HYDROGEOLOGY AND GROUNDWATER QUALITY ASSESSMENT OF SHEET 78 (FUNTUA SE) NORTHWESTERN NIGERIA

BY

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DEDICATION

This Research work is dedicated to the King of Kings (Almighty), my helper and sustainer who saw me through this work. The Lord's name be glorified forever. Also to my mother who never cease praying for my success and for her support. The Lord continues to reward her. Amen.

DECLARATION

I declare that the work in this dissertation entitled “Hydrogeology and Groundwater Quality Assessment of Sheet 78, (Funtua SE), Northwestern Nigeria.” has been done by me in the department of Geology, Faculty of Sciences, Ahmadu Bello University Zaria, under the supervision of Dr. M. L. Garba and Prof. U. A. Danbatta.

All 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 any university.

Onaji Helen Odachi	____________________	________________
	Signature	Date

CERTIFICATION

The dissertation entitled "Hydrogeology and Groundwater Quality Assessment of Sheet 78, (Funtua SE), Northwestern Nigeria" by Onaji Helen Odachi meets the requirement for the award of the degree of Master of Science in Geology (Hydrogeology) of Ahmadu Bello University, Zaria and is approved for its contribution to Knowledge and literary presentation.

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Any omission is unintentional and quiet regretful.

ONAJI HELEN ODACHI (2014)

ABTRACT

Hydrogeology and Groundwater Quality Assessment of Sheet 78, (Funtua SE) was undertaken using combined geological, hydrogeological and geophysical methods. This study area is in the topographic Sheet 78, (Funtua SE). Rocks mapped in the study area include migmatite gneiss, granite gneiss, granite, schist, quartzite and phyllite. Aquifers identified include the weathered basement rocks and fractured rocks through which groundwater is transmitted.From the geophysical data analyzed, 4 to 6 geo-electric layers have been found in the area with the aquifer located within the weathered to fractured basement rock of the study area. Aquifer characteristics in the study areashow that transmissivity (T) values of the aquifer range from 0.47 to 18.89 m^2/day with a mean value of 9.68 m^2/day. Hydraulic conductivity (K) ranges between 0.31 and 5.21 m/day with a mean value of 2.76 m/day. The values of Transmissivity and the hydraulic conductivity show that the aquifer in the study area is good. The specific capacity (S) as calculated for the 20 boreholes ranges from 4.28 m^3/m/day to 105.48 m^3/m/day with an average of 54m^3/m/day, confirming good performance of the aquifer in the study area. Measured values of groundwater elevation above sea level (asl) were used to construct the groundwater configuration map for the study area from which the groundwater level fluctuation in the (phreatic) aquifer and direction of groundwater flow were determined. For the end of raining season,the maximum groundwater table elevation was 2293 ft (699m) asl and the minimum was 1896ft (578m) asl, At the peak of the dry season, coinciding with the period of minimum water level in wells, the maximum and minimum water table elevations were 2290ft (698m) asl and 1923ft (586m) asl respectively. The mean groundwater table elevation based on 143 wells was 2093ft (638m) while the mean water table elevation based on 111 wells was 2106ft (642m) for dry season. A total of 10 water samples from hand dug wells (6); boreholes (3) and river (1) in the study area were taken and analyzed for their major ions concentrations. The major ions analyzed include Sodium (Na^+) with concentration ranging from 0.66 to 28.04gmg/l, Potassium (K^+) with concentration ranging from 0.23 to 16.83mg/l, Calcium (Ca^{2+}) with concentration ranging from 8.0 to 59.28mg/l, Magnesium (Mg^{2+}) with concentration ranging from 7.24 to 15.48mg/l, Bicarbonate (HCO_3^-) with concentration ranging from 444.4 to 668.8mg/l, Chloride (Cl^-) with concentration ranging from 21.30 to 85.1mg/l, Nitrate (NO_3^{2-}) with concentration ranging from 2.2 to 12.8mg/l and Sulphate (SO_4^{2-}) with concentration ranging from 4.3 to 75mg/l. The major and minor elements concentrations are mostly within the limit of WHO guideline and Nigeria standard for drinking water (NSDW). The results show that the groundwater in the study area is potable and suitable for domestic, agricultural and industrial uses.

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CHAPTER ONE

INTRODUCTION

1.1 PREAMBLE

Water is essential to life. From the beginning of human civilization, people have settled close to water sources, along rivers, besides lakes or near natural springs. Indeed in areas where people lived, water is usually available for drinking, for domestic use and possibly for watering plants and for animal consumption.Increase in demand for water has stimulated development of groundwater resources. Because of that, different techniques have been developed in investigating the occurrence and movement of groundwater resources.

Groundwater is simply water that occurs in the ground; in the pore spaces between mineral grains or in cracks and fractures in the rock mass. It is usually formed by rainwater that seeps down through the soil and into the rocks. Groundwater exploitation in northern Nigeria is becoming a necessity for the sustainable development of the economy for both the rural and urban regions.

There are two provinces where groundwater can occur namely, the crystalline hydrogeological province and the sedimentary hydrogeological province.The crystalline hydrogeological provinces include the weathered basement forming a shallow, patchy, minor aquifer system of low storage and the deep fractured zone of the basement rock. The Sedimentary hydrogeological provinces include consolidated sedimentary rocks which form generally deeper, but less extensive and geologically more complex, aquifers. Groundwater isaccessible through dug-wells, at spring’s heads and in seepage areas; and also drilled boreholes.

Groundwater from springs, boreholes and dug wells is the raw material of improved rural water supplies on a very widespread basis, with the current level of dependency that is put at over 75%.This is the critical function for groundwater resources and its importance cannot be overstated, because groundwater development for community water supply has far reaching benefit in terms of reducing health hazard and improving socio economic opportunity (Banks Robins, 2002).

The study area falls within the northwestern part of Nigeria and is underlain by crystalline rocks of the Basement Complex. The Basement Complex is very important in groundwater development; this is because it provides about 50% of needed water to the rural populace in Nigeria (Offodile, 2002).

Groundwater is preferred to surface water because of its relative cheapness compared to surface water, its availability in most areas, freshness without treatment and also its harnessing requires low cost technology.It is also clear that, it is difficult to locate sustainable groundwater supplies of large magnitude in the crystalline area. This is because of the low porosity and consequently low storage value in this terrain. However, for this goal to be realized there is need for proper investigation to be carried out in the study area.The occurrence of groundwater in the study area is variable and somewhat unpredictable. However, success has been achieved in its development in this terrain through the combined use of geological, hydrogeological and geophysical surveys (Ayandele, 2010).

1.2 DESCRIPTION OF THE STUDY AREA

1.2.1 Location and Accessibility

The area under investigation falls within the Nigerian Basement Complex which lies between Latitudes 11º30'00"N to 11º45'00"N and Longitude 7º15'00"E to 7º30'00"E. The study area is covered by topographic sheet 78 Funtua SE (Fig.1). It has area coverage of 748.0225km². Sheet 78 SE (1:50,000) forms part of Nigeria topographic Sheet 78 Funtua at a scale of 1:100,000. The study area extends into 4 local government areas which include Funtua, Bakori, Danja and Faskari Local Government Areas of Katsina State. Major towns in the area include, Funtua and Bakori; while other built up settlements include Jargaba, Guga, Kanawa, BakinKogi, DutsenReme, Kwai, UngwaBalarabe and Nabuka.

Easy accessibility was provided by a network of footpaths,minor roads, major roads and railway line.A major road connects Zaria to Funtua on the southern part, and another connectsFuntua through Bakori to Makurdi on the way to Malumfashi at the eastern part.A railway line connectsFuntua through Tafoki on the way to Gusau at the western part, and a motorable road links Bokori town through Guga at the northern part of the study area.

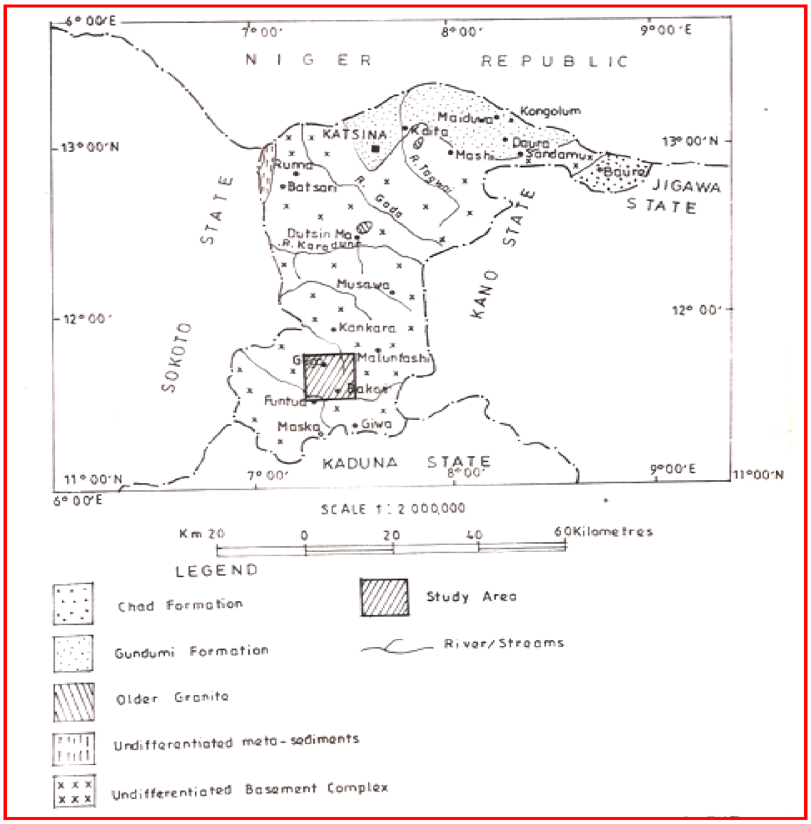

Fig. 1: Map of Katsina state showing the location of the study area.

1.2.2 Relief and Drainage

Generally, relief in the area ranges from 1900ft to 2377ft (579m -725m) above sea level (asl), with the topography composed of gently undulating plains which generally rise gently from 1900ft in the northwest around Kwai, to 2377ft above sea level (asl) around Funtua in the Southwest. The area is underlain by crystalline rocks of the Basement Complex. There are numerous gneissitic, migmatitic and granitic hills, which rise from 60m – 200m above the surrounding plain. The eastern part ofthe study area haveDutsenMakurdi thatforms a linear topographic feature with height of 2300ft (701m)asl, and to the west (Batari Hill) with a horse shoe-like ridge. It forms an elongated quartzite ridge which extends in height of about 30 meters. In the southern part, there is the DutsenNassarawa and Reme Hills that are of 2352ft (717m) and 2377ft (725)asl and DutsenHakuni of 2354ft (718m)asl.

The study area is well drained by a network of rivers and streams (Fig. 2). At the northwest, River Doma and River Magogie and their tributaries drained into River Fatsa. At the northeast, River Gagare and it tributaries drained (flows) northwest. At the southeast, River Jare and River Gora along with their tributaries drain eastward. At the southwest, River Sokoto and it tributaries drains westward. However, all are seasonal rivers systems that contain water in their channels only during the rainy season, with little or no water in the dry season. The pattern of these rivers seems to suggest features of structural significance, which tend to drain almost radially from the central part. Along its path of flow, it forms dendritic flows both in the north and south direction.Streams draining from the Funtua watershed are characterized by high frequencies and densities. These reflect intense head water erosion consequent upon greater land slope (Funtua) and active head water migration of North of the Kano-Chad system. The elevated outcrops as well as the fractures associated within the rocks also control the flow pattern.

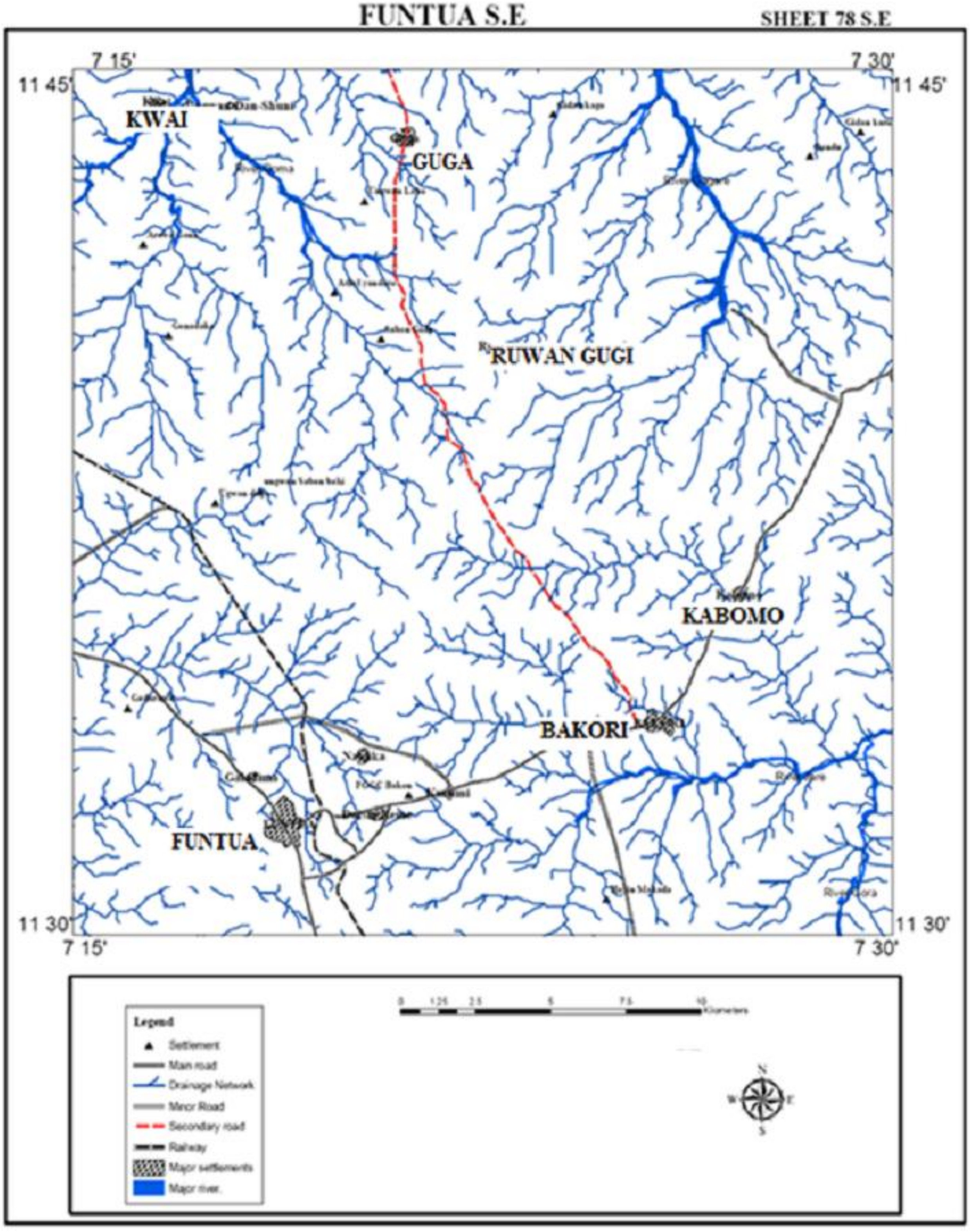

Fig 2: Drainage map of the study area.

1.2.3 Climate and Vegetation

The area belongs to the tropical continental climatic zone of Nigeria with total annual rainfall ranging from 1000mm around Funtua to about 700 to 800 mm as you move northwards. Generally, climate varies considerably according to months and seasons. They are:

- A cool dry (harmattan) season from December to February;
- A hot dry season from March to May;
- A warm wet season from June to September;
- A less marked season after rains during the months of October to November and ischaracterized by decreasing rainfall and a gradual lowering of temperature.

The pool of rainfall data shows that the climate is humid tropical, characterized by a relatively long dry season and somewhat smaller wet seasons. The rainfall, and indeed throughout West Africa, depend upon the interaction of the warm moist tropical maritime air mass and the hot and dry tropical continental air mass. The two air masses meet along the inter-tropical convergence zone (ITCZ) which moves in response to the seasonal disposition of the overhead sun.

Rainfall amounts are generally related to the thickness of the tropical maritime air mass. The tropical maritime air mass is wedge-shaped and thins northwards. Consequently when the ITCZ moves northwards over the study area in May, rainfall becomes progressively heavier and more steady, reaching its peak at about August. In September, as the ITCZ moves southwards, rainfall becomes lighter and sporadically. The rainfall is concentrated in the month of July, August and September, with figures generally from 700 – 800mm annually.

Despite this however, rains have been noted to start from the month of May and June of each year with very limited intensity and duration. Similarly, monthly total rainfall, or annual total rainfall, can vary considerably as shown in Fig. 3a (2008) and Fig. 3b (1941-1970). The patterns show a very strong seasonal cycle, the large variability from year to year and periods of relatively high and relatively low rainfall. The period from 1926 – 1965 was one of the relatively wet spell time, the period from 1966 – 1977 was one of the dry spell, and the period from 1998 – 2007 has a wet spell.

The mean monthly dry season temperatures are above 30˚C, but significantly drop in the harmattan periods that stretch from November to February, when the dry North East trade winds prevail. During this period, the ambient air mass is very dry, cold and dusty during the day and chilly dry at night (Zayyana 2010).During this period, night temperatures can drop as low as between 18 and 21˚C, resulting in a relatively high diurnal range of temperature. In the rainy season month of July and September, temperatures of about 22 to 28˚C prevailed.

Relative humidity in the area never exceeds 20 – 25%; the highest humidity in the area occurs in the month of August and September, while the lowest occur in the month of February and March (Zayyana, 2010).

The study area belong to the Northern Sudan Savannah Zone,the vegetation is dominated by fine-leaved Acacia spp. and their associates. These trees include *Adonsoniadigitata, Parkiabigloboza, Anogeissumleiocarpus, Afrormosialaxiflora, Bombaxcostatum, Boswelliadalzielii, Burkeaafricana etc. The common shrub and shrubby species include Annonasenegalensis, Brideliaferruginea, Gardenia spp, Grewiamollis, Hymenocardiaacida, Lanneakerstingii, May tenussenegalensis, Nauclealatifolia, and Pillostigmathonningii*(Zayyana, 2010).

