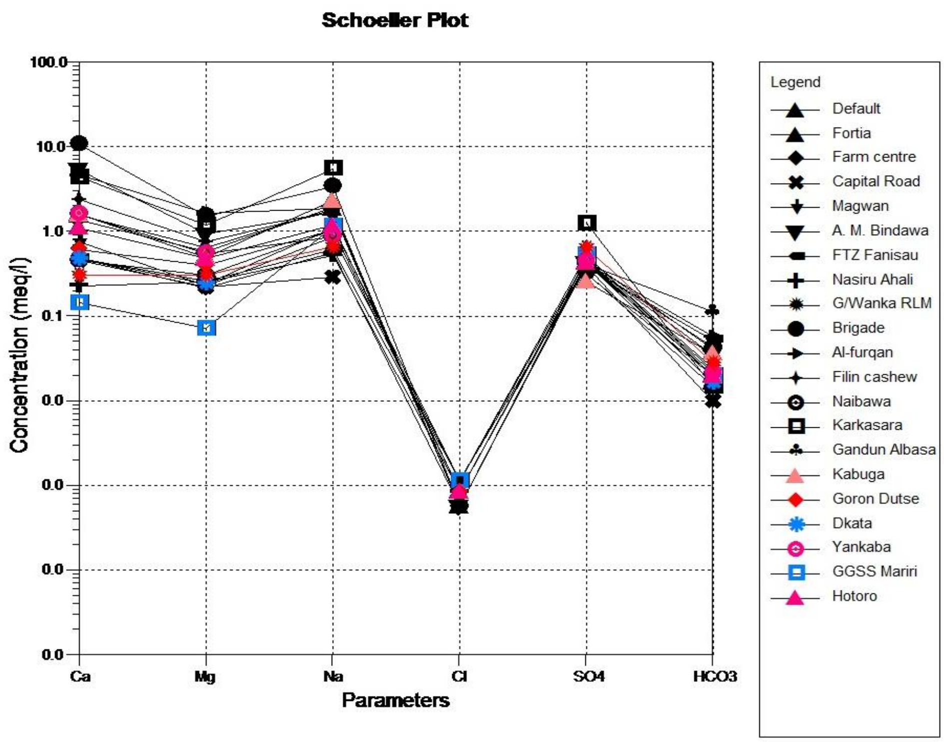

Figure 19: Schoeller plot showing concentration of major ions in the study area.

The above plot displays actual concentrations of the major cations and anions analysed. From the plot, Ca has the highest concentration ranging from < 10 mg/l to about 300 mg/l. Mg ranges from <1 mg/l to about 20 mg/l. Na has a concentration from about 10 mg/l to over 100 mg/l. SO_4 concentration ranges from 10 mg/l to about 100 mg/l. HCO_3 have concentration from <1 mg/l to about 10 mg/l. The ion with least concentration is Cl with < 1mg/l.

Wilcox Plot

A Wilcox plot can be used to quickly determine the viability of water for irrigation purposes. The Wilcox plot has the following sections:

Conductivity (us/cm)

C1: Low (0-249) (Excellent for irrigation);

C2: Medium (250-749) (Good for irrigation);

C3: High (750-2249) (Moderately good for irrigation); and

C4: Very High (2250-5000).

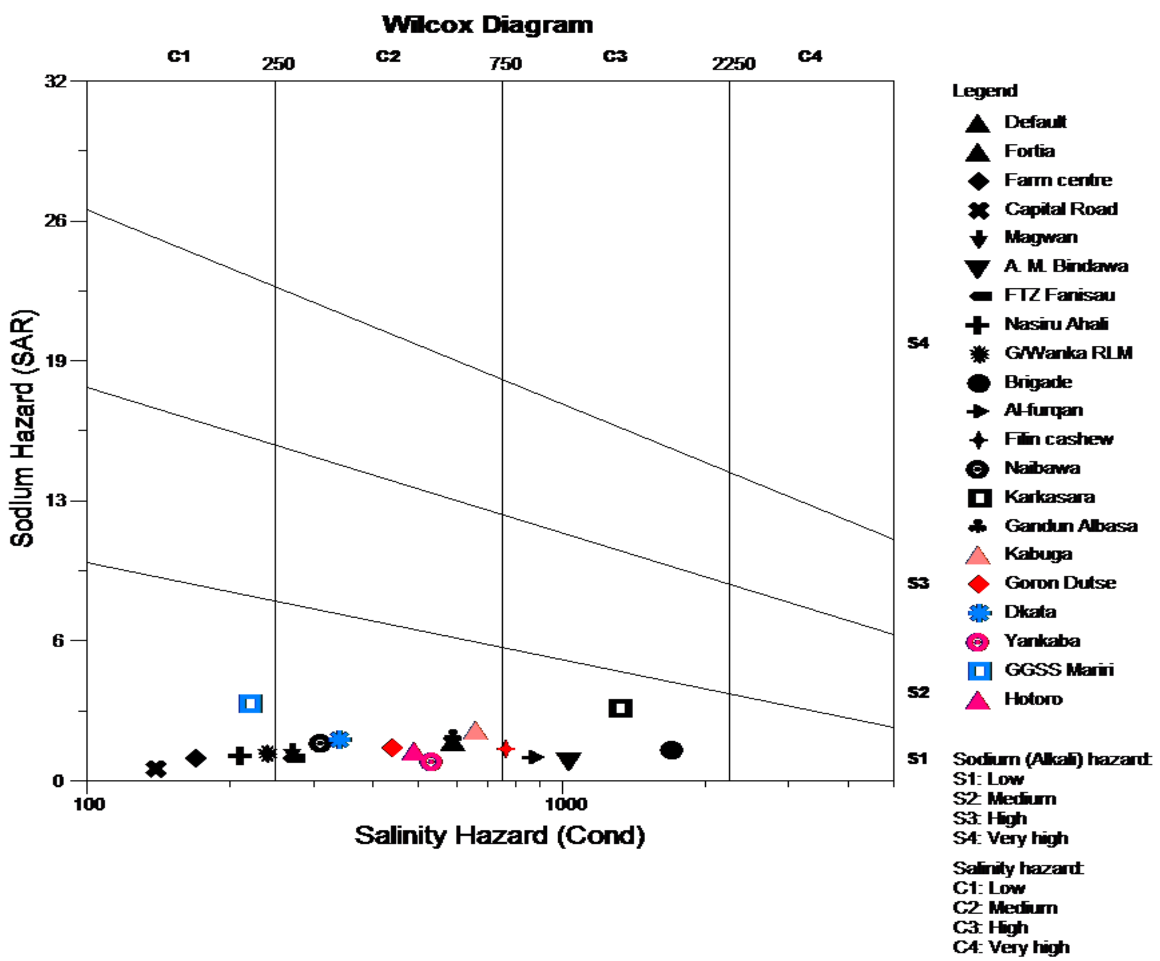

Figure 20: Piper Wilcox Diagram showing suitability of water for irrigation in the area.