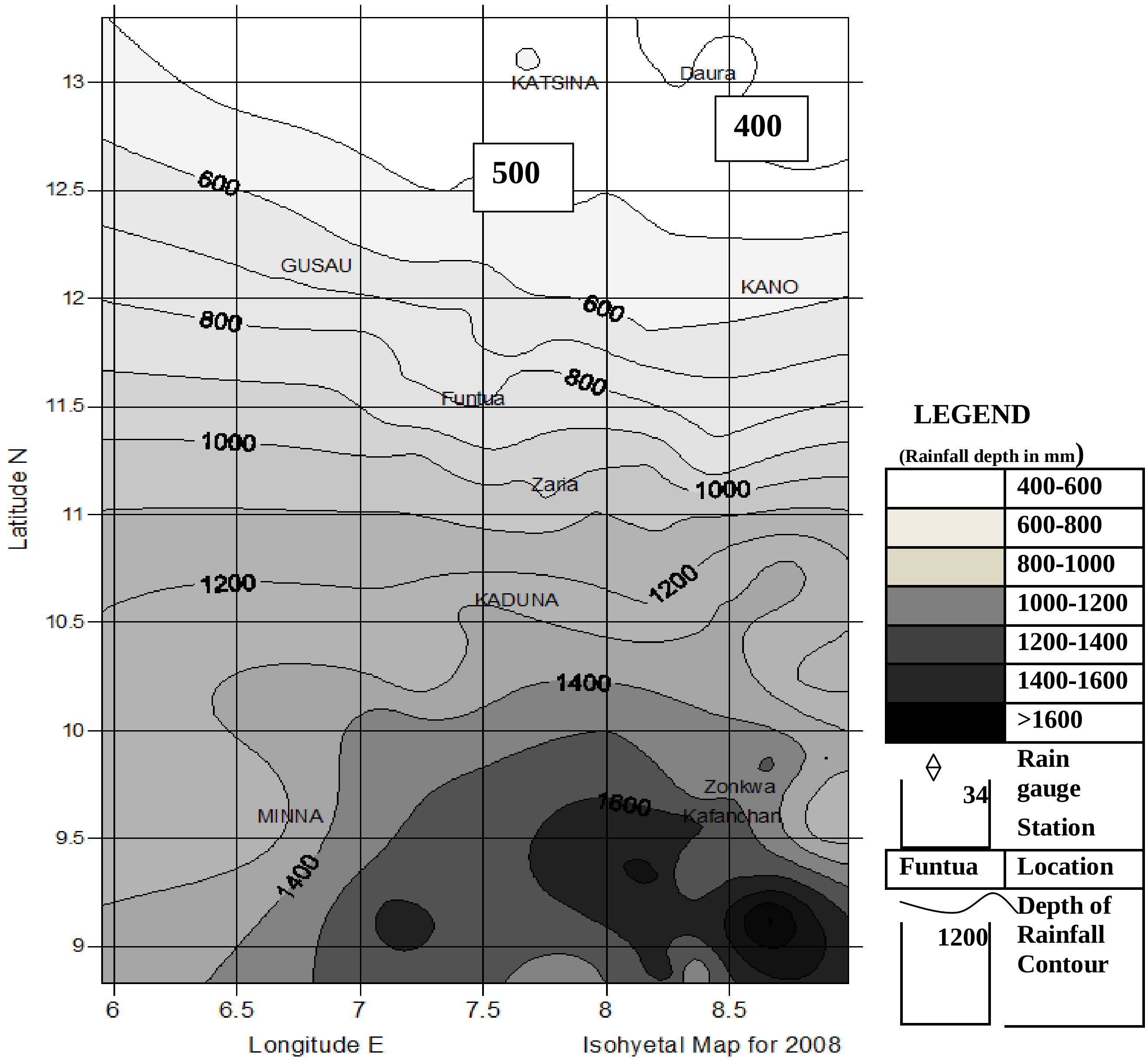

Fig.3a: Annual Rainfalls (mm) from 120 station records,(Source: Jasper, 2010).

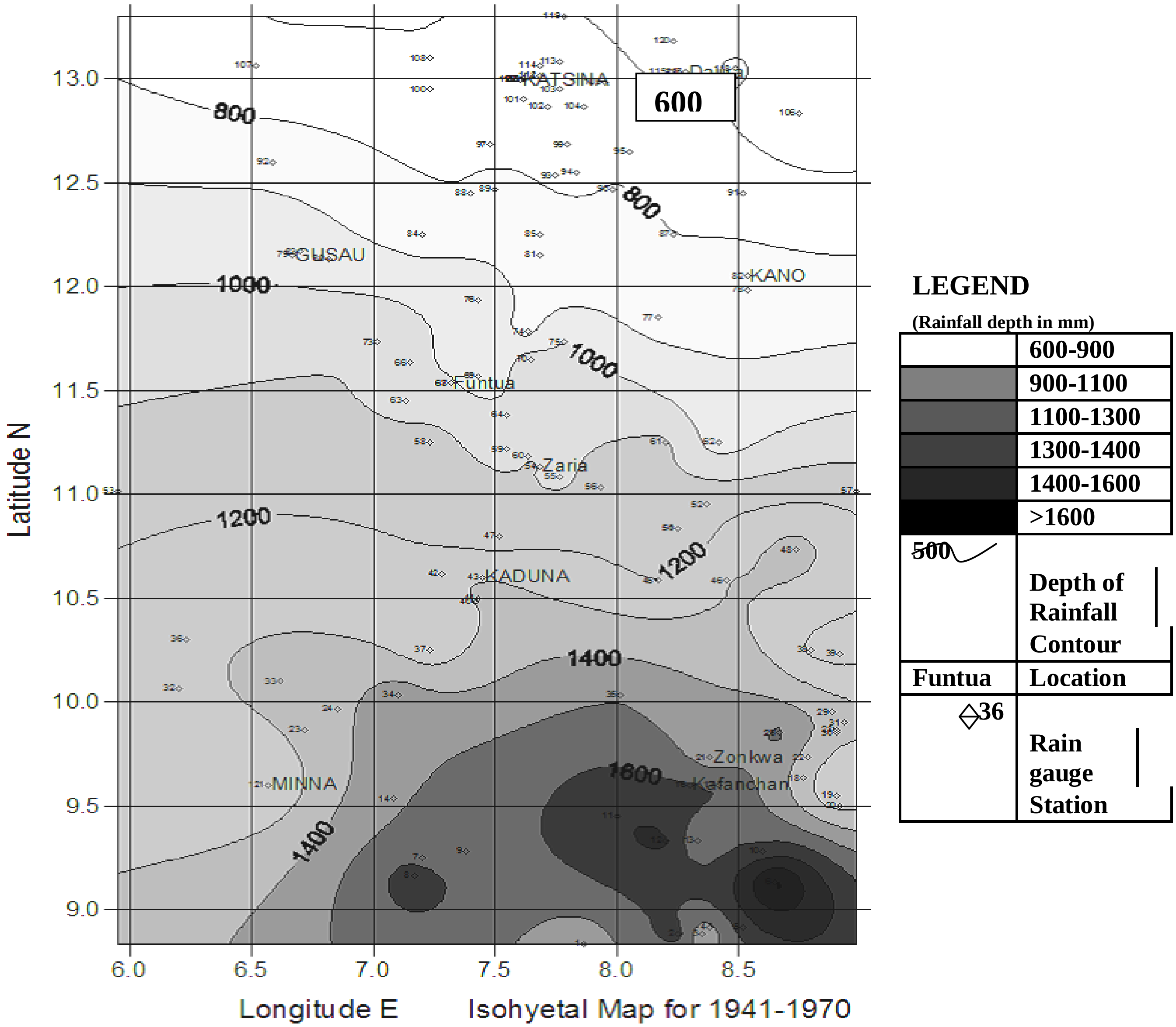

Fig. 3b: Annual rainfalls (mm) from 120 station records, 1941-1970(Source: Jasper, 2010).

The trees characteristically grow long tap roots and thick barks, both of which make it possible for them to withstand the long dry season and bush fires. The grass cover is mostly perennial, with durable roots, which remain underground after stalks are burnt away or wilted in the dry season only to germinate with the first rains. The precise and mixture of the various species is determined by such factors as soil type, moisture conditions, and the degree of human disturbance. The main physiographic communities encountered in order of importance are: cultivated parkland, shrub savanna and floodplain grassland.

The existing vegetation is a function of many years of human interference and degradation. Exploitation of the vegetation has been largely for fuel wood cultivation and grazing. This degradation has been exacerbated in recent years as a result of decreasing rainfall since 1965 by about 30% and especially after drought by the early 1970s (Zayyana, 2010).

Wood is scarce in the area as only 12% of the total area is forested.Most of the forest reserves have few standing trees which occur at the North eastern part of the study area.

1.2.4 Land Use

Land use in the study area is dominated by commercial use, for residential and areas mostly not developed for farming. Aside the major urban land uses, other land uses such as livestock production is also carried out in the area.

Residential area cover most part of the study area, different land uses such as commercial, institutional and educational are also located within the residential area. There exists smaller and two major central markets. The major markets in the area includethe Funtua central market and Bakori central market.

Agricultural activities are confined to open spaces within the built up areas, suburbs and on the stretches of flood plains. Other areas include the little floodable plains of part of the low terrace depressions that retain water, undeveloped lands within the area and other extensive areas just outside the towns.

The most common market gardening crops grown are Okro, cabbage, spinach, sugar cane etc., perennial crops and fruits. The area supports large number of cattle, sheep and goats. All livestock in the area graze on natural pastures and shrubs for their nutritional needs, and supplementary feeding from the owners.

Gathering of Non-Timber Forest Products (NTFPS), form a small but important part of human activities in the study area. Such items provide subsistence goods and services, as well as items of trade. Throughout the area, plant medicines are used for bite, curative and preventive treatments. Fuel wood constitutes the main energy source for cooking. Besides gathering and processing, trading of the products provides a good source of supplementary income to many households in the area (Zayyana, 2010).

1.3 PREVIOUS WORK IN THE STUDY AREA

1.3.1 Regional Geology

The Nigerian Basement lies to the south of the Tuareg shield. Evidence from the eastern and northern margins of the West African Craton indicates that the Pan-African belt evolved by plate tectonic processes which involved the collision between the passive continental margin of the West African Craton and the active continental margin (Pharusian belt) of the Tuareg shield about 600 Ma ago (Burke and Dewey, 1972; Leblanc, 1981; Black *et al*., 1979; Caby *et al*., 1981). The collision of the Plate margins is believed to have led to the reactivation of the internal region of the belt, with Nigerian Basement Complex lying in the reactivated part of the belt.
Within the Basement Complex, three main lithological units are distinguishable, which include:

1.3.1.1 A polymetamorphic migmatitic-gneiss-quartzite complex with ages ranging from Pan-African to Eburnean. It makes up about 60% of the surface area of the Nigerian Basement (Rahaman and Ocan 1978). A polymetamorphic migmatite-gneiss complex composed largely of migmatites and gneisses of various compositions and amphibolites Fig. (4).

The migmatite-gneiss complex is considered to be a basement sensu stricto, and isotopic ages varying from Liberian to Pan–African, have been interpreted as due to isotopic rehomogenization in pre-existing rocks during the Pan- African Orogeny.

1.3.1.2 Low grade Metasediments-dominated, schist belts (including some metavolcanic units) trending N – S, which are best developed in the western part of Nigeria. Some may include fragments of ocean floor material from small back arc basins.

The schist belts are believed to be upper Proterozoic relicts of a supra crustal cover which was folded into the migmatite-gneiss complex (Russ, 1957; McCurry, 1973). The schist belts are intruded by Pan-African granitoids. Examples of the schist belts of Northwestern Nigeria includes: (a) Zuru, (b) Anka, (c) Maru, (d) Wonaka, (e) Malumfashi, (f) Kushaka, (g) BirninGwari, (h) Ushama, (i) Kazaure, and (j) Toto belts.

1.3.1.3 Pre-syn and the post-tectonic rocks of the Older Granite suite which cut both the migmatite gneiss-quartzite complex and the schist belts. They range widely in age (750-450 Ma) and composition. The granitoids include rocks varying in composition from granite to tonalite and charnockite with smaller bodies of syenite and gabbro. The granitoids have yielded radiometric ages in the range of 750-500 Ma which lie within the Pan-African age spectrum. These Pan-African granitoids are called the Older Granites in Nigeria to distinguish them from the Mesozoic, tin bearing granite complexes of Central Nigeria which are referred to as the Younger Granites (Ajibade *et al*., 1989).

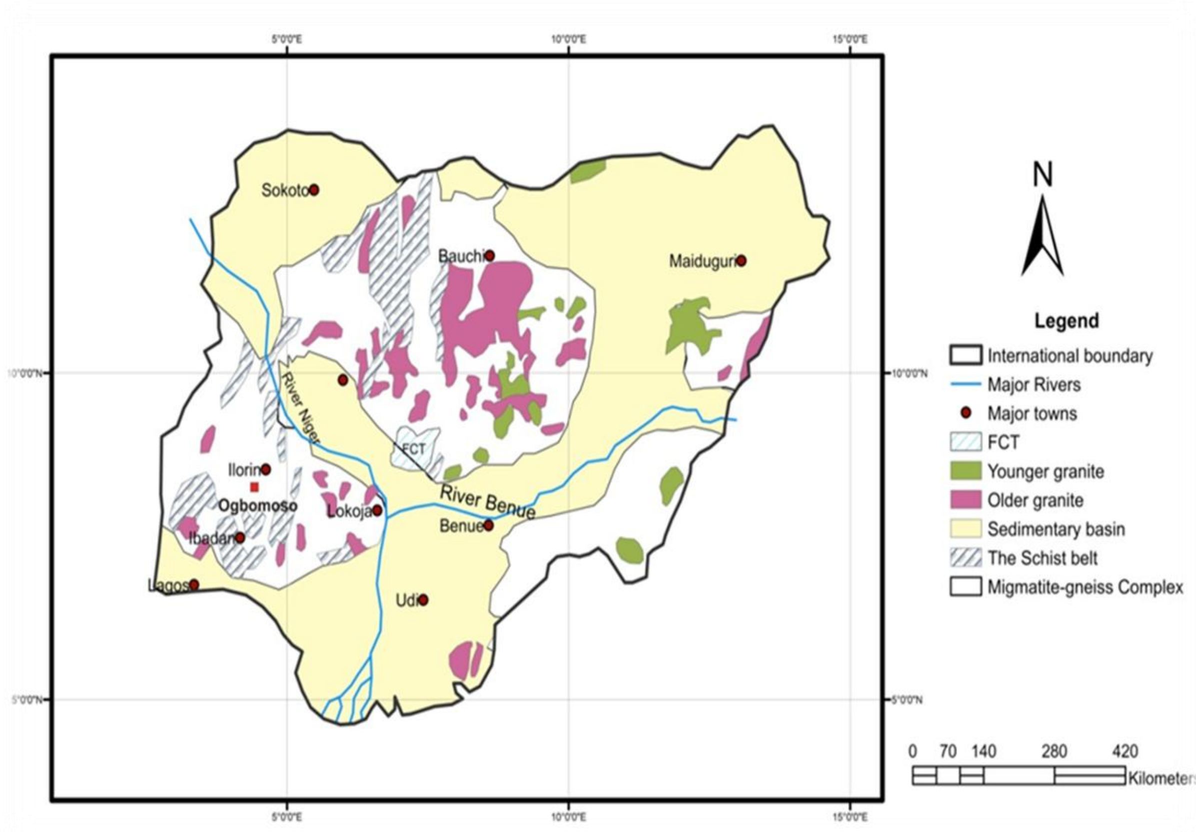

Fig.4: Simplified Geologic Map of Nigeria. (Source: Adanu, 2012)

1.3.2 Hydrogeology

In 1928, the Geological Survey commenced hydrogeological investigation in Nigeria and undertook the actual exploitation of groundwater in Katsina area. The first reports dealing with the groundwater occurrence were published by Jones (1934) and Tottam, (1935). Jones gave a short account of the Geology and water supply of the Daura and Katsina Emirates. Tottam surveyed the Ruma area and described types of Granite and metamorphic rocks and water supply works in Katsina town.

Other earlier workers include Du-Preeze (1961), who researched on the groundwater distribution in the Northern Nigeria. He observed that groundwater could be extracted by open wells and boreholes located in the fracture system in fresh and the weathered portion of the basement complex. Also, in 1965, Du-Preeze and Barber gave an account of the distribution and chemical quality of groundwater in northern Nigeria while Kiser (1968) described chemical quality of water in the northern Nigeria.

Akpoborie (1972) reported that structures developed in rocks such as joints and fractures control the storage and flow of groundwater in the basement complex.

Uzoma (1973) and Adefila (1973) described the problems of groundwater investigation in the Northern part of the old Kaduna State which cover parts of the present southern Katsina.

Hazell et al. (1988) carried out geological and geophysical investigations for groundwater development in various part of the basement complex of Northern Nigeria using combined Electromagnetic and Electric resistivity methods. Potential groundwater areas for development were delineated and recommendations were made for further studies in the area.

From the analysis of Deuterium and oxgygen-18 variation in water samples from the basement complex, Adanu (1989) reported that rainfall is the primary recharge sources of the groundwater in the Basement Complex terrain.

Hydrogeological setting of an area is generally controlled by factors such as geology, structural features and climate. This is due to the fact that the geological formations underlying an area and the associated structures do determines the type and nature of aquifer to be encountered, while climate determines the amount and rate of recharge of the aquifer (Davies *et al*. 1966; Todd 1980; and Tijani, 1994).Basement aquifers are of particular importance in tropical and sub-tropical regions both because of their wide spread extent and accessibility and because there is often no readily available alternative source of water supply, particularly for rural population (Wright, 1992).

In Crystalline Complex, the porosity of rocks determines its hydrogeological properties and this depends on the texture and mineralogy. Groundwater availability in the basement complex is unpredictable because potential good aquifers are localized and not widespread, furthermore; physical make-up of the rock vis-à-vis development of structures is generally not favourable for storage and transmission of economic supply of water (Dunama, 2000).

Groundwater tends to be limited in the basement terrain and other crystalline rock setting the study area inclusive. It is often localized into small interconnected weathered and fractured rocks. In fresh non fractured crystalline rocks, the porosity is often less than 3%. However, this can be increased considerably by fracturing or weathering. In the weathered zones, a lot of void space is created and groundwater stored therein. The highest permeability is found in the partly decomposed levels below the predominantly clay soil mantle of the bedrock (Mijinyawa, 2010).

Rocks dominated by unstable ferromagnesian minerals tend to weather into clayey, sometimes micaceous, impermeable, non-water bearing rock formations. However, rock consisting mainly of quartz and other stable minerals will disintegrate into porous and permeable water-bearing gravelly or sandy medium. The average yield of metamorphic and plutonic igneous rocks decreases rapidly with depth. This decrease is due to the combined effect of the weight of the material overlying the rock. The increasing weights of the overlying rock tend to close the joints, fractures and faults at depth. In the Basement complex, where the rocks are predominantly gneiss and migmatite, the relief is generally low; while deep weathering is common with attendant widespread variation in groundwater level.

For the purpose of groundwater exploration, the weathered aquifer unit is considered relatively more important compared to fractured crystalline unit not only because of its highstorage capacity, but because of the groundwater occurs at a shallower depth and can be tapped by hand dug wells (Mijinyawa, 2010).

1.4 AIM OF THE PRESENT WORK

The study is aimed at a detailed investigation of groundwater occurrence in the study area, based on borehole records and field studies of hand dug-wells and by analyzing hydro meteorological, geophysical, pumping test and water quality data.

1.5 SCOPE OF THE PRESENT WORK

The scope of the present work includes:

(i) Producing a geological and hydrogeological map of the study area on the scale of 1:50,000 using topographic map, Sheet 78 Funtua SE.

(ii) Establishing the structural disposition of the area and its control on groundwater occurrence and distribution.

(iii) Identifying possible groundwater flow direction.

(iv) Collect, review and analyse both geophysical, borehole and pumping test data that are relevant to the study area.

(v) Provision of information that can be useful for optimum development and proper management of groundwater resources of the study area. It is intended to serve as a baseline study for reference purposes and to update available records.

CHAPTER TWO

RESEARCH METHODOLOGY

2.1 GEOLOGICAL AND HYDROGEOLOGICAL FIELDWORK

Geological and hydrogeological mapping were carried out along traverses provided by roads and footpaths as well as rivers and streams courses. The base map,topographic sheet Funtua 78SE, scale of 1: 50, 000 covering the study area and Global Position System (GPS) were used for the exercise.

Geological mapping was carried out to locate the different rock types and their geological boundaries. The hydrogeological studies involved the location of wells and other water bodies in the area and the measurement of depth to water level in the wells during the dry and wet seasons of the 2011-2012 hydrological year. Thedepths to water level in hand-dug wells were measured at the end of the rainy season (September/October 2011) and at the peak of the dry season (March 2012). The data obtained were used to construct maps of water table configuration and direction of groundwater flow at the end of the rainy and dry seasons by subtracting the water level measured in meter in the well from the elevation above sea level of that well.

2.2 WATER SAMPLING AND LABORATORY WORK

Water samples from selected wells, boreholes and river were collected and analyzed in order to determine the chemical quality of the groundwater.

Water sample from wells were collected using a clean plastic bucket attached with rope and poured into a clean plastic container. The samples from boreholes were collected directly from pumped boreholes after pumping for some period into clean sampling bottles. Clean sampling bottle was dipped directly into the flowing river to collect water.

Two sets of water samples were collected, one for cations analysis while the other for anions analysis. The sampling bottles for the cations were acidified with 0.5 ml of concentrated nitric acid on each 250 ml of water equivalent. The sampling bottles were labeled, refrigerated and taken to the laboratory the next day for analysis.

The chemical analysis of water samples taken from dug- wells, boreholes and surface water body were done the Laboratory of the National Research Institute of Chemical Technology (NARICT), Zaria and Department of Water Resources Engineering Laboratory, Ahmadu Bello University, Zaria. A total of six wells, three boreholesand a river were sampled following the established sampling procedures.

To obtain accurate results, some properties that are likely to change in the water sample on exposure to the atmosphere, like Temperature, pH and specific Electrical Conductance were determined on the spot before sampling. The cations, Ca^{2+}, Na^{+}, K^{+}, and Mg^{2+}were analyzed using Atomic Absorption Spectrometer (AAS) and Flame Photometer,while Cl^{-} and $HC0_3^{-}$ weredetermined titrimetrically and $S0_4^{2-}$and $N0_3^{-}$ were determined by Colorimetric technique.

Water sample data were collected from Aqua terra sundry service Laboratory, Katsina State in addition to the analyzed sampled water mentioned above.

2.3 PUMPING TEST DATA ANALYSIS

Borehole data (archival) from different Agencies and Consultancy services/Contractors, who have worked in the area, such as the Ministry of Water Resources and Rural Development, Katsina State., Rural Water Supply and Sanitation Agency (RUWASA), Geo-invest Nig. Ltd. were collected. Values of drawdown (s) in meter and time (t) in minutes obtained during pumping test were used to plot the drawdown – time graph on a semi-logarithm paper. The slope values obtained inputted into given formula was used to determine the hydraulic characteristics of the aquifer in the study area.

2.4 GEOPHYSICAL SURVEY

Existing geophysical data of the area were acquired from the Rural Water Supply and Sanitation Agency (RUWASSA), Katsina State,Katsina State Water Board and Geo-invest Nig. Ltd.Vertical Electrical Sounding (VES) geophysical method was used for the geophysical investigation. The electrical resistivity method with Schlumberger array using ABEM SAS 300 C Terrameter was employed for the acquisition of the VES data in the field. This was carried out by passing electric current through two current electrodes and measuring the voltage or potential difference across two potential electrodes. The ratio of voltage to current is multiplied by a geometric factor (a function of the distance between the electrode) to give an apparent resistivity value. A total of twenty four (24) VES points at a lateral distance of 100m apart were investigated. The depth investigatedis 100m.

The acquired field data were first plotted on a log - log paper to produce a field curve which was subsequently correlated with a standard curve using the curve matching method. The data generated were interpreted using Zhody and OFFIX computer software to give information on the geo-electric layers, the thickness of the layers, the resistivity of the layers and depth to bedrock.

CHAPTER THREE

FIELD GEOLOGY OF THE STUDY AREA

3.1. GENERAL DESCRIPTION OF ROCK TYPES IN THE STUDY AREA

The study area is underlain by the Crystalline Basement Complex. The Basement Complex comprises mainly igneous and metamorphic rocks which were overlain by a thin mantle of decomposed weathered rocks, whichinturnwere capped by a superficial laterite crust, top soil and alluvium.

This succession is not uniform and in some isolated locations the basement rock outcrops at the surface in form of hills. These hills are probably the result of the intrusion of Older Granites into the Basement Complex which have undergone long period of denudation, the metamorphosed pelitic sediments which also give rise to the schists, gneisses and migmatites.

Figure 5shows the geologic map of the area which identifies the following rock types. Gneiss forms about 50%, migmatitesforms about 45% of the entire area, granite, schist, quartzite and phyllite which form the remaining 5% of the study area (Fig. 5).

3.1.1 Migmatite

This rock has been grouped as the Older Metasediments and dated as Birrimian in age (about 2500 M.y.). It is believed to be of sedimentary origin but was later profoundly altered into metamorphic and granite conditions (Oluwu, 1967). Migmatite is the second most dominant rock type in the study area. It occupies about 45% of the study area. Outcrops of migmatite occur as elongated body of low lying ridges and whalebacks with average height of about 18 meters. It occupies mostly the southwestern portion and few others scattered within the study area. The migmatites commonly show granoblastic texture and swirled foliation with large blocks of undisturbed banded gneiss as the rock exhibits alternating bands of light and dark bands. Biotite, muscovite, plagioclase and quartz constitute the visible minerals. The rock in hand specimen is coarse grained and dark in color with layering and folding of the felsic (leucosome) minerals and mafic (melanosome) minerals (Plate 1).

Plate 1: Migmatite exposure at 500m south ofGanjar(latitude 11°36’57.6”N and longitude 07°25’38.34”E)

3.1.2 Gneiss

The gneiss occurs in various sizes ranging from low lying isolated outcrops of less than 1 m² in size to fairly huge bodies of more than 200 m² which sometimes forms extensive ridges. It varies in texture from being medium, even-grained to coarse porphyroblastic. The outcrops are pinkish to very dark grey, strongly foliated with associated joints and quartz veins. The mineralogy includes orthoclase feldspar which is pinkish, quartz which is colourless, and biotite which is flaky and dark in the rock.

The gneissic banding is more prominent towards the north of Batari Hill and along the south-western part of the Kabomo Bridge (Plate 2). It is well exposed along river channels and few outcrop in the northern portion of the study area. It is recognized by its strong foliation, which is defined by the alignment of minerals (gneissosity). The gneiss exposure along the river channel which is weathered shows light grey to white colouration. It is affected by both chemical and physical (exfoliation) weathering. The outcrops generally display a porphyroblastic texture and elongated along N-S. Structures such as joints, foliations, quartz veins and pegmatite veins are observed on the gneiss outcrops.

Plate 2: Field view of a well exposed outcrop of gneiss on the south-western part of the Kabomo Bridge (Latitude 11°35'54.6"N and Longitude 7°27'23.8"E)

3.1.3 Older Granite

These are the magmatic products of the Pan-African Orogeny.Older Granites are widespread throughout the Basement Complex and occur as large circular masses within the schists and the Older Migmatite-gneiss complexes. The Older Granites vary extensively in composition. The granite is coarse grained and fairly jointed without foliations. The major minerals are feldspars, quartz and biotite.

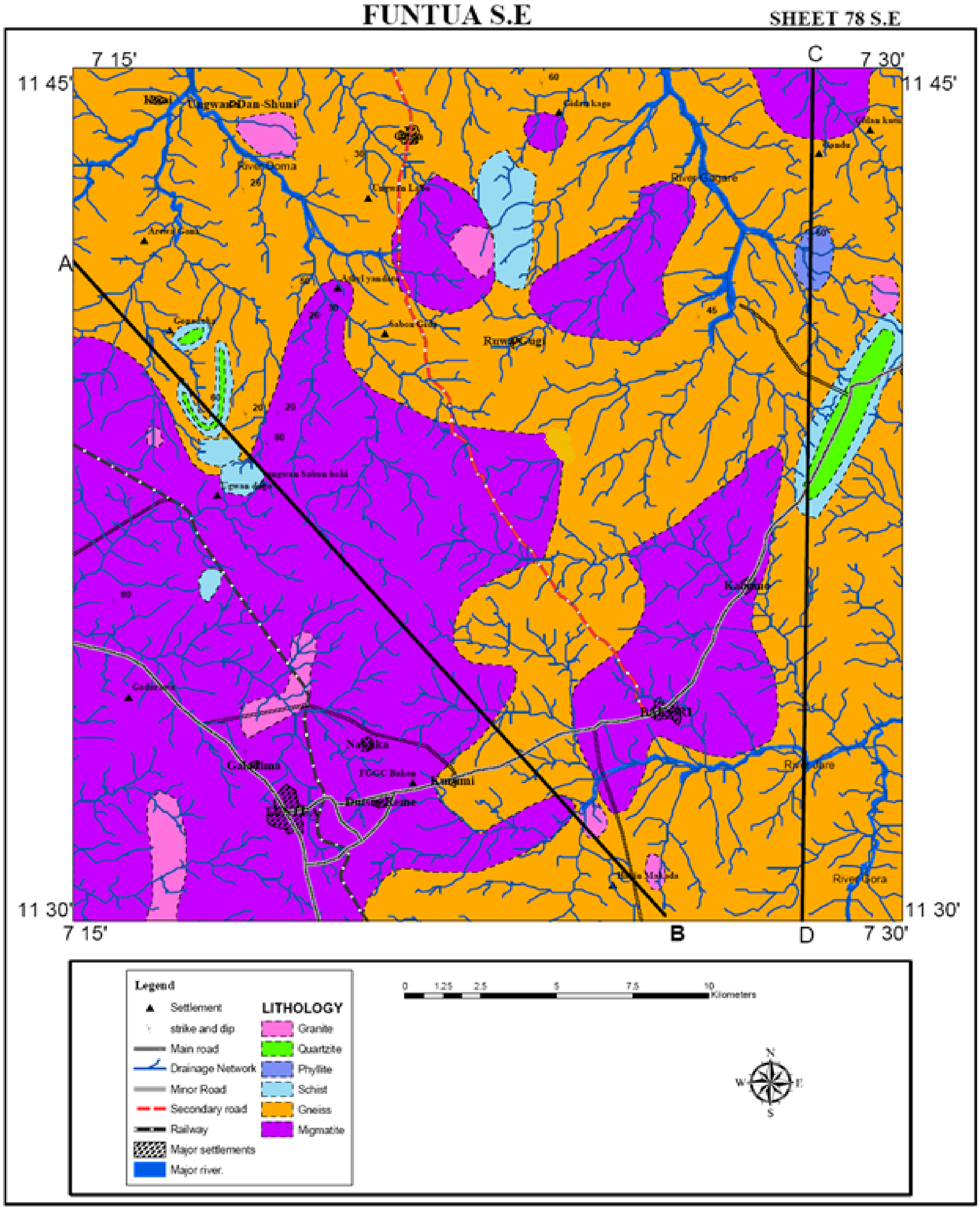

Fig. 5: Geologic map of the study area Produced by H. O. Onaji (2014)

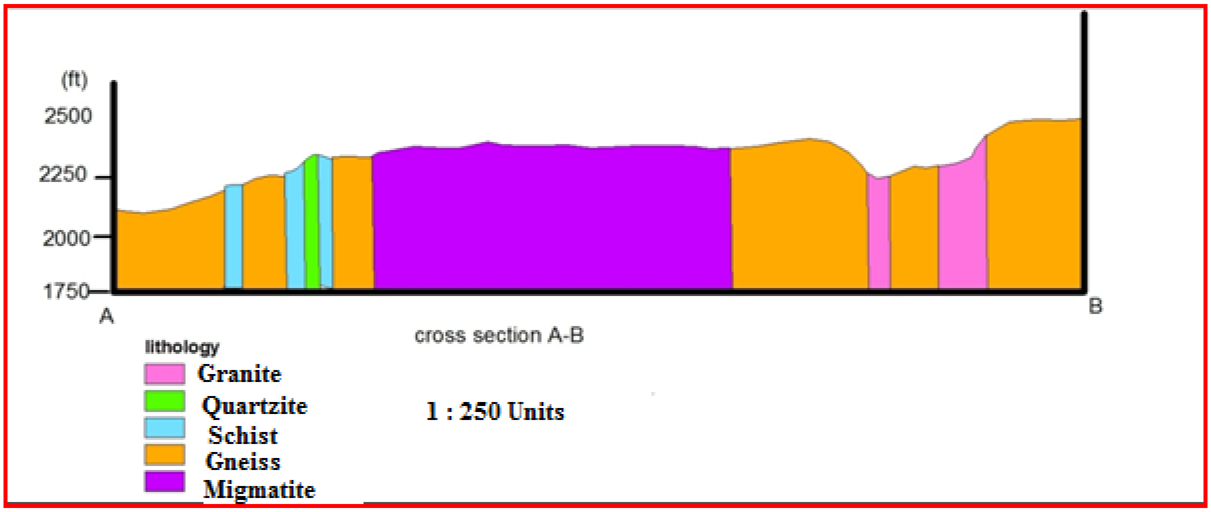

Fig.6a: Cross section A-B of the geological map of the study area.

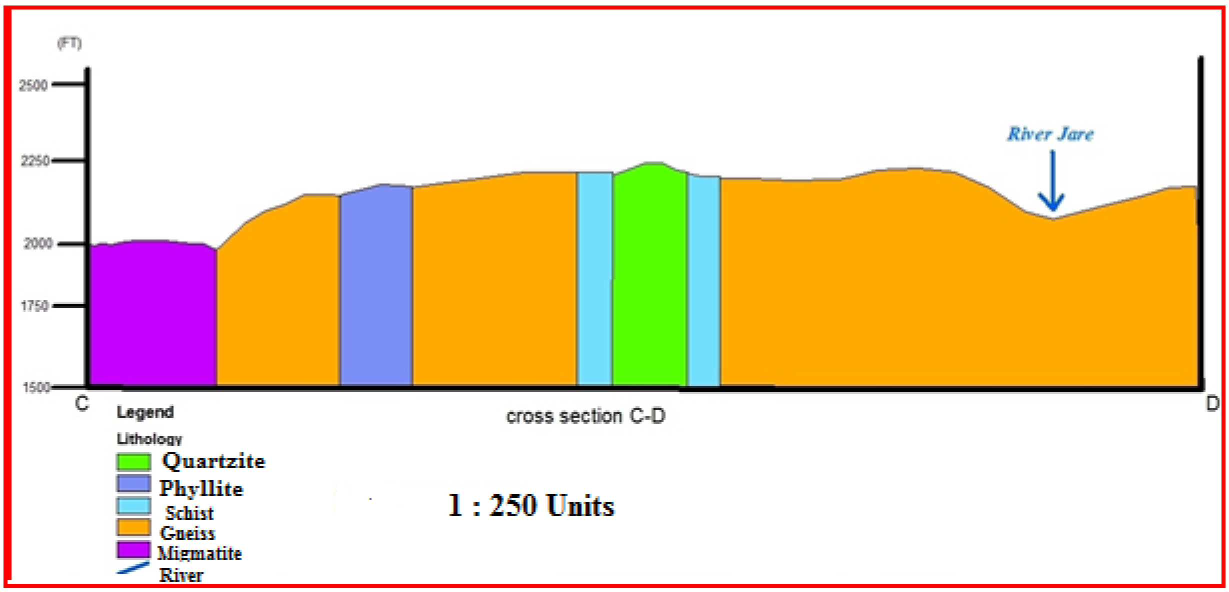

Fig. 6b: Cross section C-D of the geological map of the study area.

3.1.4 Schist and Quartzite

These metamorphic rocksschist and quartzite occur in the eastern part of the study area (Fig. 5). The quartzite occurs as a ridge known as the Kabomo ridge which forms part of the Malumfashi schist belt. It also occurs on lowland in the northwestern portion of the study area which flanked the Batari Hill along river channels. The schist belts are believed to be upper Proterozoic relicts of a supra crustal cover which was folded into the Migmatite-gneiss Complex

(Russ, 1957; McCurry, 1973). The major rock types are ancient shally rocks which are now referred to as quartz-biotite-muscovite schist. These change laterally into coarse-grained feldspar-bearing micaceous schists which are medium to coarse grained with mineralogy mainlyof muscovite and quartz, foliated with well-defined schistosity due to the presence of platy minerals. The foliation has dip values ranging from 42^0 to 60^0trendingin the N-S direction typical of the Pan-African Orogeny.