Using the Wilcox diagram plotted above, and conductivity values of the samples presented in table12 and 13; the salinity hazard of the samples from the study area can be classified as follows:-

1. C1: KN2 (New layout), KN3 (Kano capital Rd), KN4 (Magwan), KN6 (FTZ Fanisau), KN7 (Nasiru Ahali), KN8 (Gidan wanka), and KN19 (Mariri). They are excellent for irrigation.
2. C2: KN1 (Fortia), KN12 (Naibawa), KN14 (Gandun albasa), KN15 (Kabuga), KN16 (Goron dutse), KN17 (Dakata), KN18 (Yankaba) and KN20 (NNPC Hotoro). These are considered good for irrigation.
3. C3: KN5 (A.A. Bindawa), KN9 (Brigade), KN10 (Alfurqan), KN11 (Filin cashew) and KN13 (Karkasara). These are regarded as moderate for irrigation.

CHAPTER FIVE:

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY

Field study has shown that the area is underlain by schists, diorites and granites. These rocks vary in areal extent. While granites occupy about three quarter of the whole area, schists occupy only small part. There are also minor intrusions of quartz, and aplite dykes in some localities. Geological structures are fractures, joints and foliations. The trends of these structures show a predominating NNE-SSW direction. These trends depict the final imprints of Pan African orogeny.

Electrical Resistivity Method investigated the variations of the electrical property of the subsurface materials (rocks). Results from the Vertical Electrical Sounding (VES) data indicates that the area is generally underlain by three to four layered-type curves, obtained from the VES points in the study area consisting of Topsoil/Laterite/Clay, Weathered layer, Fractured layer, and Fresh basement. Based on the result obtained, the fractured and the weathered basement make the aquiferous zone within the study area. The resistivity obtained from these zones has been interpreted which shows thickness of the aquiferous zone to vary from 5.29 to 54.34 m. Amongst those stations, VES BUK 1, SOK 1, FCT1, BRJ 2, BMP1, CLB 1, DKT 1 and BDW 2, are identified as good potentials for groundwater development because the aquifer thicknesses are highest at the stations.

Pumping test and its interpretations is useful, in that it allow estimates to be made of the local aquifer properties. Pump test data of twenty (20) deep and shallow boreholes were analysed to determine the aquifer characteristics. These properties includes: - transmissivity (T), hydraulic conductivity/ coefficient of permeability (k), and storage coefficient/ storativity (S).

The Transmissivity values for the deep boreholes have a range between $6.02x10^{-5}$ m^2/s and $5.30x10^{-5}$ m^2/s (5.20 m^2/day and 4.58 m^2/day), while the shallow boreholes have a range between $2.49x10^{-4}$ m^2/s and $5.12x10^{-6}$ m^2/s (21.51 m^2/day and 0.44 m^2/day). The hydraulic conductivity values are between $2.26x10^{-6}$m/s and $1.06x10^{-6}$m/s or 0.20 m/day and 0.09 m/day for the deep boreholes, while that of shallow boreholes is $3.11x10^{-5}$ m/s and $3.42x10^{-7}$ m/s (2.69 m/day and 0.03 m/day). The specific capacity values in the study area ranges between $1.79x10^{-5}$ and $1.29x10^{-5}$ m^2/s for deep boreholes,$7.96x10^{-4}$ m^2/s and $1.34x10^{-5}$ m^2/s for shallow ones.

Transmissivity values of the aquifers in the study area are within the low potentials. The high values of Transmissivity and hydraulic conductivity in some boreholes; BH1 & 2 (Farm centre), BH 3 (Nasarawa G.R.A), BH 6 (Dangauro), BH 13 (Masallacin Lawal), BH 14 (Barnoma), are associated with fracture zones. While low values of transmissivity and hydraulic conductivity are associated with boreholes drilled within clayey weathered aquifer, or crystalline rock with limited fractures.

For Specific capacity, the time of pumping was not adequate. This made conclusion difficult on the likely long-term sustainable yield of the boreholes.

Lineament analysis of the area indicates a predominantly NW-SE trend of lineaments. The zones of high lineaments density could probably be feasible zones for groundwater prospecting. From the nature of deep boreholes drilled in some parts of the study area; it can be assumed, unless proved otherwise, that the deep boreholes might not be tapping the suspected deep seated fractures, and therefore their long term sustainability is not certain.

Recently, groundwater quality has become a matter of concern due to discharge of industrial and domestic effluents, the use of agricultural chemicals, land use and cover changes.

The water samples analysed when compared with WHO and SON standards were mostly within the permissible limits. The most noticeable issue of concern is the concentration of heavy metals e.g. Pb and Cd above maximum permissible limit in some samples, and this made the water to be objectionable for drinking.

5.2 CONCLUSION

Owing to the large population of the study area, the importance of groundwater development in the area needs not be overemphasized. The available water to support various uses is largely exploited from the basement aquifer. From the foregoing, the aquifers are variable in extent and thickness, ranging from deep weathering to fracture zones. The material which constitutes the aquifers differs in composition, and hydraulic characteristics, depending on the nature of the rock, its tectonic history and extent of weathering. Lithology of the rock determines the nature of regolith, and both lithology and tectonic factors control the disposition of deeply weathered and fractured zones.

The study has shown that the area is generally good for groundwater development, especially in places underlain by porphyritic granite, because it has a distinctive weathering profile and contains fractures. Boreholes drilled through this rock type, may provide sufficient water to sustain a community supply.