The schist is associated with cobble and pebbles of quartzite which is an indication of schist underlying the area. The schist is reddish-brown with shiny flakes of micaceous minerals (muscovite and biotite but dominantly muscovite) and plagioclase feldspar. It is badly weathered in burrow pits and along river channel. Differential weathering of the terrain has produced a low-lying topography where the schist outcrops. Plate 3 shows quartzite embedded within schist occurring at north of UngwanUsmanDogoTafoki.

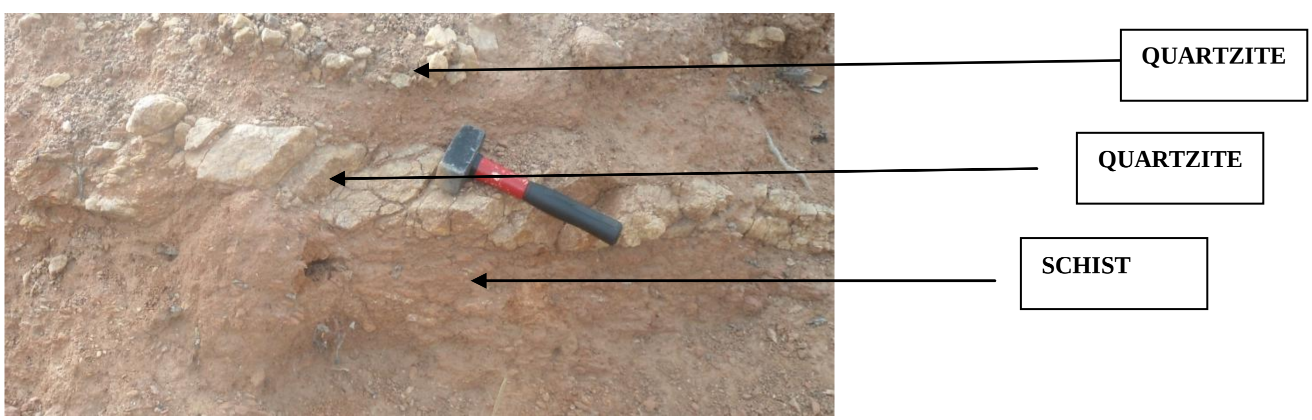

Plate 3: Photograph of quartzite vein within schist, 520m north of Ungwan UsmanDogoTafoki(Coordinate: 11˚38′17.1N, 7˚17′33.8E) (Hammer= 30cm)

3.1.5 Phyllite

Phyllite was found at the north of the schist belt. It is a lower grade metamorphic rock compare to schist.

3.1.6. Pegmatite

These are tabular structures or sheet like bodies of mineral form which have intruded into a joint or fissure. The pegmatite found in the study area occurs both as dykes and also as pod-like structure which are fairly small cutting through all the lithologies in the study area. It was observed at northwest of Kabomo (Plate 4). The pegmatite is leucocratic and is distinguished from other bodies which it intrudes by their colour and texture. It is composed of very coarse crystalline orthoclase feldspar with some measuring up to seven centimeter (cm), coarse quartz measuring about three centimeters and micas (biotite) measuring about one centimeter.

The dominant mineral is the orthoclase feldspar about 60-75%, followed by quartz, about 25-15% and then biotite 10-15%. The pegmatite occurring in migmatite as pod-like bodies indicates that there was a stage of slow cooling during its crystallization. The pegmatite occurring on the gneiss exposures due north of the study area are coarser and larger, which therefore indicates they are of different rate of cooling.

3.1.7 Superficial Deposits

3.1.7.1 Laterite

Lateritic capping occurs in most of the study area. They are reddish brown with ferruginous concentrations. Laterite is formed from the laterization of rocks. It is both in consolidated and unconsolidated form with pebbles of quartzite inter-bedded in it and occurs as ridges which are distributed toward the south of Batari Hill showing sharp contact with gneiss (Plate 5). Other exposure occurs along the Kabomo ridges as a result of decomposed schist.

Plate 4: Pegmatite within gneiss located 25m northwest of Kabomo(latitude 11°37’84.6”N and longitude 7°26’38.34”E)

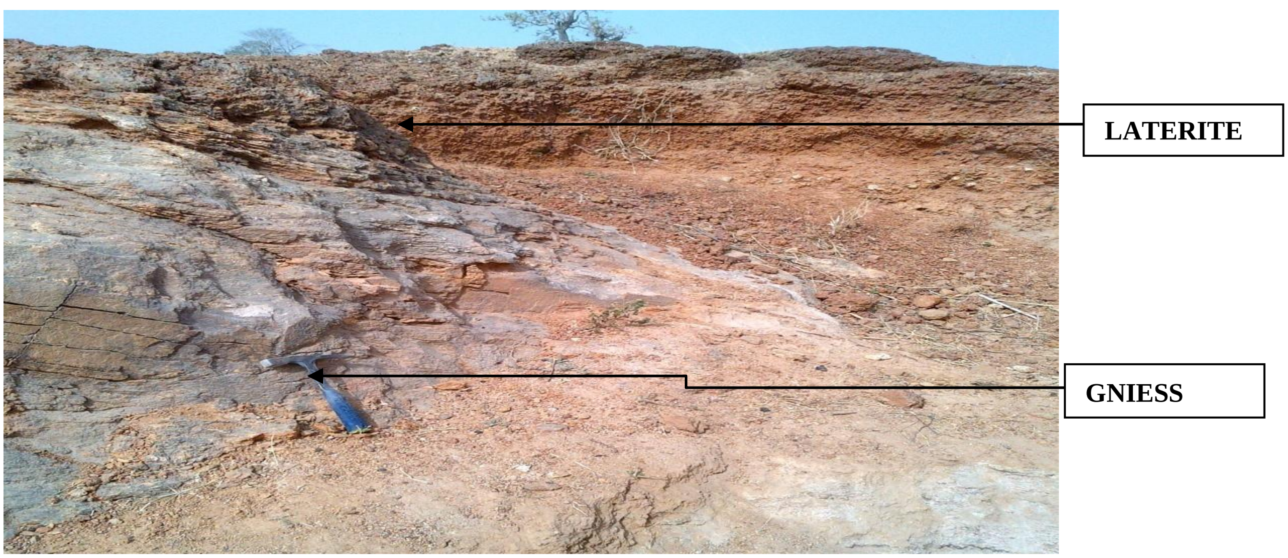

Plate 5:Ferruginous laterite overlying gneiss with sharp contact
150 meters south of BatariHill (Coordinate: 11˚38′18.9N, 7˚17′20.8E)(Hammer= 35cm)

3.1.7.2 Alluvium

Alluvium consists of weathered materials that is washed from the basement hills and accumulated in the depression and plains, occurring over a large area together with untransported weathering residues in the area. The alluviums are also deposited along the major rivers and their tributaries. In the study area, alluvium tends to cover the entire region except areas where the basement rock outcropped with less weathering.

This alluviumdeposits can generally be subdivided into hydroclastic deposits, slope deposit, and aeolian deposits (Tokarski, 1971). The hydroclastic deposit is made up of younger alluvium which is the product of the most recent cycle of grey-brown sands, silts and clays, while the slope deposits are derived from the pre-existing layers.The aeolian deposits, which form an extensive cover almost the whole area, are derived from large quantities of dust brought annually by harmattan winds. The components of the drift cover, however, are difficult to distinguish.

3.2 GEOLOGIC STRUCTURES

3.2.1 Joints/Fractures

These are openings found within the migmatite, gneiss and granite but there is no relative movement or displacement of the rock unit. These joints are trending NE/SW and are discontinuous. Both curvilinear and orthogonal jointingare present in the area whichgave rise to exfoliationas seen in the gneiss and migmatite gneiss, while the orthogonal jointing occurs within the quartzite and granite.Joints/fracturesin the basement rock vary greatly in lateral extent and depth. They may form cracks to open fissures (Plate 6).

The prominent structural trends are the N-S, NE/SW and NW/SE. These joints provide permissive fracture into the rock outcrop through which water infiltrates to enhance chemical weathering of the rock. Joints are important in controlling topography and drainage pattern of the area and also enhance weathering processes. All jointsmeasured in the field were recorded and displayed or plotted in rosette diagrams (Fig. 7a and 7b).

Plate 6: A joint observed on gneiss outcrop at KaropinDoka striking 009°

3.2.2 Faults

These are features found on rocks showing evidence of movement or displacement. Most of the faults are dextral fault with displacement ranging from about 2cm to 12cm. A normal fault along a stream channel was mapped on a gneissic rock near Kabomo (Plate 7). The relative displacement is about 23cm and it trends 010°. This fault is due to relative displacement of block along a fractured plane.

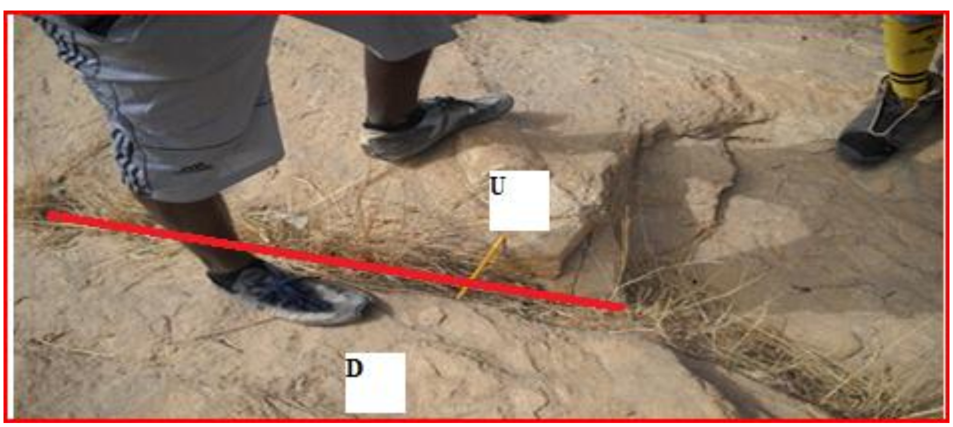

Plate 7: A normal fault on gneiss 105m NWKabomo(Latitude 11°35’54.6”N and Longitude 7°27’23.8”E). Note the upthrow (U) and downthrow (D) side of the fault line marked red.

3.2.3 Quartz Veins

These are discordant veins and generally in filled by quartz. They vary in length ranging from 5cm to 2m, with an average diameter of 0.5cm to 2cm. The veins are oriented in the NE-SW direction which indicates that quartz generally in filled the fractures. Majority of the veins strike between 0 and 30 NE, sizes ranges from 3.5 to about 15cm. Quartz Veins are widely distributed in the study area. They occur in the migmatites and gneisses. Example is shown in plate 8.

Plate 8: A quartz vein within gneiss outcropping near Kabomo at latitude 11°35'50.6"N and longitude 7°27'23.58"E

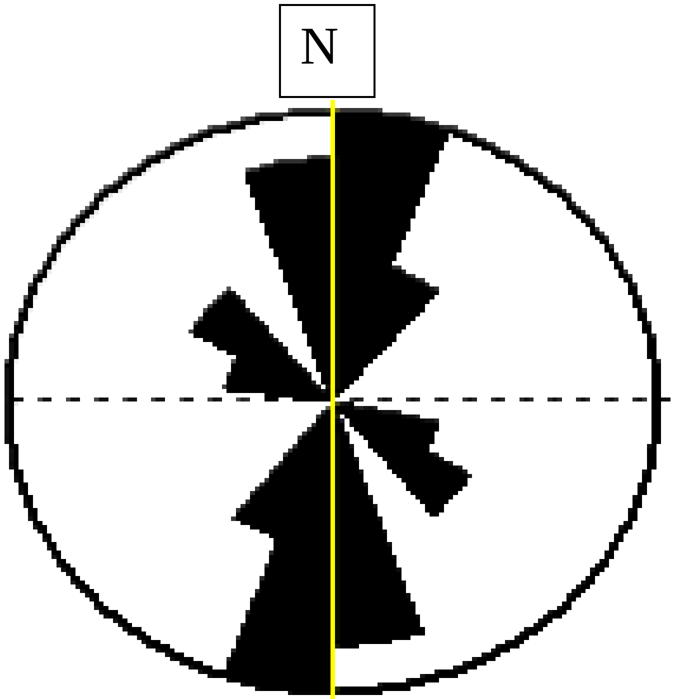

Fig. 7a: Rose diagram of the joints in a migmatite
Scale=1cm represents 2units

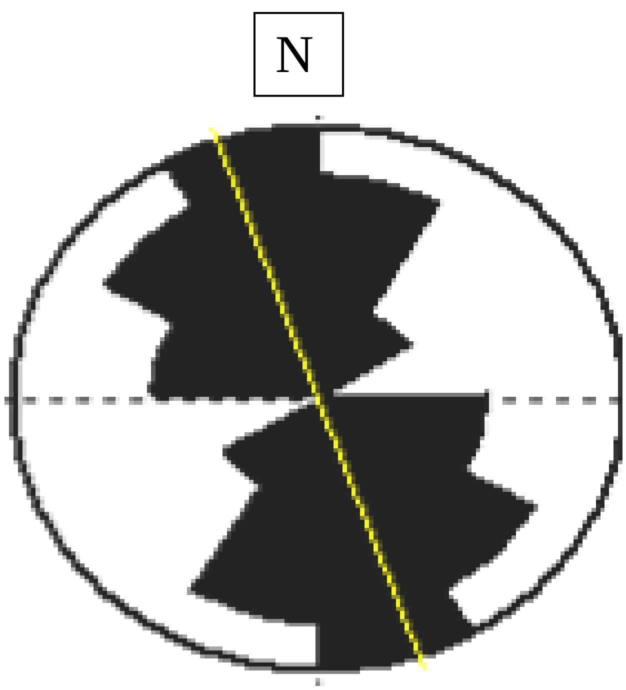

Fig. 7b: Rose diagram of the joints in gneiss.Scale=1cm represents 2units

CHAPTER FOUR

HYDROGEOLOGIC INVESTIGATIONS

4.1 GEOPHYSICAL INVESTIGATIONIN THE STUDY AREA

Groundwater occurrence and distribution in Basement Complex is localized and confined to weathered /fractured zones. It is one essential but necessary substitute to surface water in every society. Hence exploration for groundwater in such terrains posses a great challenge to groundwater development agencies as in most cases, the risk of failure of such projects is very high.Consequently, the identification of sizeable fracture and deep weathered zones, which provide good aquifers by means of surface geophysical investigation, is highly desirable. The failure rate in most groundwater project recorded in Basement Complex aquifers has informed the general acceptance of a geophysical survey as a compulsory prerequisite to any successful water well drilling project (Dan Hassanand Olorunfemi, 1999). The geophysical data obtained from Geo-Invest Nig. Ltd and RUWASSA shows that the Vertical Electrical Sounding method was employed to investigate and assess the subsurface within the study area.

The fundamental equations governing the application of resistivity method in exploration are derived from ohm's law. The electrical resistance of, for example, a piece of wire is defined as the potential difference (voltage) across it divided by the current flowing through it. (Zohdy, et al. 1974; Telford et al, 1976; and Dobrin, 1976).

R = V/I----------------------------- (1)

Where R = resistance

V = Voltage

I = Current

The resistance is a function of the dimensions of the wire and the resistivity of the material of which it is made.The resistivity of a material, an intrinsic property of the material, is then related to experimentally measure extrinsic parameter by:

ρ= (V/I) (A/L) =Rapp K----------------------------- (2)

whereρ = resistivity

L = length of material

A = Cross-sectional area.

Rapp = Apparent Resistance

K = geometric factor (A/L)

The resistivity is given by the product of the "apparent resistance" Rapp = V/I and a "geometric factor" k = A/L that carries information about the geometry of the material.

As a rule of thumb in the principle of the Schlumberger layout, the measured current and voltage values are increasingly influenced by deeper parts of the earth when the spacing of the input electrodes (A, B) increases. Since the so called "depth of Investigation" is mainly influenced by the spacing of electrodes A and B, it is easy to obtain a vertical resistivity profile by employing different spacing A-B and a constant spacing between M and N (Fig. 8).

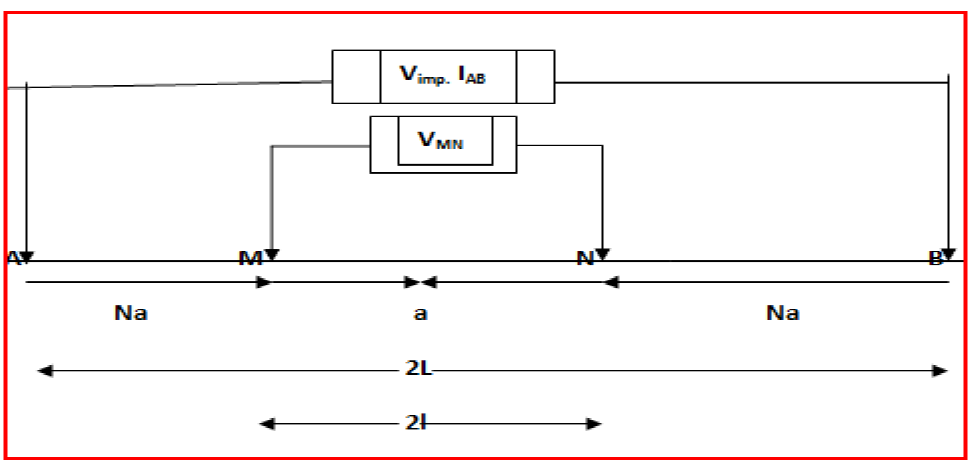

Fig. 8: Principle of a Schlumberger –Layout most suitable for resistivity sounding.

General: L = AB/2: l = MN/2

$$\rho_a^{Schlumberger} = \pi \times \frac{(L^2 - l^2)}{2l} \frac{V_{MN}}{I_{AB}}$$

For geophysical work, resistivities are usually quoted in units of ohm-metres; the inverse of resistivity is conductivity. An alternative way of expressing ohm's law is that the potential gradient is equal to the product of the current density and the resistivity (GWRD, 1986).

The results of the 24 VES points are presented in Table 1. The simulated results of the 24 VES points reveal the presence of about 4 - 6 Geo-electric layers.

These layers are grouped as: topsoil (clayey, sandy or lateritic), weathered basement (clays/sandy clays), slightly weathered/ fractured basement (clayey sand) and fresh bedrock. The resistivity of the topsoil varies from 6-395 ohm-m while the thickness varies from 0.15- 9m. The resistivity of the weathered basement range from 6 - 233 ohm-m, while the thickness ranges from 0.3- 11.98m respectively. The resistivity of the slightly weathered/fractured layer ranges between 16- 105 ohm-m, while thickness ranges from0.9-15.4m. The resistivivity of the fresh bed rock is in the range of 217- 1219 ohm-m.

The aquifer in the study area is therefore defined by the highly weathered zone and the slightly weathered/fractured zones which are in agreement with Ariyo, 2007 and Olayinka, 1999 observation that, common aquifers in typical Nigerian basement complex are composed of weathered and fractured basement. The variation recorded in the resistivity and thickness of the aquiferous materials is due to the different rates at which different rocks respond to weathering from one location to another.

Table 1: Results of the VES investigation in the study area using Schlumberger Array

S/NO	Locations (VES)	1st layer Thickness (m)	1st layer Resistivity (ohm-m)	2nd layer Thickness (m)	2nd layer Resistivity (Ohm-m)	3rd layer Thickness (m)	3rd layer Resistivity (Ohm-m)
1	**GidanBarmo**	0.4	105	1.63	25	5	40
2	**Kawari**	0.4	56	1.01	117	6.83	80
3	**FGGC Bakori**	0.56	300	0.5	163	5.6	97
4	**Gwamutsawa**	0.75	50	13.1	32	7.2	56
5	**LimansaaduSani Sch.Bakori**	0.4	336	1.1	8	0.76	13
6	**KabomoGari**	3.4	18	8.5	45	5.8	80
7	**Rafin/S/Zango**	0.2	50	0.7	22	1.6	56
8	**S/HayinKakumi**	0.5	395	0.3	233	0.4	115
9	**Yankwani**	0.2	24	1.2	32	2	46
10	**Hadiqutul Quran, Zaria Rd.Funtua**	0.3	106	0.5	10	18	0.4
11	**Ramalan Annex**	9	6	5	11	7	30
12	**Fire service, Funtua**	0.5	50	2	6	6	40
13	**Daawa field Office**	0.5	50	8.33	25	5.05	50
14	**Alaramma Mai Gidan Kara,Bakori**	3.6	18	4.54	30	10	70
15	**Yantandu**	0.5	35	2	17	11	38
16	**Tafoki Road**	0.22	25	1.55	99	13	18.5
17	**Bagari Mosque**	0.5	60	8.48	18	11	74
18	**Ganjar**	0.9	60	1.6	80	1.4	60
19	**AlarammaSabiu**	0.41	10.5	11.98	18	10	50
20	**Sabuwar Abuja**	0.6	30	3.8	24	5.6	16
21	**Jumat Mosque, D/Reme**	1.3	7	2	26	4	105
22	**HayinAlhaji**	0.15	7	2	26	4	105
23	**Layin Gora**	0.2	15	1.25	8	0.9	21
24	**Mashanya**	0.56	57	6.1	80	15.4	27

Table 1: Results of the VES investigation in the study area using Schlumberger Array (Continued)

S/No	Locations (VES)	4th layer Thickness (m)	4th layer Resistivity (ohm-m)	5th layer Thickness (m)	5th layer Resistivity (Ohm-m)	6th layer Thickness (m)	6th layer Resistivity (Ohm-m)	Estimated Depth to Basement (m)
1	**GidanBarmo**	35	90	12	652	-	-	24
2	**Kawari**	4.08	145	6	328	-	-	19
3	**FGGC Bakori**	15.43	90	10.4	220	-	-	33
4	**Gwamutsawa**	10.5	156		546	-	-	33
5	**LimansaaduSaniSch .Bakori**	2.8	60	11	600	8	1219	24
6	**KabomoGari**	5.8	132	-	217	-	-	27
7	**Rafin/S/Zango**	6.4	40	11	90	10	170	30
8	**S/HayinKakumi**	3.5	80	9	117	8	252	27
9	**Yankwani**	4.6	30	5.82	62	7.5	157	27
10	**Hadiqutul Quran, Zaria Rd.FT**	1.2	29	1.8	64	2.7	141	27
11	**Ramalan Annex**	18.34	115	-	-	-	-	21
12	**Fire service, Funtua**	4.4	70	6.5	130	10	605	30
13	**Daawa field Office**	4.4	113	16	396	-	-	30
14	**Alaramma Mai GidanKara,Bk**	0.08	118	8	218	-	-	24
15	**Yantandu**	6.5	80.86	10	600	-	-	30
16	**Tafoki Road**	7	70	10.5	512	-	-	32.3
17	**Bagari Mosque**	9	310			-	-	30
18	**Ganjar**	5	40	4.4	76	16	250	30
19	**AlarammaSabiu**	21.1	652	-	-	-	-	30
20	**Sabuwar Abuja**	4.6	25	7.1	45	10.5	81	33
21	**Jumat Mosque, D/Reme**	3.6	194	5.2	341	10	577	24
22	**HayinAlhaji**	3.2	107	11.6	-	-	-	22
23	**Layin Gora**	16	60	8.6	162.5	-	-	27
24	**Mashanya**	10.7	83-306	-	306	-	-	33

4.2 AQUIFER IN THE STUDY AREA

Based on the geologic nature of the zone, two major types of aquifer can be identified. These are weathered overburden/intermediate aquifers and fractured basement aquifer.

4.2.1 Weathered Overburden/Intermediate Aquifers

This is the best aquiferous zone. It represents a mantle of in-situ weathering products which are quite variable and highly weathered, degrading to material containing a very high proportion of kaolinite. This stage of weathering is often found in the uppermost part of the zones and its extensiveness and storage potential is significant (Eduvie, 1989). The weathered mantle is permeable because of its cellular and concretionary texture. In the intermediate zone, there is good expectation of groundwater production with an average thickness of about 6 metres (Eduvie, 1991).

Majority of hand-dug wells in these areas terminate in this part of the zone. However, the aquifers are more productive at the base of the weathered zone where the rocks have been broken down into sand size and larger fragment that are not subjected to the extensive weathering process (Offodile, 1983; Jones, 1983 and Egboka, 1989).

4.2.2 Fractured Basement Aquifer

Groundwater in the fresh Basement rocks is restricted to fissure systems, cracks, joints and fractures. The ability for crystalline rocks to store and transmit water depends on the development of secondary openings formed by fracturing and weathering. It is important to note that the capacity of these rocks to store, allow movement and yield water, chiefly depends on the extent, pattern, size, openness and continuity of the fractures and the degree to which these fractures are hydraulically connected.

4.3 BOREHOLE AND PUMPING TEST DATA

4.3.1 Borehole Data

The borehole data that were used for this work were from RUWASSA, STROJEXPORT DevelopmentNigeria Ltd and GEO- Investment Ltd.

The pieces of information cover some of the settlements in the study area.

For each borehole, information on location, borehole depth, depth to static water level, pumping rate and drawdown is as shown in Table (2)

4.3.2 Pumping test Data

Pumping test data from twenty (20) boreholes located in the study area were used. Each well was pumped at a given discharge rate, with each pumping session lasting between 240 to 600 minutes. The limitation of the data is linked to the duration of the test, and lack of observable wells.

4.3.3 Aquifer Characteristics

Most commonly, an aquifer test is conducted by pumping water from one well at a steady rate and for at least one day, while carefully measuring the drop in water levels in the monitoring wells. When water is pumped from a pumping well, the pressure in the aquifer which feeds the well declines.The decline in pressure will show up as drawdown (change in hydraulic head) in an observation wells. Drawdown decreases with radial distance from the pumping well and drawdown increases with the length of time that the pumping continues. Pumping test data from boreholes located in the study area were use to determine the aquifer characteristic. This involves the pumping of borehole at a known discharge rate (Q) and observing the drawdown (s) in the pumped borehole as the pumping continues.

The aquifer characteristics which are evaluated by aquifer tests include:

(i) Transmissivity

(ii) Hydraulic Conductivity

(iii) Specific Capacity

(iv) Specific Yield

Table 2: Borehole data in the study areaafter STROJEXPORT(1983)

S/no	**Location**	**Borehole depth (m)**	**DWL(m)**	**SWL(m)**	**Drawdown (m)**	**Yield (Q) l/sec**
1-FB 61	DINYA	70	56.88	20.01	36.87	0.91
2-FB 62	UNGWA DAHIRU	35	17.42	3.6	13.82	1.09
3-FB 64	ADAKO	50	29.57	9.10	20.47	0.95
4-FB 65	ZAGIZAKI	68	37.39	13.71	23.68	0.50
5-FB 76	JARGABA	60	28.28	7.52	20.76	0.58
6-FB 77	UNGWA KOTSE KABOMO	48	14.82	8.76	6.06	0.58
7-FB 78	UNGWA ALH. JARGABA	50	22.96	8.02	14.94	0.71
8-FB 79	MORAWA KABOMO	54	17.50	6.67	10.83	3.33
9-FB 96	MAKURDI HAYIN KUDU	75	23.80	15.90	7.90	0.72
10-FB 103	UNGWA TAFIDU	40	18.40	4.62	13.78	0.68
11-FB 105	GIDAN MAIKWARI	40	21.09	9.37	11.72	0.60
12-FB 132	UPE WTC KABOMO	66	25.45	7.70	17.75	0.50
13-FT 35	UNGWA DANJILI	59	17.28	7.90	9.38	0.71
14-FT 37	UNGWA MAJE MAIRUWA	62	18.64	13.20	5.44	0.61
15-FT 41	UNGWA SALLA DUKKE	75	30.45	11.70	18.75	54.00
16-FT 42	UNGWA INJIN DUKKE	53	32.38	11.75	20.63	0.60
17-FT 57	GAURUWA	57	29.62	18.42	11.20	0.68
18-FK 117	UNGWA LIMA YANKIDO	90	34.87	15.90	16.42	1.67
19-FK 121	UNGWA GALAMINA	52	25.24	9.63	51.61	0.90

SWL (Static water level) DWL (Dynamic water level)

4.3.4 Data Analysis and Aquifer Characteristics

The aquifer characteristics of an aquifer depend on its ability to transmit and store water and can be accessed by the determination of three main quantities. These are the coefficient of transmissivity, permeability/hydraulic conductivity and the thickness of the aquifer (Table 3).

4.3.4.1 Transmissivity

Transmissivity represents the water transmitting capacity of a unit width of the entire saturated thickness of the aquifer. Garg, 1981; Todd, 1980, also defined transmissivity of an aquifer as the rate at which water of prevailing kinematic viscosity is transmitted through a unit width of the aquifer under unit gradient. And this could be expressed as the product of permeability and the saturated thickness of the aquifer and can be written as:

$T = Kb$………………………….. (1)

Where:

T = Transmissivity in (m^2/day)

K = Permeability in (m/day)

B = Saturated thickness (m)

Figure 9 shows a pumping test graph using drawdown in meter and pumping time in minute to obtain the transmissivity value in one of the boreholes in the study area.

From the graph, transmissivity values were calculated using the (Modified Jacob's Non-equilibrium Formula) which is based on the recognition that Theis's equation could be greatly simplified if certain restrictions as to the elapsed pumping time or distance from the pumped borehole could be made, essentially restrictions to the value of u (Kruseman and De Ridder, 1983).

Table 3: Results of Pumping test data

S/No	Borehole Location	Borehole Depth (m)	Borehole Diameter (mm)	Dynamic Water Level (m)	Static Water Level (m)	Drawdown (m)	Yield (m^3/ day)	Specific Capacity (m^3/m/day)
1	**Funtua , Near Palace**	38.5	7	16.86	4.60	12.26	79.49	23.37
2	**GanjjarPri. School**	36	6	14.82	3.88	10.94	53.57	8.77
3	**Yankwani, Pri. School**	21	6.5	18.09	2.93	15.16	50.98	7.28
4	**Nabukka, Pri. School**	30	6	20.48	3.90	16.58	24.19	2.52
5	**Ungwar, Danjili**	59	7.5	17.28	7.90	9.38	60.48	12.10
6	**Tudun Wada**	22	6	20.18	6.18	14.00	24.19	3.10
7	**BabbanKufai**	18	6.5	15.30	4.54	10.76	25.92	4.47
8	**HawanDankaki**	18.5	5	14.09	4.30	9.79	37.15	13.27
9	**GidanMaikwari**	40	7.5	21.09	9.37	11.72	51.84	22.06
10	**Ungwar, Lima Yankido**	90	7.5	32.32	15.90	16.42	144.29	78.00
11	**Ungwar,AlhajiLawal**	50	6.5	22.99	8.02	14.97	61.34	27.88
12	**DutseReme, Pri. School**	24	6	8.72	1.71	7.01	72.58	103.68
13	**Jargaba**	60	7.5	28.28	7.52	20.76	50.11	19.27
14	**Ungwar, KotseKabomo**	48	6	14.82	8.76	6.06	50.11	71.59
15	**UngwarDinya**	70	7.5	56.88	20.01	36.87	81.22	4.28
16	**MakurdiHayin kudu**	75	6.5	23.80	15.90	7.90	62.21	13.67
17	**UPE WTC Kabomo**	66	6.5	25.45	7.70	17.75	43.2	4.91
18	**UngwarMairuwa**	62	7.5	18.64	13.20	5.44	52.71	105.41
19	**Guga**	40.5	7	35.08	15.72	19.36	64.8	48.00
20	**Jiba**	18.5	6	7.25	4.37	2.88	43.20	14.14

Table 3: Results of Pumping test data (Continued)

S/No:	**Borehole Locations**	**Transmissivity (m^2/day)**	**Hydraulic Conductivity K (m/day)**	**Hydraulic Conductivity K (m/s)**
1	**Funtua , Near Palace**	4.28	1.417	1.641×10^{-5}
2	**GanjjarPri. School**	1.6	1.188	1.376×10^{-5}
3	**Yankwani, Pri. School**	1.33	0.712	8.243×10^{-6}
4	**Nabukka, Pri. School**	0.47	0.503	5.818×10^{-6}
5	**Ungwar, Danjili**	2.21	1.111	1.286×10^{-5}
6	**Tudun Wada**	0.57	0.60	6.942×10^{-6}
7	**BabbanKufai**	0.82	0.700	8.1044×10^{-6}
8	**HawanDankaki**	2.43	1.581	1.829×10^{-5}
9	**GidanMaikwari**	4.04	0.903	1.045×10^{-5}
10	**Ungwar, Lima Yankido**	14.27	1.613	1.867×10^{-5}
11	**Ungwar,AlhajiLawal**	5.1	0.961	1.113×10^{-5}
12	**DutseReme, Pri. School**	18.98	2.974	3.448×10^{-5}
13	**Jargaba**	3.52	0.475	5.495×10^{-6}
14	**Ungwar, KotseKabomo**	13.1	3.100	3.5589×10^{-5}
15	**UngwarDinya**	0.78	0.379	4.371×10^{-6}
16	**MakurdiHayin kudu**	2.5	1.668	1.930×10^{-5}
17	**UPE WTC Kabomo**	0.9	0.472	5.459×10^{-6}
18	**UngwarMairuwa**	5.85	1.669	1.931×10^{-5}
19	**Guga**	8.78	0.658	7.610×10^{-6}
20	**Jiba**	7.53	5.206	6.025×10^{-5}

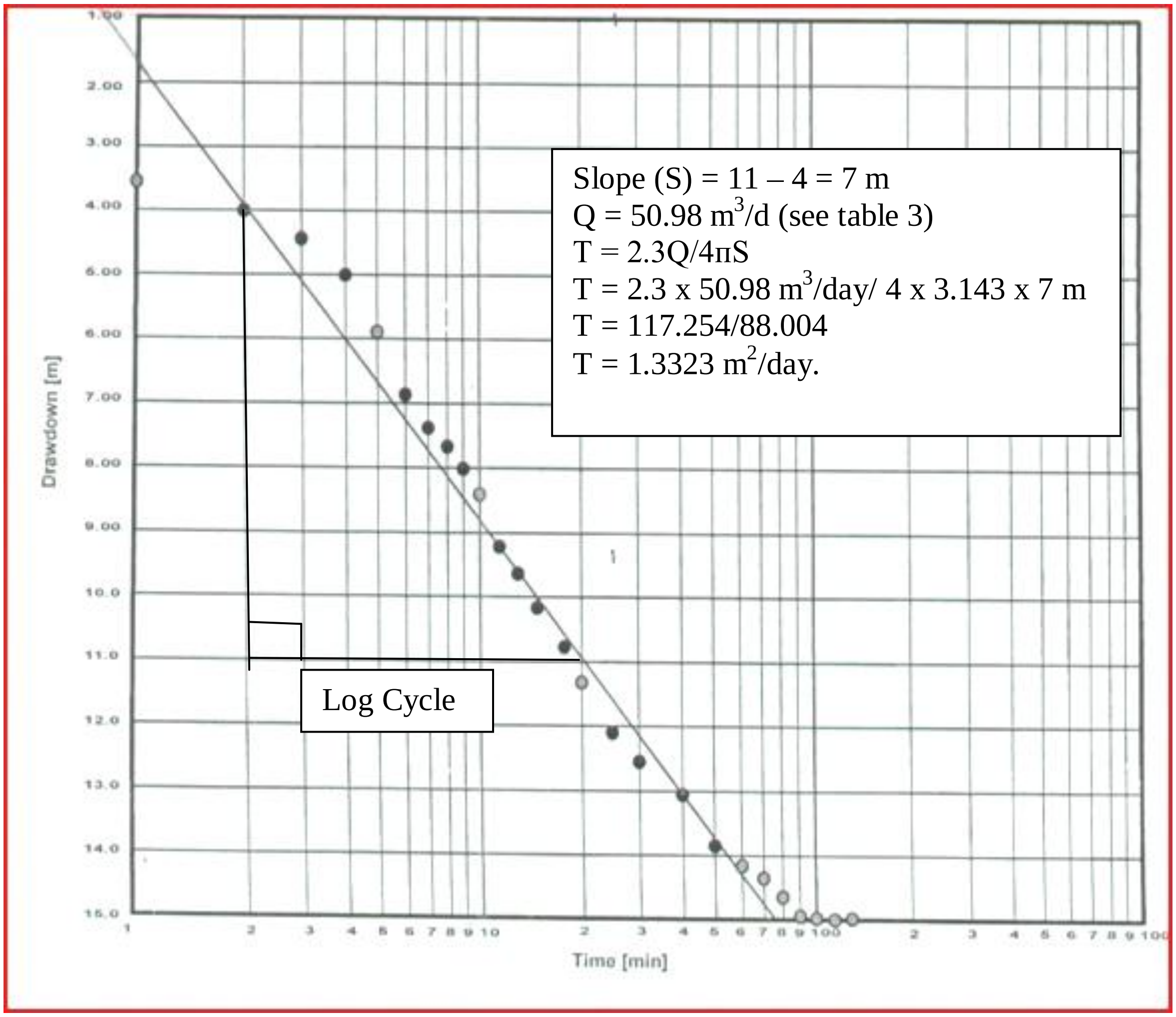

Fig. 9: A semi logarithm graph showing the plotting of drawdown verses time in determination of Transmissivity. (Borehole location 3:Yankwani Primary School, Katsina State)

Theis's equation is expressed as:

S= Q x w(u) /4πT………………… (2)

Where Q = discharge (m^3/day)

W (u) = well function of u: representing an exponential integral.