Therefore low values of the aquifer properties in the study area; could generally be due to depth of the boreholes drilled and/or design. With the proper drilling, design and development of boreholes in the study area, the values of aquifer characteristics; transmissivity (T), hydraulic conductivity (k), and storage coefficient (S) could be higher.

The study has also revealed that, groundwater quality analysis have shown that the concentration of toxic metals (Pb and Cd), above permissible limits in more than 80% of the samples analysed. That is a dangerous proportion, as they are known to be very dangerous to human health. It is possible that the groundwater of the study area may contain significant amount of these metals released from use of insecticides, and improper dumping of waste (including chemicals), usually from industrial sections of the study area.

RECOMMENDATION

- It is recommended that, detailed geophysical exploration be carried out using integrated exploration approaches of geophysical method and structural geology of the area.
- The drilling of deep of boreholes of about 200m should be discouraged because of lack of sustainability and cost

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APPENDICES

APPENDIX I

Table I: WHO 2003 and 2011 Standard Permissible Limit for Physical and Chemical Parameters of Water for Drinking and Domestic Use

Water Quality Standard	Unit Measurement	2003 WHO STANDARD		2011 WHO Recommended Values
		Desirable Limit	Permissible Limit	
Turbidity	NUT	< 5	< 25	
Colour	Pt/Co	< 5	< 50	
Hydrogen ion Potential, PH	-	7.0-8.5	6.5-9.2	6.5-8.5
Hardness, Total	Mg/l $CaCO_3$	< 100	< 500	
Oxygen, O_2	Mg/l	>5	-	
Total Dissolve Solid, TDS	Mg/l	< 500	< 2000	
Chloride, Cl	Mg/l	< 250	< 500	250
Sodium, Na	Mg/l	< 120	< 400	50
Calcium, Ca	Mg/l	< 75	< 200	100
Magnesium, Mg	Mg/l	< 125	< 125	50
Iron, Fe, Total	Mg/l	< 0.1	< 1.0	0.1
Manganese, Mn	Mg/l	0.01	< 0.5	0.4
Sulphate, SO_4	Mg/l	< 200	< 400	250
Nitrate, NO_3	Mg/l	< 10	< 45	50
Nitrite, NO_2	Mg/l	< 10	< 2.0	3
Fluoride, F	Mg/l	0.7-1.2	1.2-2.4	1.5
Cadmium, Cd	Mg/l	< 0.01	< 0.01	0.003
Lead, Pb	Mg/l	< 0.020	< 0.050	0.01
Copper, Cu	Mg/l	< 0.05	< 1.0	2.0
Zinc, Zn	Mg/l	< 0.5	< 5.0	0.01
Chromium, Cr	Mg/l	< 0.05	< 0.1	0.05
Selenium, Se	Mg/l	< 0.01	< 0.01	0.04
Antimony, Sb	Mg/l	< 0.05	< 0.05	
Arsenic, As	Mg/l	< 0.01	< 0.05	0.01

Table II: International Standards for Drinking Water, World Health Organisation (WHO), 2004

S/ No.	Substance Characteristics / Elements	Recommended Limit (mg/l)	Maximum Permissible Limit (mg / l)
1	P^H	6.5	8.5
2	Total Dissolved Solids (TDS)	500	1500
3	Electrical Conductivity (EC)	-	1480
4	Sodium (Na^+)	150	200
5	Potassium (K^+)	10	15
6	Magnesium (Mg^{+2})	39	150
7	Calcium (Ca^{2+})	75	200
8	Sulphate (SO_4^{2-})	150	250
9	Chloride (Cl^-)	200	500
10	Bicarbonate (HCO_3)	500	1000
11	Iron (Fe^{+2})	0.3	1.0
12	Nitrate (NO_3)	20	45

Table III: International Standards for Drinking Water (WHO, 2005)

S/no	Elements	Permissible Limit mg/l	Maximum permissible limit (mg/l)
1	Magnesium (Mg)	50	150
2	Arsenic (As)	0.10	0.05
3	Calcium (Ca)	75	200
4	Copper (Cu)	0.1	1.5
5	Lead (Pb)	0.05	0.10
6	Iron (Fe)	0.01	1.0
7	Zinc (Zn)	5	15
8	Manganese (Mn)	0.05	0.5
9	Chloride (Cl)	200	600
10	Sulphate (SO_4)	200	400
11	Bicarbonate (HCO_3)	-	200
12	Nitrate (NO_3)	50	100

Table IV: **Nigerian Standards for Drinking Water (After SON 2007)**

S/ No.	Substance Characteristics / Elements	Recommended Limit (mg/l)	Maximum Permissible Limit (mg / l)
1	p^H	6.5	8.5
2	Total Dissolved Solids (TDS)	500	1500
3	Electrical Conductivity (EC)	-	1000
4	Sodium (Na^+)	150	200
5	Potassium (K^+)	-	
6	Magnesium (Mg^{+2})	39	150
7	Calcium (Ca^{2+})	75	200
8	Sulphate (SO_4^{2-})	100	400
9	Chloride (Cl^-)	250	600
10	Bicarbonate (HCO_3)	-	-
11	Iron (Fe^{+2})	0.3	1.0
12	Nitrate (NO_3)	-	50

Table V: Chemical Parameters (Inorganic constituents- NIS 2007)

Parameter	Unit	Maximum permitted levels	Health impact	Note
Aluminium (Al)	mg/l	0.2	Potential neuro-degenerative disorders	Note 1
Arsenic (As)	mg/l	0.01	Cancer	
Barium (B)	mg/l	0.7	Hypertension	
Cadmium (Cd)	mg/l	0.003	Toxic to the kidney	
Chloride (Cl)	mg/l	250	None	
Chromium (Cr^{6+})	mg/l	0.05	Cancer	
Conductivity	µS/cm	1000	None	
Cupper (Cu^{2+})	mg/l	1	Gastrointestinal disorder	
Cyanide (CN^-)	mg/l	0.01	Very toxic to the thyroid and the nervous system	
Fluoride (F^-)	mg/l	1.5	Fluoresces, skeletal tissue morbidity	
Hardness ($CaCo_3$)	mg/l	150	None	
Hydrogen Sulphide (H_2S)	mg/l	0.05	None	