T = Transmissivity.

Transmissivity (T) and Storativity (S) respectively are determined from the following expression.

$T = 2.3Q/4\pi s$ where Q = discharge (m^3/day) and s = drawdown (m)

$S = 2.25Tto/r^2$ where T = transmissivity (m^2/day), to = time at 0 drawdown and r = well radius (m)

The transmissivity values computed using this method varies from 0.47m^2/day to 18.98m^2/day. See details on Table (3).

Slope = 9.52 (Borehole 4)
$T = 2.3 \times 0.28 \times 10^{-3} / 4 \times 3.143 \times 9.52$
$T = 5.38 \times 10^{-6}\ m^3/s$ or
$T = 0.4649\ m^2/day$.

Slope = 0.7 (Borehole 12)
$T = 2.3 \times 0.84 \times 10^{-3} / 4 \times 3.143 \times 0.7$
$T = 2.20 \times 10^{-4}\ m^3/s$ or
$T = 18.96\ m^2/day$.

4.3.4. 2 Hydraulic Conductivity

Babuskin in 1954 developed a method for the determination of permeability of anisotropic rocks by pumping test (Eduvie, 1991). For an unconfined aquifer representing the aquifer system in the study area, the coefficient of hydraulic conductivity calculated from the pumping rate, drawdown and length of screen using the Babuskin formula are giving in table (3).

The formula is express as

$K = 0.366\ Q/Ls \log (1.32L)/rw$………………………. (3)

Where K = Coefficient of Conductivity (m/day).

Q = discharge of the borehole (m^3/day)

L = Length of screen (m)

s = drawdown (m)

rw = radius of borehole (m)

The hydraulic conductivity values obtained vary from0.472m/day to 5.206m/day with average value of 1.400m/day.

Q = 0.58, L = 8, s = 20.76, rw = 3.75 (Borehole 13)

K =0.366 x 0.58 x 10^{-3} /8 x 20.76 x log 1.32(8)/ 3.75

0.0021228 x 0.272977 / 166.08

= 5.495 x 10^{-6} m/s or 0.472 m/day (1m/day = 86400m/s)

Q = 0.5, L = 4, s = 2.88, rw = 3 (Borehole 20)

K = 0.000183 x 0.240877 / 11.52

= 3.82647 x 10^{-6}m/s or 5.206m/day

4.3.4.3 Specific Capacity

The specific capacity of a well is the ratio of its yield to its drawdown expressed as m^3/day/m. Specific capacity depends on the transmissivity of the aquifer and well construction factors, such as type of screen, well diameter, and degree of aquifer penetration and completeness of well development. Specific capacity therefore assesses the productivity, both of the aquifer and the well (Eduvie, 1991). It value ranges from 2.52m^3/day to 105.41m/m^3/day

4.3.4.4 Yield of Aquifer

The yield of aquifer range from 24.19 to 144.29m^3/day.

4.3.4.5 Aquifer Recharge and Discharge

Recharge and discharge of groundwater in aquifer is very important, although typically inconspicuous aspects of the global hydrologic cycle. Recharge involves the downward and influx of groundwater to an aquifer while discharge involves the upward movement and outflow of groundwater from an aquifer. The main source for aquifer recharge in the study area is from the direct infiltration of rainfall during the rainy period, which is about six months, starting from

May to October. Similarly, groundwater recharge is also from perennial rivers such as River Doma, Gagare, Magoje, Jare and Gora which are influent.

The discharge of aquifer in the area of study is mainly by artificial abstraction from wells and boreholes by pumping. Discharge from the groundwater in aquifer could also contribute to stream flow in perennial rivers during dry season.

4.4 WATER TABLE CONFIGURATION AND GROUNDWATER FLOW DIRECTION

Water table configuration was depicted by contours of water table elevations above sea level. The resultant maps, Figure 10 and 11 show the situations at the end of the rainy season and the peak of dry season.

4.4.1 End of Rainy Season

The water table map at the end of rainy season was based on the static water level in hand-dug wells measured in September, 2011. The Maximum water level elevation was 2307 ftasl and the minimum was 1909ft asl, with difference of 398ft. The mean water table elevation based on 118 wells was 2108 ft.

4.4.2 Peak of Dry season

Water level in hand-dug wells was taken in March, 2012. At the peak of the dry season, coinciding with the period of minimum water level in wells, the maximum and minimum water table elevations were 2306 ftasl and 1936ft asl respectively with a difference of 470 ft.

4.4.3 Groundwater flow direction

Groundwater in the study area flows generally from a higher water table elevation to a lower water table elevation as shown in figure 10 and 11. Figure 12 shows the hydrogeologic map of the area which include overlaying the geology over the groundwater configuration map.

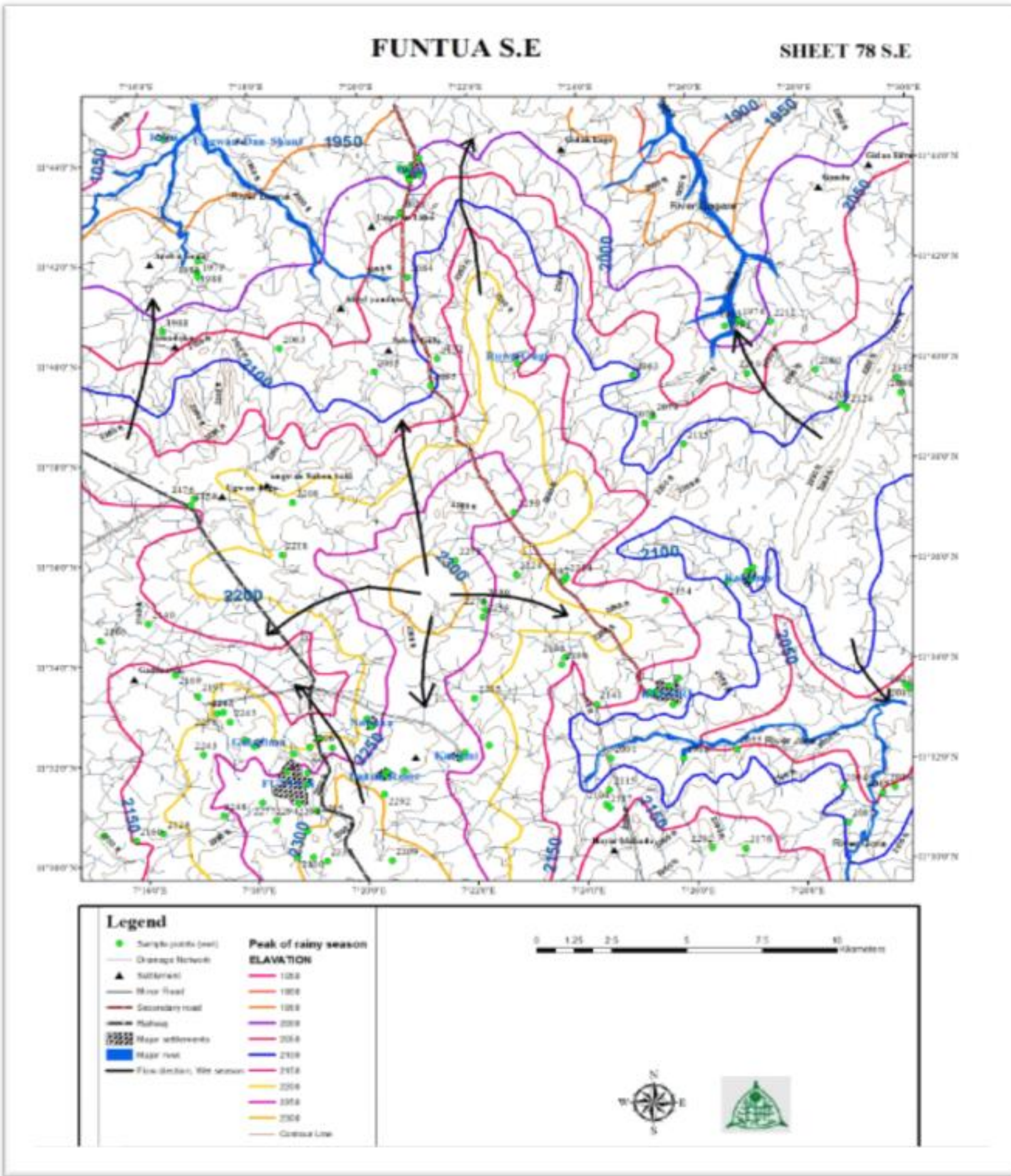

Fig. 10: Groundwater Configuration map at end of raining season showing groundwater flow direction.Produced by H. O. Onaji (2014)

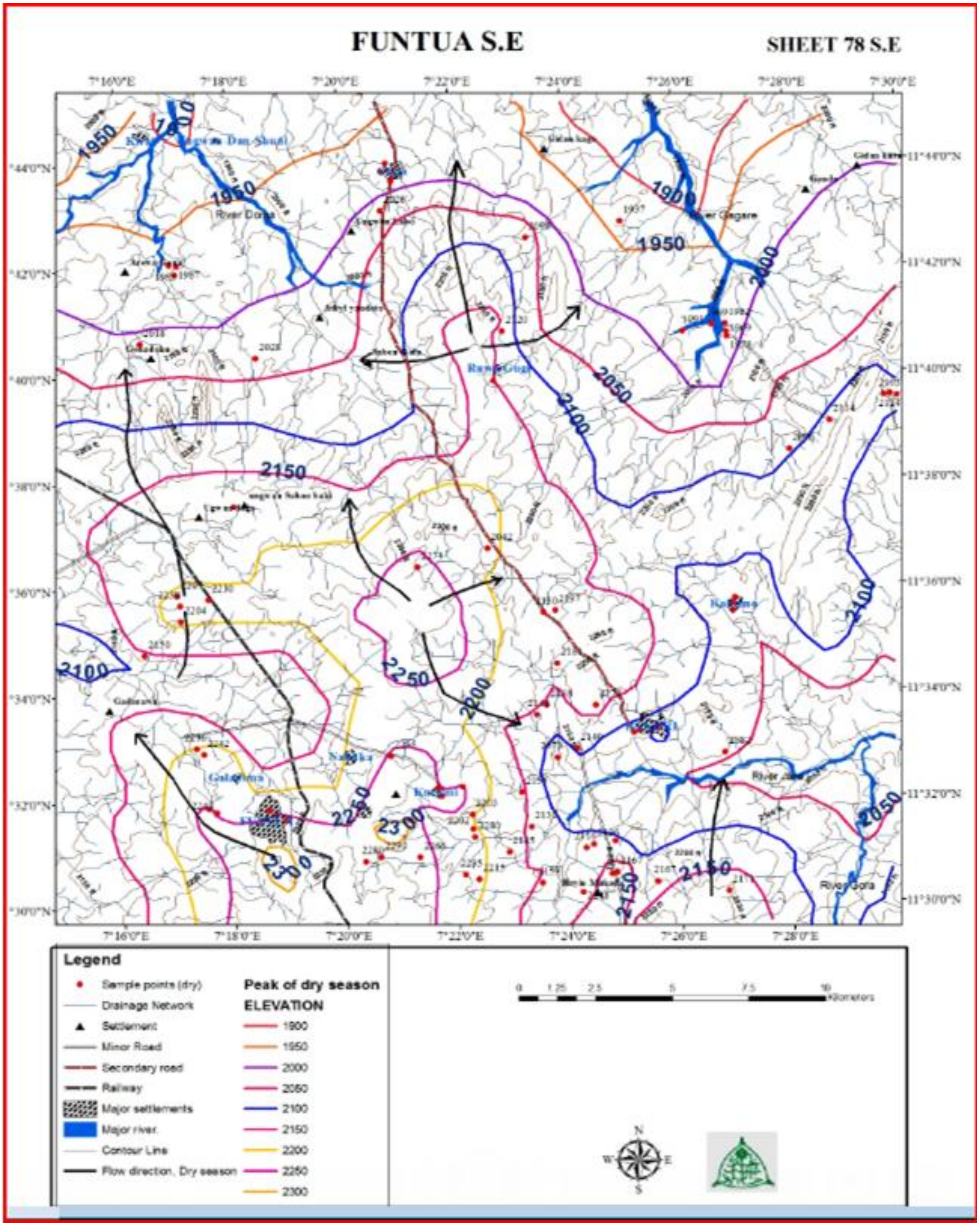

Fig. 11: Groundwater Configuration map at peak of dry season showing groundwater flow direction. Produced by H. O. Onaji (2014)

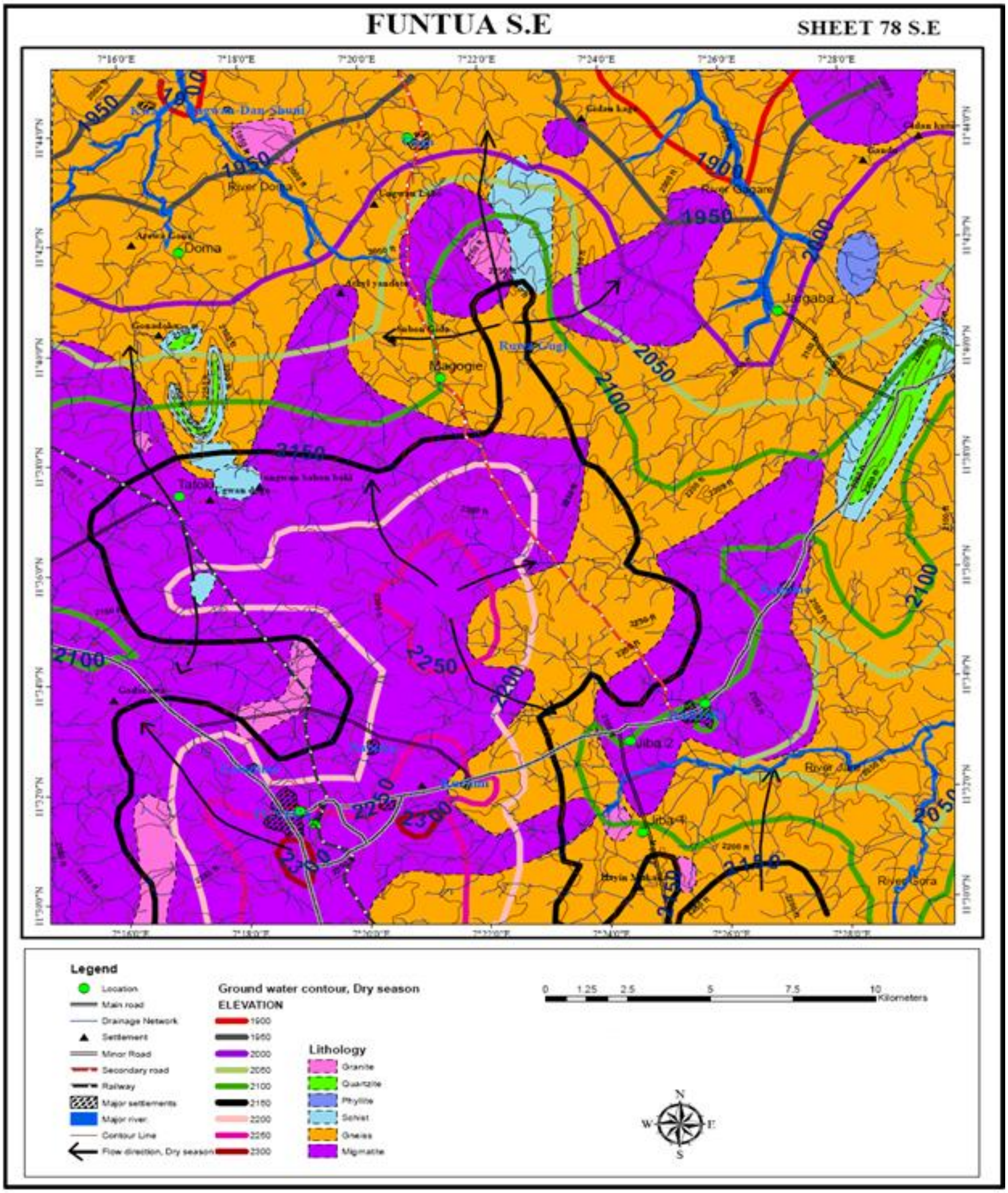

Fig. 12: Hydrogeologic Map of the study area showing the groundwater flow direction. Produced by H. O. Onaji (2014)

CHAPTER FIVE

GROUNDWATER QUALITY

5.1 GROUNDWATER HYDROCHEMISTRY

The main objective of studying the quality of groundwater is in relation to its intended use, as domestic, agricultural, or industrial use. It could also give idea of the groundwater flow system, including the distribution of the recharge and discharge areas.

The sources of chemical elements in groundwater can be from rain, soil/ biological processes and weathering of the minerals in the rocks through which the groundwater flows (Eduvie, 1991). The chemical parameters which are the most essential in groundwater chemistry and present in important quantities, and should therefore be analyzed for, are major ions concentrations, (Sodium, Calcium, Magnesium, Potassium, Bicarbonate, Sulphate, Nitrate and Chloride). The enrichment of groundwater in these constituents depends on the rock type in which the water is found, residence time of water in the rock, and water circulation process which takes place in the rock including evaporation and transpiration (Adanu, 1989). Thus, the water-rock interaction contributes significantly to evolved chemical composition of the groundwater system in the study area in addition to contribution from precipitation.

5.2 LOCATION OF WATER SAMPLING POINTS

Water was collected from sources such as Wells, Boreholes and river which are distributed across the study area. Figure 13 shows locations where these water are sampled before taken for analysis. The locations include Tafoki, Doma, Funtua, Bakori, Guga, Magogie, Jiba and Jargaba.