Iron (Fe^{+2})	mg/l	0.3	None	
Lead (Pb)	mg/l	0.01	Cancer, Interference with Vitamin D metabolism, etc.	
Magnesium (Mg^{+2})	mg/l	0.20	Consumer acceptability	
Manganese (Mn^{+2})	mg/l	0.2	Neurological disorder	
Mercury (Hg)	mg/l	0.001	Affect the kidney and central nervous system	
Nickel (Ni)	mg/l	0.02	Possible carcinogenic	
Nitrate (NO_3)	mg/l	50	Cyanosis and asphyxia in infant under 3 months	
Nitrite (NO_2)	mg/l	0.2	Cyanosis and asphyxia in infant under 3 months	
Ph	mg/l	6.5-8.5	None	
Sodium (Na)	mg/l	200	None	
Sulphate (SO_4)	mg/l	100	None	
Total Dissolved Solids	mg/l	500	None	
Zinc (Zn)	mg/l	3	None	

Note 1: parameter to be monitored only if Aluminium chemicals are used for water

APPENDIX II

Table VI: Measurement of depth to water table in hand dug well at peak of dry season (April) 2013. (Source: Field data)

S/No.	Location	Coordinates	Date of WL measurement	Well elevation masl/(ftasl)	Depth to WL mbgl/(ftbgl)	Elevation of WL masl/(ftasl)
1.	Layin Haru manager U/uku	11°57´38´´N 08°34´03´´E	27/04/2013	436 (1430.08)	5.80 (19.02)	430.20 (1411.06)
2.	Fandaudu U/uku	11°57´38´´N 08°34´02´´E	27/04/2013	442 (1449.76)	5.20 (17.06)	436.80 (1432.70)

3.	Babban layi	11°57´35´´N 08°33´50´´E	27/04/2013	431 (1413.68)	5.40 (17.71)	425.60 (1395.97)
4.	Kasuwar kuka	11°57´31´´N 08°33´51´´E	27/04/2013	435 (1426.80)	5.10 (16.73)	429.90 (1410.07)
5.	Kundila market	11°57´49´´N 08°33´24´´E	27/04/2013	458 (1502.24)	6.00 (19.68)	452.00 (1482.56)
6.	Maiduguri road	11°58´04´´N 08°33´15´´E	27/04/2013	462 (1515.36)	5.70 (18.70)	456.30 (1496.66)
7.	Abubakar Rimi TV	11°57´47´´N 08°35´18´´E	28/04/2013	491 (1610.48)	11.00 (36.08)	480.00 (1574.40)
8.	Marafa Hotoro	11°57´41´´N 08°35´17´´E	28/04/2013	486 (1594.08)	12.60 (41.33)	473.40 (1552.75)
9.	Farawa A	11°57´44´´N 08°35´54´´E	28/04/2013	491 (1610.48)	10.50 (34.44)	480.50 (1576.04)
10.	Layin gidan peter Farawa	11°57´48´´N 08°35´56´´E	28/04/2013	482 (1580.96)	9.00 (29.52)	473.00 (1551.44)
11.	Layin madaki Mariri	11°56´53´´N 08°36´48´´E	28/04/2013	509 (1669.52)	12.50 (41.00)	496.50 (1628.52)
12.	Kasuwar itace Mariri	11°56´43´´N 08°36´47´´E	28/04/2013	488 (1600.64)	11.50 (37.72)	476.50 (1562.92)
13.	Hadejia Road Yankaba	11°59´35´´N 08°35´17´´E	28/04/2013	487 (1597.36)	8.80 (28.86)	478.20 (1568.50)
14.	Zangon walawa	11°59´37´´N 08°35´19´´E	28/04/2013	479 (1571.12)	7.90 (25.91)	471.10 (1545.21)
15.	Kawo A	11°58´27´´N 08°35´35´´E	28/04/2013	475 (1558.00)	6.00 (19.68)	469.00 (1538.32)
16.	Kawo B	11°58´01´´N 08°35´39´´E	28/04/2013	485 (1590.80)	8.00 (26.24)	477.00 (1564.56)
17.	Ring Road	11°59´10´´N 08°33´40´´E	28/04/2013	453 (1485.84)	4.20 (13.78)	448.80 (1472.06)
18.	Saadatu Rimi college	11°55´21´´N 08°33´12´´E	04/05/2013	465 (1525.20)	4.60 (15.09)	460.40 (1510.11)
19.	Cabano, Kumbotso	11°55´35´´N 08°29´35´´E	04/05/2013	466 (1528.48)	6.00 (19.68)	460.00 (1508.80)
20.	Jaen	11°52´12´´N 08°28´47´´E	04/05/2013	454.90 (1492.07)	11.2 0 (36.74)	443.7 (1455.34)
21.	Chiranchi A	11°56´53´´N 08°28´35´´E	04/05/2013	461 (1512.08)	6.00 (19.68)	455.00 (1492.4
22.	Chiranchi	11°57´07´´N	04/05/2013	487	6.50	480.50

	B	08°28´39´´E		(1597.36)	(21.32)	(1576.04)
23.	Dorayi babba	11°57´56´´N 08°28´55´´E	04/05/2013	495 (1623.60)	11.70 (38.38)	483.30 (1585.22)
24.	Gwammaja	12°01´20´´N 08°30´11´´E	04/05/2013	474 (1554.72)	4.00 (13.12)	472.00 (1541.60)
25.	Dala	12°00´34´´N 08°30´32´´E	04/05/2013	491 (1610.48)	10.00 (32.8)	481.00 (1577.68)
26.	Kasuwar Kurmi	12°00´09´´N 08°30´56´´E	05/05/2013	464 (1521.92)	7.20 (23.62)	456.80 (1498.30)
27.	Yola	11°59´57´´N 08°31´10´´E	05/05/2013	475 (1558.00)	7.00 (22.96)	468.00 (1535.04)
28.	Kofar Nasarawa	11°59´34´´N 08°31´41´´E	05/05/2013	493 (1617.04)	9.30 (30.50)	483.70 (1586.54)
29.	Gyadi-gyadi	11°58´28´´N 08°32´41´´E	05/05/2013	491 (1610.48)	7.90 (25.91)	483.10 (1584.57)
30.	Yar akuwa Central Mosque	11°56´27´´N 08°33´14´´E	05/05/2013	464 (1521.92)	5.00 (16.40)	459.00 (1505.52)
31.	Islamic school Y/akuwa	11°57´26´´N 08°33´40´´E	05/05/2013	440 (1443.20)	4.80 (15.74)	435.20 (1427.46)
32.	InuwaDutse Road	11°56´38´´N 08°33´38´´E	05/05/2013	477 (1564.56)	4.20 (13.78)	472.80 (1550.78)
33.	Darmanawa	11°57´05´´N 08°33´06´´E	05/05/2013	456 (1495.68)	4.00 (13.12)	452.00 (1482.56)
34.	Karkasara	11°57´32´´N 08°32´47´´E	05/05/2013	440 (1443.20)	3.90 (12.79)	436.10 (1430.41)
35.	Dan agundi	11°59´01´´N 08°31´22´´E	05/05/2013	495 (1623.60)	9.60 (31.49)	485.40 (1592.11)
36.	Kofar kudu	12°06´62´´N 08°32´06´´E	05/05/2013	493 (1617.04)	9.20 (30.18)	483.80 (1586.86)
37.	Mandawari Sabon titi	11°59´27´´N 08°30´27´´E	05/05/2013	493 (1617.04)	9.00 (29.52)	484.00 (1587.52)
38.	Goron dutse	12°00´51´´N 08°31´12´´E	05/05/2013	471 (1544.88)	7.60 (24.93)	463.40 (1519.95)
39.	Kurna asabe	12°02´12´´N 08°29´28´´E	05/05/2013	492 (1613.76)	10.80 (35.42)	481.20 (1578.34)
40.	Rijiyar lemo	12°04´05´´N 08°27´53´´E	05/05/2013	505 (1656.4)	12.90 (42.31)	492.10 (1614.09)
41.	Dawanau market	12°05´19´´N 08°26´13´´E	05/05/2013	519 (1702.32)	19.00 (62.32)	500.00 (1640.00)
42.	Bukabo	12°01´45´´N	05/05/2013	495	10.50	484.50

	Katsina Rd.	08°30´22´´E		(1623.60)	(34.44)	(1589.16)
43.	Airport Rd	12°01´10´´N 08°31´10´´E	09/05/2013	447 (1466.16)	8.70 (28.54)	438.30 (1437.62)
44.	Fagge	12°01´37´´N 08°31´54´´E	09/05/2013	479 (1571.12)	6.60 (21.65)	472.40 (1549.47)
45.	Civic centre	12°00´01´´N 08°32´13´´E	09/05/2013	478 (1567.84)	5.80 (19.02)	472.20 (1548.82)
46.	Nasarawa Qtrs	11°59´49´´N 08°33´00´´E	09/05/2013	482 (1580.96)	7.00 (22.96)	475.00 (1558)
47.	Farm centre	11°58´38´´N 08°33´01´´E	09/05/2013	493 (1617.04)	11.90 (39.03)	481.10 (1578.00)
48.	Audu Bako Secretariat	11°59´03´´N 08°32´46´´E	09/05/2013	492 (1613.76)	10.60 (34.77)	481.40 (1578.99)
49.	Dan marke	11°57´56´´N 08°34´51´´E	09/05/2013	493 (1617.04)	9.00 (29.52)	484.00 (1587.52)
50.	GSS Tarauni	11°58´46´´N 08°33´44´´E	09/05/2013	486 (1594.08)	6.90 (22.63)	479.10 (1571.45)
51.	Tamburawa	11°51´14´´N 08°31´34´´E	04/05/2013	447.2 (1466.82)	3.20 (10.50)	444.00 (1456.32)

Table VII: Measurement of depth to water table in hand dug well at peak of rainy season (September) 2013. (Source: Field data)

S/No.	Location	Coordinates	Date of WL measurement	Well elevation masl/(ftasl)	Depth to WL mbgl/(ftbgl)	Elevation of WL masl/(ftasl)
1.	Layin Haru manager U/uku	11°57´38´´N 08°34´03´´E	02/09/2013	436 (1430.08)	1.50 (4.92)	434.50 (1425.16)
2.	Fandaudu U/uku	11°57´38´´N 08°34´02´´E	02/09/2013	442 (1449.76)	1.95 (6.40)	440.05 (1443.36)

3.	Babban layi	11°57´35´´N 08°33´50´´E	02/09/2013	431 (1413.68)	0.50 (1.64)	430.50 (1412.04)
4.	Kasuwar kuka	11°57´31´´N 08°33´51´´E	02/09/2013	435 (1426.80)	1.35 (4.43)	433.65 (1422.37)
5.	Kundila market	11°57´49´´N 08°33´24´´E	02/09/2013	458 (1502.24)	0.60 (1.97)	457.40 (1500.27)
6.	Maiduguri road	11°58´04´´N 08°33´15´´E	02/09/2013	462 (1515.36)	1.00 (3.28)	461.00 (1512.08)
7.	Abubakar Rimi TV	11°57´47´´N 08°35´18´´E	02/09/2013	491 (1610.48)	7.30 (23.94)	483.70 (1586.54)
8.	Marafa Hotoro	11°57´41´´N 08°35´17´´E	02/09/2013	486 (1594.08)	7.90 (25.91)	478.10 (1568.17)
9.	Farawa A	11°57´44´´N 08°35´54´´E	02/09/2013	491 (1610.48)	6.75 (22.14)	484.25 (1588.34)
10.	Layin gidan peter Farawa	11°57´48´´N 08°35´56´´E	02/09/2013	482 (1580.96)	6.30 (20.66)	475.70 (1560.30)
11.	Layin madaki Mariri	11°56´53´´N 08°36´48´´E	02/09/2013	509 (1669.52)	10.80 (35.42)	498.70 (1635.74)
12.	Kasuwar itace Mariri	11°56´43´´N 08°36´47´´E	02/09/2013	488 (1600.64)	10.30 (33.78)	477.70 (1566.86)
13.	Hadejia Road Yankaba	11°59´35´´N 08°35´17´´E	02/09/2013	487 (1597.36)	6.00 (19.68)	481.00 (1577.68)
14.	Zangon walawa	11°59´37´´N 08°35´19´´E	02/09/2013	479 (1571.12)	6.40 (20.99)	472.60 (1550.13)
15.	Kawo A	11°58´27´´N 08°35´35´´E	02/09/2013	475 (1558)	5.00 (16.4)	470.00 (1541.6)
16.	Kawo B	11°58´01´´N 08°35´39´´E	02/09/2013	485 (1590.8)	5.80 (19.02)	479.20 (1571.78)
17.	Ring Road	11°59´10´´N 08°33´40´´E	02/09/2013	453 (1485.84)	2.20 (7.22)	450.80 (1478.62)
18.	Saadatu Rimi college	11°55´21´´N 08°33´12´´E	02/09/2013	465 (1525.20)	4.10 (13.45)	463.30 (1519.62)
19.	Cabano, Kumbotso	11°55´35´´N 08°29´35´´E	03/09/2013	466 (1528.48)	4.80 (15.74)	461.20 (1512.74)
20.	Jaen	11°52´12´´N 08°28´47´´E	03/09/2013	454 (1492.07)	2.60 (8.53)	446.30 (1463.86)
21.	Chiranchi A	11°56´53´´N 08°28´35´´E	03/09/2013	461 (1512.08)	4.90 (16.07)	456.10 (1496.00)