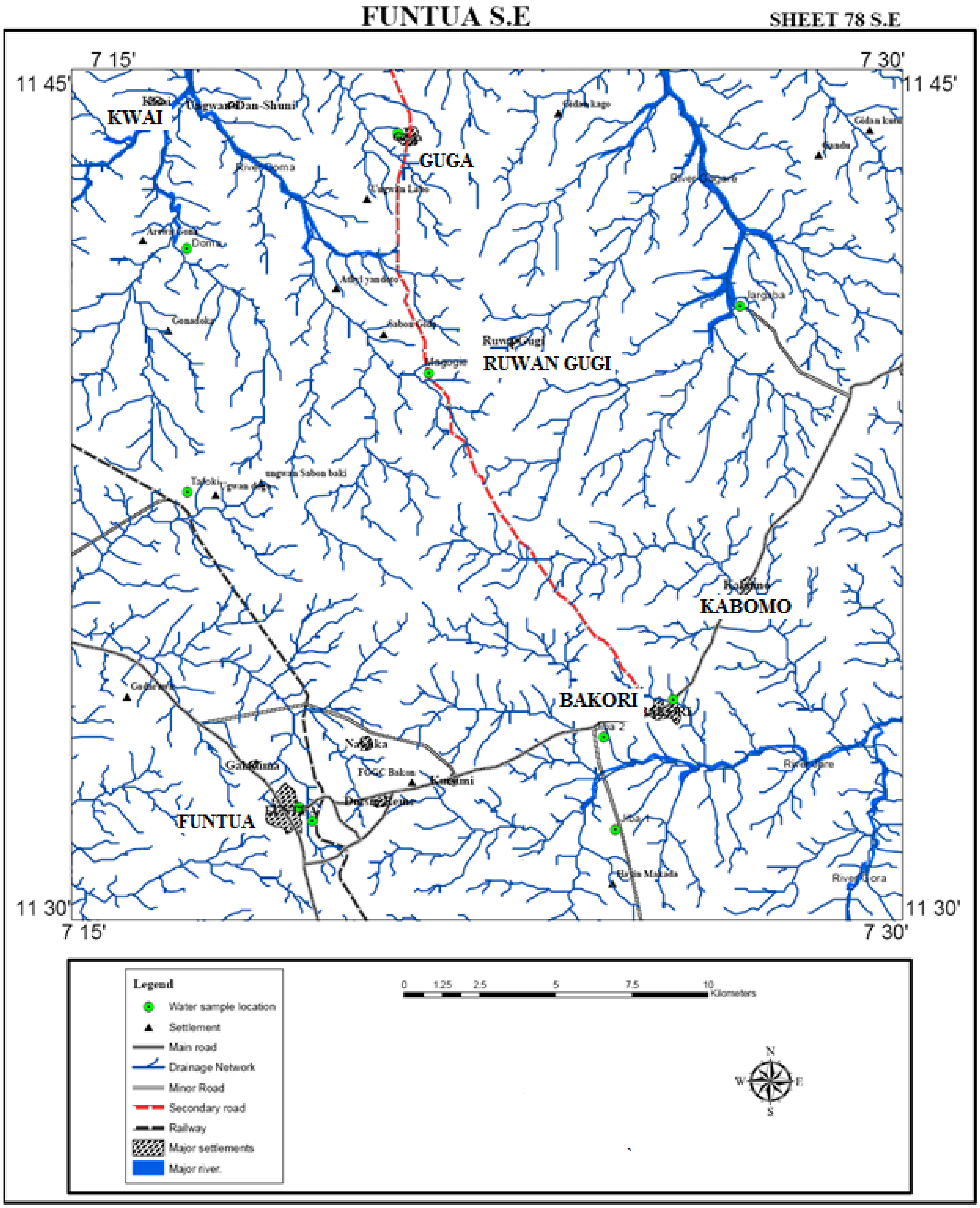

Fig. 13: Drainage Map of the study area showing locations of Water Sampling. Produced by H.O. Onaji (2014)

5.3 PHYSICAL PROPERTIES OF WATER

5.3.1 Temperature

Temperatures of water which were measured with maximum thermometer in-situ vary from 26.4˚c to 33.5˚c with average of 27.72˚c.

5.3.2 Electrical Conductivity

The conductivity of the sampled water was measured on the spot with a Conductivity meter. The EC values ranges from 238 to 608 uS/cm. The highest conductivity value of 608uS/cm was recorded in Guga well (sample 5); while the lowest conductivity value of 238uS/cm were recorded in Doma Borehole (sample 2). Generally, the ionic concentration of the water is low. They are all within the WHO recommended standards.

5.3.3 Hydrogen ion Concentration (pH)

Hydrogen ion concentration of water (pH) is the measure of the acidity or alkalinity of water. The pH value ranges from 6 to 8 (slightly acidic to slightly alkaline). However, on exposure to air, the CO_2 escapes and the pH rises (Brown, 1977). The values of pH recorded after exposing it to air, range from 6.5 to 8.5 and fall within the recommended level. (Hutton, 1983; Hem, 1970).

5.3.4 Total Dissolved Solids (TDS)

This is the residue left when a certain amount of water is vaporized. When the experimental errors and undetected trace or minor constituents in water during measurements are ignored, the Total Dissolved Solids in a water sample can be represented by the sum of the ionic concentrations of the major constituents (Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-},and NO_3^{2-}) ions. The TDS calculated using the above formula varies from 440.34 to 905.6 mg/l.The low TDS in the study area was a reflection of the general characteristics of groundwater in the basement terrain. Groundwater of such basement terrain has limited migratory history and its composition was controlled by recharge water from rainfall and mineral dissolution from slow weathering of the minerals constituting the bedrock.

5.4 CHEMICAL CHARACTERISTICS

The analyzed major cations in the water were Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, while major anions were Cl^-, NO_3^{2-}, and SO_4^{2-}ions.

5.4.1 Sodium ion concentration

Sodium ion in the water varies from 0.66 mg/l to 28.04 mg/l, which is a typical of the water in igneous and metamorphic terrain with moderate to high rainfall. Sodium in the groundwater is derived from weathering of the feldspars.

5.4.2 Potassium ion concentration

Potassium ion ranges from 0.23mg/l to 16.85 mg/l, and is derived mainly from the weathering of feldspathic minerals of the basement rocks. Generally, the small percentage of potassium in water despite its abundance in the earth's crust has being attributed to its high resistance to weathering of many potassium minerals in the sodium minerals (Davis and Wiest, 1966).

5.4.3 Calcium ion concentration

Calcium ion ranges from 1.51 mg/l to 59.28 mg/l and represents the second most dominant cation in the water sample analyzed. In the igneous and metamorphic terrain, weathering releases calcium from such mineral as apatite, fluorite and various member of the feldspar, amphibole and pyroxene group. The values are low and fall within the permissible standard.

5.4.4 Magnesium ion concentration

The Magnesium ion concentration in the water varies from 7.24 mg/l to15.45 mg/l. Although the geochemistry of magnesium is quite similar to that of calcium as can be obtained from the weathering of igneous and metamorphic rocks containing feldspars, mica (biotite) and pyroxene, magnesium salt are less soluble than those of calcium, hence its generally lower concentration in groundwater.

5.4.5 Chloride ion concentration

Chloride ion varies between 21.3 mg/l to 127.6mg/l. In the basement complex generally, chloride concentration is low (Davis and De wiest 1966). The probable source of chloride in this area could be from the accumulation by evaporation of water (vapour) contributed into the groundwater by precipitation. The chloride concentration is safe for all purpose, as it falls below the 250mg/l chloride level described as been satisfactory (Garg, 1981)

5.4.6 Sulphate ion concentration

Sulphate ion concentration in groundwater is probably derived from the oxidation of Sulphates in igneous rocks. The concentration varies from 4.3 mg/l to 95 mg/l. The Sulphate in the water could have been derived from rain water passing through the atmosphere or from the oxidation of Sulphur dioxide in the soil/ aquifer. (Guideal,2010).The values fall within desirable concentration level.

5.4.7 Bicarbonate ion concentration

It varies from 363.6 mg/l to 668.8mg/l. Bicarbonate in groundwater is derived from the Carbon dioxide in the atmosphere, Carbon dioxide in the soil and respiration of plants in the root zones (Adanu, 1989). Some of the samples falls within the permissible standards while others falls outside the permissible standards.

5.4.8 Nitrate ion concentration

This varies from 2.2 mg/l to 12.8mg/l. Most Nitrates in natural water comes from organic sources or from industrial and agricultural chemicals while a minor source is from Nitric oxides produced by lightening discharge.

5.4.9 Bacteriological analysis

The water samples yielded no bacteriological contamination.

5.5 TOTAL HARDNESS

The Total hardness is the sum of the concentration of the alkaline earth elements present in the water sample (Hem, 1970). The alkaline earth ions present are normally exclusively magnesium and calcium. The total hardness value lies between 14.94mg/l and 67.89mg/l. The groundwater in the study area is mostly soft on the average except in location 3 where the water is moderately hard with TDS value of 905mg/l.

Table 4 shows classification of hardness after Hem (1970).

Table 4: Classification of Hardness after Hem (1970)

Hardness (Ca^{2+} Mg^{2+} Carbonate) mg/l	**Water Classification**
0 – 60	Soft Water
61 – 120	Moderately Hard
121 -180	Hard
➢ 180	Very Hard

Based on the above ranges, both the physical and chemical parameters detected in the groundwater in study area are within the Nigeria standard for drinking water and the WHO (2004) set standard limit, except in few samples where concentration of element e.g. HCO_3^- exceed the acceptable limit (Fig.5a &5b). Bicarbonate is the dominant ion in the water samples which ranges from 363.6 mg/l to 668.8mg/l followed by Chloride which ranges from 21.3 mg/l to 127.6mg/l.

Table 5a: Analysis Results of water samples from the study area.

S/No:	1	2	3	4	5	6	7	8	9	10
Sampling Date	24/4/12	24/4/12	24/4/12	24/4/12	24/4/12	24/4/12	24/4/12	24/4/12	24/4/12	24/4/12
Analysis Date	8/5/212	8/5/212	8/5/212	8/5/212	8/5/212	8/5/212	8/5/212	8/5/212	8/5/212	8/5/212
Sampling Locations	Tafoki (Well)	Doma (BH)	Funtua 1(Well)	Funtua 2(BH)	Guga (Well)	Magogie (Well)	Jiba 1 (BH)	Jiba 2 (River)	Bakori (Well)	Jargaba (Well)
Longitude	7˚16' 55.6"	7˚17' 0.3"	7˚18' 51"	7˚19' 4.3"	7˚20' 47.7"	7˚21 '18.4"	7˚24' 32.5"	7˚24' 23.2"	7˚25' 38.4"	7˚26' 57.2"
Latitude	11˚37' 25.0"	11˚41' 52.8"	11˚31 '38.9"	11˚31' 31.5"	11˚43' 56.2"	11˚39' 31.3"	11˚31' 12.9"	11˚32' 51.1"	11˚33' 31.9"	11˚40' 40.7"
Temperature(˚C)	26.8	27	27	27	27	26.4	28.5	33.7	27	27
Conductivity(us/cm)	261	323	275	238	608	450	364	408	623	299
Ph	6	5	7.5	6.2	6.7	8	6.5	7.8	6.7	6.5
TDS	586.55 182.70	655.41 226.10	1235.6 192.5	440.34 166.6	1042.69 425.6	713.74 315	695.36 254.8	622.84 285.6	743.99 436.1	591 209.3
Na^+(mg/l)(meq/l)	28.04 (1.22)	0.84 (0.04)	19.36 (0.84)	0.67 (0.03)	11.38 (0.5)	1.28 (0.06)	3.59 (12.67)	12.67 (0.55)	0.66 (0.03)	36.83 (1.60)
K^+(mg/l)(meq/l)	4.05 (0.10)	3.76 (1.10)	4.35 (0.11)	3.05 (0.08)	3.06 (0.08)	4.03 (0.1)	5.66 (0.14)	0.23 (0.01)	4.81 (0.12)	16.83 (0.84)
Ca^{2+}(mg/l)(meq/l)	1.51 (0.08)	8.0 (0.4)	99.28 (4.95)	5.81 (0.29)	39.1 (1.95)	11.01 (0.55)	14.14 (0.71)	29.4 (0.75)	8.24 (0.41)	2.31 (0.06)
Mg^{2+}(mg/l)(meq/l)	15.45 (1.27)	14.01 (1.15)	8.61 (0.71)	15.48 (1.27)	10.75 (0.88)	11.42 (0.94)	13.27 (1.09)	7.24 (0.60) (	13.98 (1.15)	12.63 (1.04)
Hco_3^-(mg/l)(meq/l)	444.4 (7.28)	525.2 (8.61)	868.8 (14.26)	363.6 (10.43)	848 (13.9)	595.5 (9.77)	606 (9.93)	474.7 (7.89)	606 (9.93)	464.66 (7.61)
Cl^-(mg/l)(meq/l)	83.8 (1.8)	85.1 (2.4)	127.6 (3.6)	42.5 (1.2)	53.2 (1.2)	63.8 (1.8)	21.3 (0.6)	85.1 (2.4)	63.8 (1.8)	42.5 (1.2)
NO_3^{2+}(mg/l)(meq/l)	5.0 (0.1)	8.50 (0.1)	12.8 (0.16)	4.3 (0.06)	2.2 (0.03)	6.3 (0.08)	6.4 (0.08)	8.5 (0.11)	6.5 (0.08)	5.3 (0.07)
SO_4^{2+}(mg/l)(meq/l)	4.30 (0.60)	10.0 (0.21)	95.0 (1.83)	5.0 (0.1)	75.0 (1.65)	20.0 (0.42)	25.0 (0.52)	5.0 (0.1)	40.0 (0.83)	10.0 (0.21)

Table 5b: Water Quality Analysis result from Aqua Terra Sundry Services Laboratory, Katsina State

S/no	Location	Odour	Taste/color	Temp. ˚c	Turbidity	Salinity	Conductivity us/cm	PH
1	MakarantaAlloJabiri Bayan	Odourless	Tasteless/1	30.7	2.7	0.1	16.2	6.7
2	KTARDA QTR, FGGC Bakori	Odourless	Tasteless/1	26.1	0.85	0.1	158	7.1
3	LimanSaaduSaniQuranicsch	Odourless	Tasteless/1	31.5	2.2	0.3	671	6.4
4	SabonLayin, Kakumi, Danja	Odorless	Tasteless/1	25	1.3	0.1	305	7.4
5	HadiqatulQuaran, Zaria Rd.	Odourless	Tasteless/1	31.1	2.7	0.6	124	6.9
6	Daawah Field office, Bakori	Odourless	Tasteless/1	26.1	1.9	0.1	147.6	6.5
7	MakarantaAlarammamusa	Odourless	Tasteless/1	31.7	2.9	------	346	6.9
8	Mkt M SabiuAlarammaRafinSarki Zango	Odourless	Tasteless/1	30.9	2.8	-------	81.5	6.2
9	UnguwarBarmo, Bakori	Odourless	Tasteless/1	26..2	4.9	0.2	329	7.1
10	BagariMoqueFuntua	Odourless	Tasteless/1	25.8	3.0	0.1	119.2	6.5
11	GobirawaBakori	Odourless	Tasteless/1	28.9	3.7	0.1	212	7.4
12	BabanKufai	Odourless	Tasteless/1	29.2	2.8	0.1	102	7.3
13	UnguwarBalarabe, danja	Odourless	Tasteless/1	28.2	4.3	------	96	7.5
14	Mai GamjiFuntua	Odourless	Tasteless/1	28.1	1.1	0.1	260	7.4
15	BabeliBakori	Odourless	Tasteless/1	29.5	3.4	0.1	202	7.5
16	kokami Road, Funtua	Odourless	Tasteless/1	25.8	1.5	0.1	269	7.3
17	Tafoki Road	Odourless	Tasteless/1	29.3	2.1	0.4	861	6.3
18	Tudun Wada	Odourless	Tasteless/1	30.6	2.6	----	151.4	6.6
19	Ungw. KwanaGuga,Funtua	Odourless	Tasteless/1	30.5	3.4	------	170.2	6.8
20	KofarfadaFuntua	Odourless	Tasteless/1	25.9	1.1	------	250	7.4

5.6 CLASSIFICATION OF WATER

The water classification in the study area is based on the classification system suggested by Gorrell (1958) which considers the total concentration of the main dissolved solids. The total dissolved solids range is as follows.

Freshwater	0 to 1,000 mg/l TDS
Brackish water	1,000 to 10,000 mg/l TDS
Salty water	10,000 to 100,000 mg/l TDS
Brine water	>100,000 mg/l TDS

The dominant cations and anions are as indicated in table 5a; with highest value of TDS 905.6mg/l in sample 5, other samples inclusive falls within the limit of the freshwater classification. The general water samples is said to be fresh water.

Using schoeller's semi-logarithmic diagram as proposed by Schoeller, 1935 and Hem, 1970, an attempt has been made to subdivide the water into groups according to the various ionic concentrations (fig. 14). The concentration of Bicarbonate, Chloride Nitrate and Sulphate is highest in Funtua 1 well sample. This suggests that, the groundwater at Funtua 1 location is influenced by human activities surrounding the well, such as litters of dumps and refuse.

The decomposition of organic matter and reaction with the water produce Chloride and Nitrate ionwhich leached down and contributed to higher concentration of the ions in the groundwater.

Piper's trillinear diagram was drawn to classify the water samples, (fig.15). It is a combination of anion and cations triangle that lies on a common baseline. It divides waters into basic types according to their placement near four corners of the diamond. The resultis shown on table 6.