22.	Chiranchi B	11°57´07´´N 08°28´39´´E	03/09/2013	487 (1597.36)	4.30 (14.10)	482.70 (1597.36)
23.	Dorayi babba	11°57´56´´N 08°28´55´´E	03/09/2013	495 (1623.6)	6.00 (19.68)	489.00 (1603.92)
24.	Gwammaja	12°01´20´´N 08°30´11´´E	03/09/2013	474 (1554.72)	2.00 (6.56)	472.00 (1548.16)
25.	Dala	12°00´34´´N 08°30´32´´E	03/09/2013	491 (1610.48)	7.30 (23.94)	483.70 (1586.54)
26.	Kasuwar Kurmi	12°00´09´´N 08°30´56´´E	03/09/2013	464 (1521.92)	4.50 (14.76)	459.50 (1507.16)
27.	Yola	11°59´57´´N 08°31´10´´E	03/09/2013	475 (1558)	5.30 (17.38)	469.70 (1540.62)
28.	Kofar Nasarawa	11°59´34´´N 08°31´41´´E	03/09/2013	493 (1617.04)	5.60 (18.37)	487.40 (1598.67)
29.	Gyadi-gyadi	11°58´28´´N 08°32´41´´E	03/09/2013	491 (1610.48)	4.20 (13.78)	486.80 (1596.70)
30.	Yar akuwa Central Mosque	11°56´27´´N 08°33´14´´E	03/09/2013	464 (1521.92)	3.00 (9.84)	461.00 (1512.08)
31.	Islamic school Y/akuwa	11°57´26´´N 08°33´40´´E	03/09/2013	440 (1443.2)	2.10 (6.89)	437.90 (1436.31)
32.	InuwaDutse Road	11°56´38´´N 08°33´38´´E	03/09/2013	477 (1564.56)	1.90 (6.23)	475.10 (1558.33)
33.	Darmanawa	11°57´05´´N 08°33´06´´E	03/09/2013	456 (1495.68)	2.30 (7.54)	453.70 (1488.14)
34.	Karkasara	11°57´32´´N 08°32´47´´E	03/09/2013	440 (1443.2)	1.90 (6.23)	438.10 (1436.97)
35.	Dan agundi	11°59´01´´N 08°31´22´´E	03/09/2013	495 (1623.6)	5.90 (19.35)	489.10 (1604.25)
36.	Kofar kudu	12°06´62´´N 08°32´06´´E	03/09/2013	493 (1617.04)	5.60 (18.34)	487.40 (1598.67)
37.	Mandawari Sabon titi	11°59´27´´N 08°30´27´´E	03/09/2013	493 (1617.04)	6.00 (19.68)	487.00 (1597.36)
38.	Goron dutse	12°00´51´´N 08°31´12´´E	04/09/2013	471 (1544.88)	4.60 (15.09)	466.40 (1529.79)
39.	Kurna asabe	12°02´12´´N 08°29´28´´E	04/09/2013	492 (1613.76)	10.20 (33.46)	488.20 (1601.30)
40.	Rijiyar lemo	12°04´05´´N 08°27´53´´E	04/09/2013	505 (1656.40)	9.30 (30.50)	499.50 (1638.36)
41.	Dawanau market	12°05´19´´N 08°26´13´´E	04/09/2013	519 (1702.32)	13.00 (42.64)	508.00 (1666.24)

42.	Bukabo Katsina Rd.	12°01´45´´N 08°30´22´´E	04/09/2013	495 (1623.60)	7.50 (24.60)	487.50 (159.00)
43.	Airport Rd	12°01´10´´N 08°31´10´´E	04/09/2013	447 (1466.16)	5.90 (19.35)	441.10 (1446.81)
44.	Fagge	12°01´37´´N 08°31´54´´E	04/09/2013	479 (1571.12)	6.60 (21.65)	472.40 (1549.47)
45.	Civic centre	12°00´01´´N 08°32´13´´E	04/09/2013	478 (1567.84)	5.20 (17.06)	472.80 (1550.78)
46.	Nasarawa Qtrs	11°59´49´´N 08°33´00´´E	04/09/2013	482 (1580.96)	6.30 (20.66)	475.70 (1560.30)
47.	Farm centre	11°58´38´´N 08°33´01´´E	04/09/2013	493 (1617.04)	11.20 (36.74)	481.80 (1580.30)
48.	Audu Bako Secretariat	11°59´03´´N 08°32´46´´E	04/09/2013	492 (1613.76)	10.60 (34.77)	481.40 (1578.99)
49.	Dan marke	11°57´56´´N 08°34´51´´E	04/09/2013	493 (1617.04)	9.00 (29.52)	484.00 (1587.52)
50.	GSS Tarauni	11°58´46´´N 08°33´44´´E	04/09/2013	486 (1594.08)	6.90 (22.63)	479.10 (1571.45)
51.	Tamburawa		04/09/2013	447.2 (1466.82)	1.6 (5.25)	445.6 (1461.57)

Table VIII: Measurements of depth to water table in hand dug wells at the peak of dry season (April,2013) and peak of rainy season (October,2013) (Source: Field Data)

S/N	Location	Coordinates Lat. (°N) Long.(°E)	Well elevation m/ (ft)	Peak of dry season GWL mbgl/(ftbgl)	Peak of dry season GWL elev. masl/(ftasl)	Peak of rainy season GWL mbgl/ (ftbgl)	Peak of rainy season GWL elev. masl/(ftasl)	WT fluctuation m (ft)
1.	Layin Haru manager	11°57´38´´N	436 (1430.08)	5.80 (19.02)	430.20 (1411.06)	1.50 (4.92)	434.50 (1425.16)	4.30 (14.10)

	U/uku	08°34′03′′E						
2.	Fandaudu U/uku	11°57′38′′N 08°34′02′′E	442 (1449.76)	5.20 (17.06)	436.80 (1432.70)	1.95 (6.40)	440.05 (1443.36)	3.25 (10.66)
3.	Babban layi	11°57′35′′N 08°33′50′′E	431 (1413.68)	5.40 (17.71)	425.60 (1395.97)	0.50 (1.64)	430.50 (1412.04)	4.90 (16.07)
4.	Kasuwar kuka	11°57′31′′N 08°33′51′′E	435 (1426.80)	5.10 (16.73)	429.90 (1410.07)	1.35 (4.43)	433.65 (1422.37)	3.75 (12.3)
5.	Kundila market	11°57′49′′N 08°33′24′′E	458 (1502.24)	6.00 (19.68)	452.00 (1482.56)	0.60 (1.97)	457.40 (1500.27)	5.40 (17.71)
6.	Maiduguri road	11°58′04′′N 08°33′15′′E	462 (1515.36)	5.70 (18.70)	456.30 (1496.66)	1.00 (3.28)	461.00 (1512.08)	4.70 (15.42)
7.	Abubakar Rimi TV	11°57′47′′N 08°35′18′′E	491 (1610.48)	11.00 (36.08)	480.00 (1574.40)	7.30 (23.94)	483.70 (1586.54)	3.70 (12.14)
8.	Marafa Hotoro	11°57′41′′N 08°35′17′′E	486 (1594.08)	12.60 (41.33)	473.40 (1552.75)	7.90 (25.91)	478.10 (1568.17)	4.70 (15.42)
9.	Farawa A	11°57′44′′N 08°35′54′′E	491 (1610.48)	10.50 (34.44)	480.50 (1576.04)	6.75 (22.14)	484.25 (1588.34)	3.75 (12.3)
10.	Layin gidan peter Farawa	11°57′48′′N 08°35′56′′E	482 (1580.96)	9.00 (29.52)	473.00 (1551.44)	6.30 (20.66)	475.70 (1560.30)	2.70 (8.86)
11.	Layin madaki Mariri	11°56′53′′N 08°36′48′′E	509 (1669.52)	12.50 (41.00)	496.50 (1628.52)	10.80 (35.42)	498.70 (1635.74)	1.70 (5.58)
12.	Kasuwar itace Mariri	11°56′43′′N 08°36′47′′E	488 (1600.64)	11.50 (37.72)	476.50 (1562.92)	10.30 (33.78)	477.70 (1566.86)	1.20 (3.94)
13.	Hadejia Road Yankaba	11°59′35′′N 08°35′17′′E	487 (1597.36)	8.80 (28.86)	478.20 (1568.50)	6.00 (19.68)	481.00 (1577.68)	2.80 (9.18)
14.	Zangon walawa	11°59′37′′N 08°35′19′′E	479 (1571.12)	7.90 (25.91)	471.10 (1545.21)	6.40 (20.99)	472.60 (1550.13)	1.50 (4.92)
15.	Kawo A	11°58′27′′N 08°35′35′′E	475 (1558.00)	6.00 (19.68)	469.00 (1538.32)	5.00 (16.4)	470.00 (1541.6)	1.00 (3.28)
16.	Kawo B	11°58′01′′N 08°35′39′′E	485 (1590.80)	8.00 (26.24)	477.00 (1564.56)	5.80 (19.02)	479.20 (1571.78)	2.20 (7.22)
17.	Ring Road	11°59′10′′N 08°33′40′′E	453 (1485.84)	4.20 (13.78)	448.80 (1472.06)	2.20 (7.22)	450.80 (1478.62)	2.00 (6.56)
18.	Saadatu Rimi college	11°55′21′′N 08°33′12′′E	465 (1525.20)	4.60 (15.09)	460.40 (1510.11)	2.90 (9.51)	463.30 (1519.62)	2.90 (9.51)
19.	Cabano, Kumbotso	11°55′35′′N 08°29′35′′E	466 (1528.48)	6.00 (19.68)	460.00 (1508.80)	4.80 (15.74)	461.20 (1512.74)	1.20 (3.94)
20.	Jaen	11°52′12′′N	454.90	11.20	443.7	5.60	446.3	2.6

		08°28´47´´E	(1492.07)	(36.74)	(1455.34)	(18.37)	(1463.86)	(8.53)
21.	Chiranchi A	11°56´53´´N 08°28´35´´E	461 (1512.08)	6.00 (19.68)	455.00 (1492.4)	4.90 (16.07)	456.10 (1496.00)	1.10 (3.61)
22.	Chiranchi B	11°57´07´´N 08°28´39´´E	487 (1597.36)	6.50 (21.32)	480.50 (1576.04)	4.30 (14.10)	482.70 (1597.36)	2.20 (7.22)
23.	Dorayi babba	11°57´56´´N 08°28´55´´E	495 (1623.60)	11.70 (38.38)	483.30 (1585.22)	6.00 (19.68)	489.00 (1603.92)	5.70 (18.70)
24.	Gwammaja	12°01´20´´N 08°30´11´´E	474 (1554.72)	4.00 (13.12)	472.00 (1541.60)	2.00 (6.56)	472.00 (1548.16)	2.00 (6.56)
25.	Dala	12°00´34´´N 08°30´32´´E	491 (1610.48)	10.00 (32.8)	481.00 (1577.68)	7.30 (23.94)	483.70 (1586.54)	2.70 (8.86)
26.	Kasuwar Kurmi	12°00´09´´N 08°30´56´´E	464 (1521.92)	7.20 (23.62)	456.80 (1498.30)	4.50 (14.76)	459.50 (1507.16)	2.70 (8.86)
27.	Yola	11°59´57´´N 08°31´10´´E	475 (1558.00)	7.00 (22.96)	468.00 (1535.04)	5.30 (17.38)	469.70 (1540.62)	1.70 (5.58)
28.	Kofar Nasarawa	11°59´34´´N 08°31´41´´E	493 (1617.04)	9.30 (30.50)	483.70 (1586.54)	5.60 (18.37)	487.40 (1598.67)	3.7 (12.14)
29.	Gyadi-gyadi	11°58´28´´N 08°32´41´´E	491 (1610.48)	7.90 (25.91)	483.10 (1584.57)	4.20 (13.78)	486.80 (1596.70)	3.70 (12.14)
30.	Yar akuwa Central Mosque	11°56´27´´N 08°33´14´´E	464 (1521.92)	5.00 (16.40)	459.00 (1505.52)	3.00 (9.84)	461.00 (1512.08)	2.00 (6.56)
31.	Islamic school Y/akuwa	11°57´26´´N 08°33´40´´E	440 (1443.20)	4.80 (15.74)	435.20 (1427.46)	2.10 (6.89)	437.90 (1436.31)	2.70 (8.86)
32.	InuwaDutse Road	11°56´38´´N 08°33´38´´E	477 (1564.56)	4.20 (13.78)	472.80 (1550.78)	1.90 (6.23)	475.10 (1558.33)	2.30 (7.54)
33.	Darmanawa	11°57´05´´N 08°33´06´´E	456 (1495.68)	4.00 (13.12)	452.00 (1482.56)	2.30 (7.54)	453.70 (1488.14)	1.70 (5.58)
34.	Karkasara	11°57´32´´N 08°32´47´´E	440 (1443.20)	3.90 (12.79)	436.10 (1430.41)	1.90 (6.23)	438.10 (1436.97)	2.00 (6.56)
35.	Dan agundi	11°59´01´´N 08°31´22´´E	495 (1623.60)	9.60 (31.49)	485.40 (1592.11)	5.90 (19.35)	489.10 (1604.25)	3.70 (12.14)
36.	Kofar kudu	12°06´62´´N 08°32´06´´E	493 (1617.04)	9.20 (30.18)	483.80 (1586.86)	5.60 (18.34)	487.40 (1598.67)	3.60 (11.81)
37.	Mandawari Sabon titi	11°59´27´´N 08°30´27´´E	493 (1617.04)	9.00 (29.52)	484.00 (1587.52)	6.00 (19.68)	487.00 (1597.36)	3.00 (9.84)
38.	Goron dutse	12°00´51´´N 08°31´12´´E	471 (1544.88)	7.60 (24.93)	463.40 (1519.95)	4.60 (15.09)	466.40 (1529.79)	3.00 (9.84)
39.	Kurna asabe	12°02´12´´N 08°29´28´´E	492 (1613.76)	10.80 (35.42)	481.20 (1578.34)	7.00 (22.96)	488.20 (1601.30)	7.00 (22.96)
40.	Rijiyar	12°04´05´´N	505	12.90	492.10	7.40	499.50	7.4

	lemo	08°27´53´´E	(1656.4)	(42.31)	(1614.09)	(24.27)	(1638.36)	(24.27)
41.	Dawanau market	12°05´19´´N 08°26´13´´E	519 (1702.32)	19.00 (62.32)	500.00 (1640.00)	13.00 (42.64)	508.00 (1662.96)	8.00 (26.24)
42.	Bukabo Katsina Rd.	12°01´45´´N 08°30´22´´E	495 (1623.60)	10.50 (34.44)	484.50 (1589.16)	7.50 (24.60)	487.50 (159.00)	3.00 (9.84)
43.	Airport Rd	12°01´10´´N 08°31´10´´E	447 (1466.16)	8.70 (28.54)	438.30 (1437.62)	5.90 (19.35)	441.10 (1446.81)	2.80 (9.18)
44.	Fagge	12°01´37´´N 08°31´54´´E	479 (1571.12)	6.60 (21.65)	472.40 (1549.47)	5.00 (16.40)	474.40 (1554.72)	1.60 (5.25)
45.	Civic centre	12°00´01´´N 08°32´13´´E	478 (1567.84)	7.80 (25.58)	470.00 (1542.26)	5.20 (17.06)	472.80 (1550.78)	2.60 (8.53)
46.	Nasarawa Qtrs	11°59´49´´N 08°33´00´´E	482 (1580.96)	7.00 (22.96)	475.00 (1558)	6.30 (20.66)	475.70 (1560.30)	0.70 (2.30)
47.	Farm centre	11°58´38´´N 08°33´01´´E	493 (1617.04)	11.90 (39.03)	481.10 (1578.00)	7.20 (23.62)	485.80 (1593.42)	4.7 (15.42)
48.	Audu Bako Secretariat	11°59´03´´N 08°3\ 2´46´´E	492 (1613.76)	10.60 (34.77)	481.40 (1578.99)	6.60 (21.65)	485.40 (1592.11)	4.00 (13.12)
49.	Dan marke	11°57´56´´N 08°34´51´´E	493 (1617.04)	11.00 (36.08)	482.00 (1580.96)	6.00 (19.68)	487.00 (1597.36)	5.00 (16.4)
50.	GSS Tarauni	11°58´46´´N 08°33´44´´E	486 (1594.08)	8.90 (29.19)	477.10 (1564.89)	6.40 (20.99)	479.60 (1573.09)	2.50 (8.2)
51.	Tamburawa	11°51´14´´N 08°31´34´´E	447.2 (1466.82)	3.20 (10.50)	444.00 (1456.32)	1.6 (5.25)	445.6 (1461.57)	1.6 (5.25)

APPENDIX III: INTERPRETED GEOPHYSICAL DATA

APPENDIX IV: RESULTS OF WATER ANALYSIS