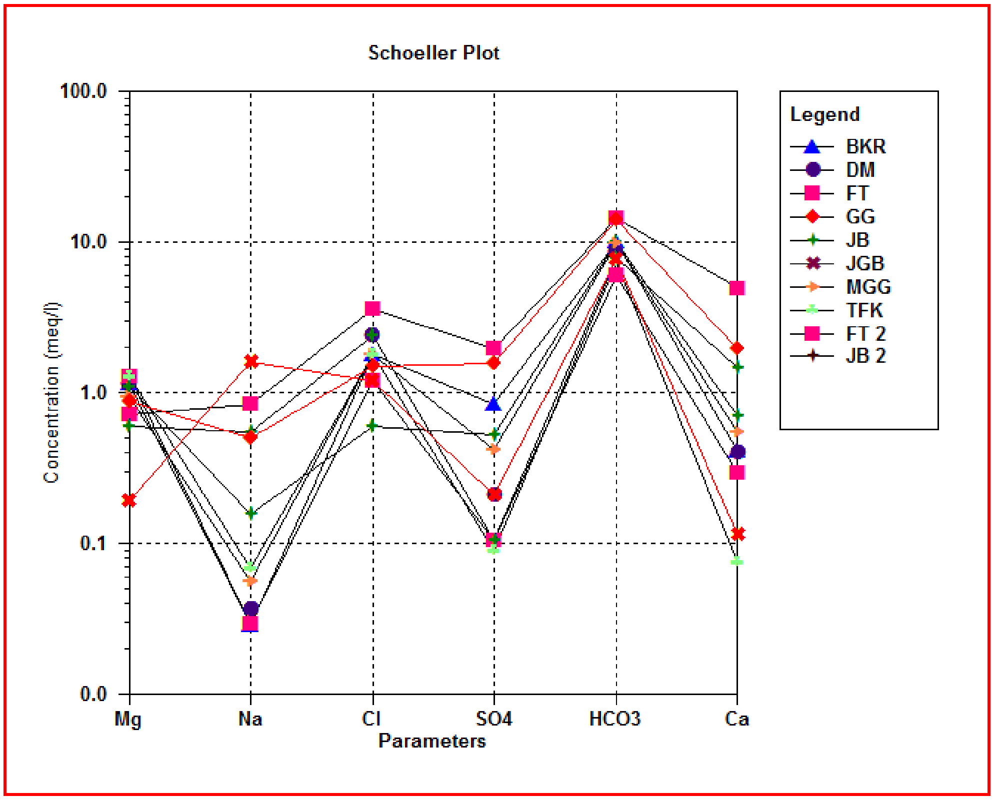

Fig. 14: Schoeller Plot showing Hydrochemical grouping of the water.

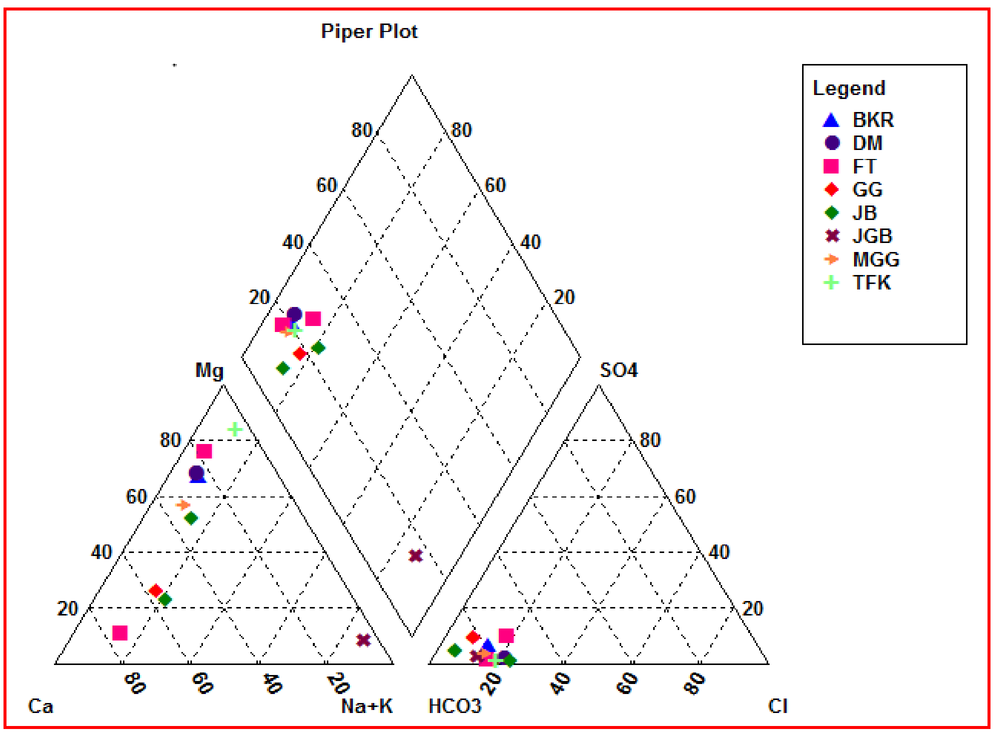

Fig.15: Piper's trilinear representation of the chemical analysis

The major water types in the study area as shown in the table above is the Ca-HCO_3-Cl and Mg- HCO_3-Cl, followed by HCO_3-Cl which is coming from Migmatite and gneiss (Fig. 16).

The higher concentration of Ca^+ and Mg^+ in the groundwater of the study area may probably be due to the dissolution of plagioclase feldspars. $HCO3^-$ might have been generated in the soil zone en route to the groundwater zone as a result of decomposition of organic matter, which releases carbon-dioxide that reacts with water in the soil zone. The reaction generates weak carbonic acid (H_2CO_3) that aids the breakdown of minerals in the rocks resulting in dissolution and the release of the ions into the groundwater which was responsible for its hydrochemical characteristics.

Table 6: Water types in the study Area

S/No:	**Location**	**Geologic Rock Type**	**Water Type**
1	Tafoki(Well)	Migmatite	Mg-HCO_3-Cl
2	Doma(Borehole)	Gneiss	HCO_3- Cl
3	Funtua 1 (Well)	Migmatite	Ca- HCO_3-Cl
4	Funtua 2 (Borehole)	Migmatite	Mg-HCO_3-Cl
5	Guga (Well)	Gneiss	Ca-HCO_3-Cl
6	Magogie (Well)	Gneiss	HCO_3-Cl
7	Jiba 1 (Borehole)	Gneiss	HCO_3-Cl
8	Jiba 2 (River)	Migmatite	Ca- HCO_3-Cl
9	Bakori (well)	Migmatite	HCO_3- Cl
10	Jargaba (well)	Gneiss	Na-HCO_3-Cl

The result of the hydrochemistry analysis reveals that among the major cations in the water samples, the concentration of the alkali earth cations Ca^{2+} and Mg^{2+} exceed those of the alkali cations Na^+ and K^+ while the concentration of the anion HCO_3^- and Cl^- exceeds those of SO_4^{2-} and NO_3^{2-}. The cations dominance is of order $Ca^{2+} > Mg^{2+} > Na^{2+} > K^+$ while for the anions dominance is $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^{2-}$

On the average, the water belongs to the same group. On the whole, the ionic concentration of the groundwater here is typical of magmatic and crystalline rock.

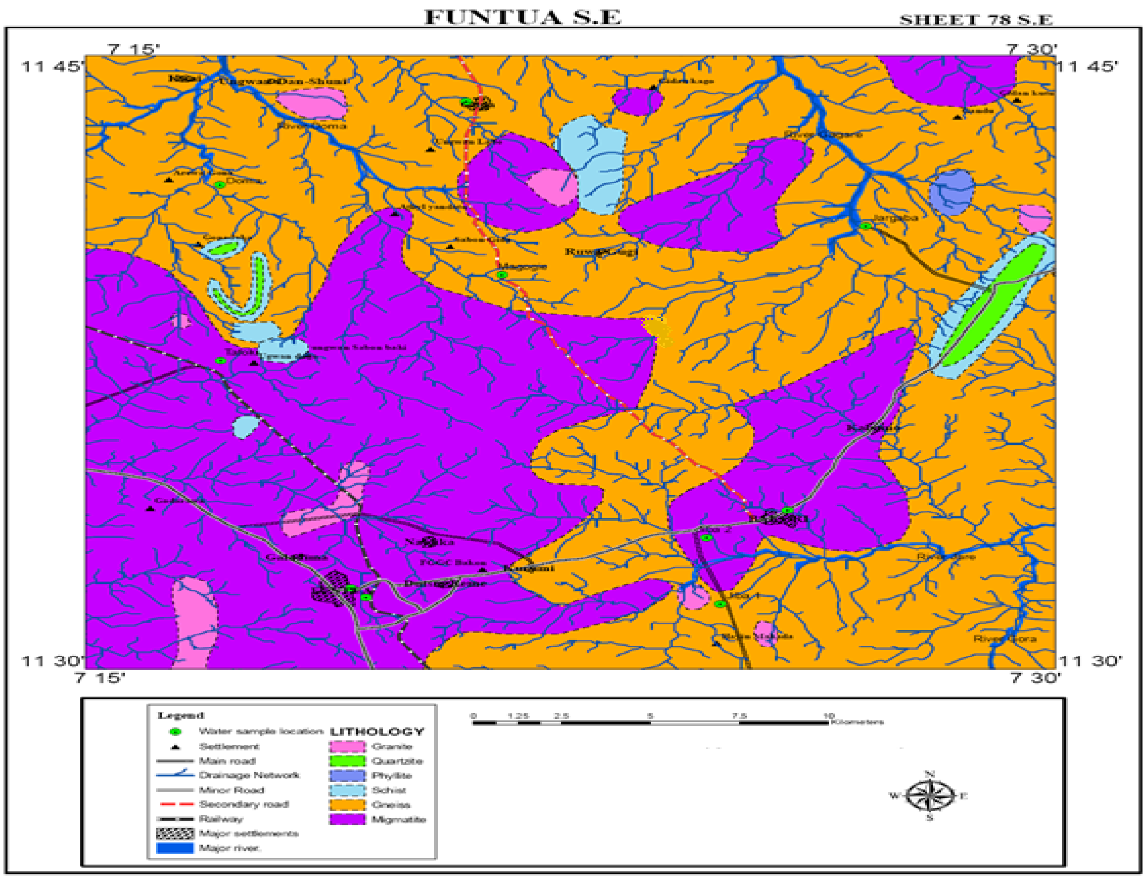

Fig. 16: Geological map showing water sampling locations. Produced by H. O. Onaji (2014)

5.7 SODIUM ADSORPTION RATIO (SAR).

The extent to which soil adsorb sodium from water is influenced by the concentration and composition of soluble salts. This is important because, above certain levels, the adsorbed sodium has an adverse effect upon the physical properties of the soil-namely, permeability and infiltration rate (GWRD, 1986).

Sodium Adsorption Ratio (SAR) is therefore used to define the sodium hazard of irrigation waters. The SAR is defined and calculated from the equation:

$$SAR = Na^{+} / \sqrt{(Ca^{2+} + Mg^{2+})/2}$$

(Where the ionic concentrations expressed in meq/l).

Table 7 shows the values of sodium and salinity hazard while Fig. 17 shows the plot of salinity and sodium adsorption classification for irrigation water. All point falls in the low region of sodium hazards while, for the salinity hazard, some point falls within the low region and others falls within the medium region.

Table 7: Values of Sodium and Salinity Hazards.

SALINITY HAZARD (COND)	SODIUM HAZARD (SAR)
623	3.25E-02
323	4.15E-0.2
243	0.500592
238	3.30E-02
608	0.415706
364	0.164714
408	0.542647
299	4.099929
450	6.45E-02
216	8.38E-02

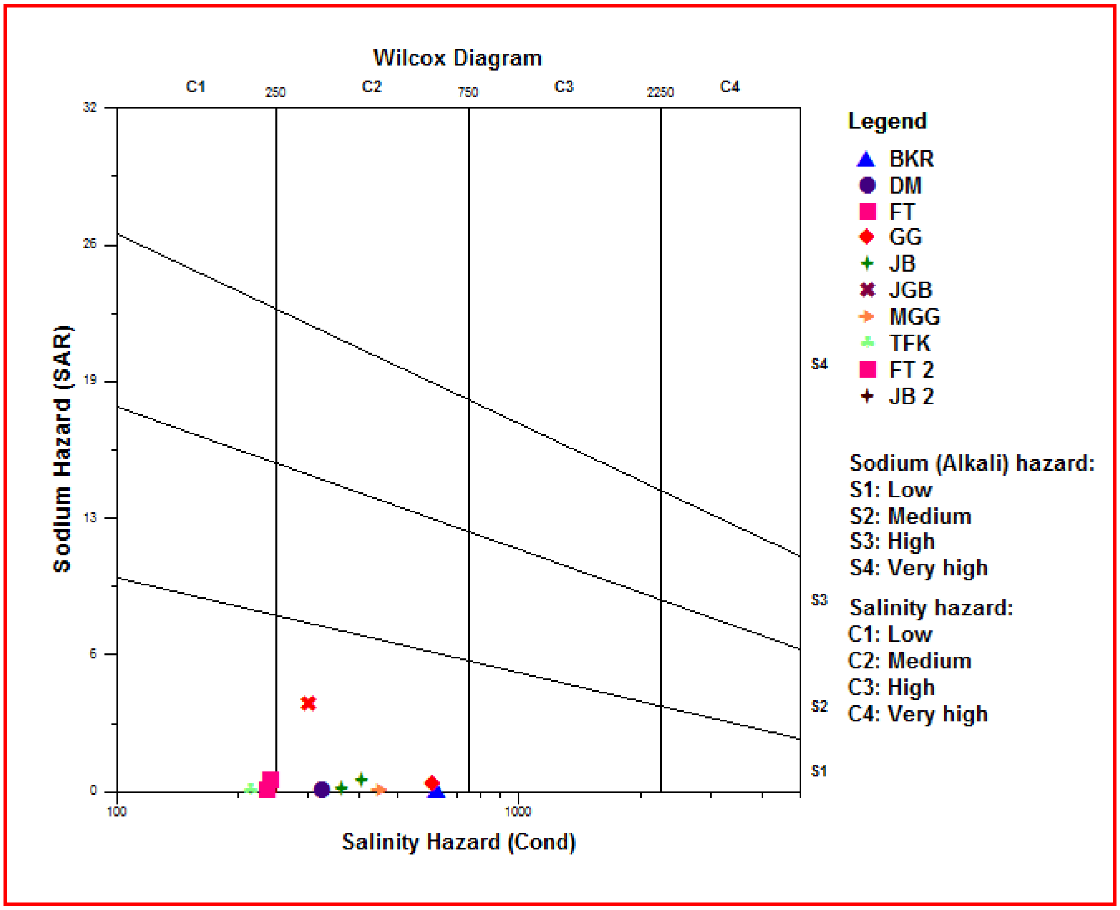

Fig. 17: Wilcox Diagram Showing Salinity Hazard verses Sodium Hazard

5.8 Percentage Sodium (Na %)

The sodium content in a sample of groundwater is estimated as a percentage of all the alkali and alkali earth metals present in the sample. This is expressed as

$Na\% = (N^{+} + K^{+} / (Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}))\ 100$

(All Concentrations are given in meq/l).

These indices were used to study the sodium hazard and access the quality of water for irrigation purpose. Higher percentage of Na^+ in groundwater can lead to stunted growth in the plants at the same it will reduce soil permeability.

The percentage of sodium in the water from the study area ranges between 7% and 69% Na, Table (8). The values recorded may be due to the process of ion exchange taking place between the alkali metal ion (Na^+) and the alkali earth metals ion Ca^{2+} and Mg^+) present in the water samples and clay (finer grains) in the soil respectively. Todd (1980) shows that, ion exchange process leads to changes in the physical properties of the soil leading to deflocculating which causes reduction in the soil permeability and drainability.

Table 8: Results of Na% of the water samples in the study area.

S/No:	**Location**	**Na%**
1	Tafoki(Well)	50
2	Doma(Borehole)	43
3	Funtua 1 (Well)	15
4	Funtua 2 (Borehole)	7
5	Guga (Well)	17
6	Magogie (Well)	9
7	Jiba 1 (Borehole)	42
8	Jiba 2 (River)	30
9	Bakori (well)	9
10	Jargaba (well)	69

For the sampled water in the area of study, five samples are in excellent class, one is in the good class, and three are in the permissible class and one in the doubtful class. Table (8) shows the results of Na% of the water samples in the area while table (9) gives the classification ranges by Wilcox (1955).

Table 9: Suitability of groundwater for Irrigation based on Percentage Sodium, after Wilcox (1955).

% Na	**Result**
< 20	Excellent
20 – 40	Good
40 – 60	Permissible
60 – 80	Doubtful
>80	Unsuitable

5.9 DISCUSSION ON THE USABILITY OF WATER

The ranges of both TDS and Total Hardness are all within the accepted limit, the recorded values for these two indices shows the water from the area of study to be fresh and soft, which is good for drinking and other domestic uses.

The recorded values of Sodium Adsorption ratio of 0.032 to 4.10 is an indication of low or zero sodium hazard on crops. The TDS which also refer to the salinity hazards have values of less than 1000, it shows water to be of low salinity, hence can be safely use for irrigation on all types of soil, and livestock farming.

CHAPTER SIX

CONCLUSION AND RECOMMENTATIONS

6.1 CONCLUSION

The study area is underlain by rocks of the basement complex predominantly gneiss, migmatite, granite, schist, quartzite and phyllite as shown in the geologic map.

From the fieldwork and geophysical data acquired, it indicates that the groundwater occurrence in the study area is distributed according to the nature of the rock types forming the aquifer and the degree of weathering and fracturing of the rocks.

Interpretation of the Vertical Electrical Sounding (VES) have revealed that the area consists of four to six geo-electric layers; topsoil (clayey, sandy or lateritic), weathered basement (clays/sandy clays), slightly weathered/ fractured basement (clayey sand) and fresh bedrock.

Hydraulic characteristics of the aquifer evaluated from the borehole pumping test data (Transmissivity (T), Hydraulic conductivity (K) and Storage coefficient (S)) were confirmed to be in good performance.

The groundwater configuration map of the study area was constructed using the difference between the ground elevation and static water level in the hand dug wells. The contour map was used in establishing the groundwater flow direction of the aquifer in the area.

Results of the water samples analyzed shows most of the major ions falls within the standard limit fordrinking water and domestic use which is in accordance to the Nigeria drinking water standards of 2007 and that of the World Health Organization (WHO) drinking water standards of 2004.Water types established in the study area using the piper diagramincludes Ca-HCO_3-Cl, Mg-HCO_3-Cl, andHCO_3-Cl. The chemical quality of groundwater in the study areafor irrigation based on Sodium Adsorption Ratio (SAR) indicates that, it is suitable for irrigation purpose.

Generally, the chemical quality of the groundwater of the area reveals that the water is soft to moderately hard and pH slightly acidic with an average of 6

6.2 RECOMMENDATIONS

Groundwater resources have played and will continue to play an important role in meeting the water needs in the study area, especially for domestic, livestock and irrigation. The groundwater resources management of the area is absolutely essential for sustainable groundwater development and economic advancement of the people.There is need to investigate further and establish areas for groundwater exploitation using the geophysical method of survey and effective and accurate borehole pumping test data.Some areas have insufficient boreholes and good dug wells. In order to reduce the sufferings of the populace in those areas and dependency on surface water which is prone to pollution, then more boreholes and good dug wells should be constructed in such areas. These areas include Kwai and environs.

The proliferation of tube wells (washed boreholes) in the study area should be looked into especially the mode of construction. There should be proper check by Government on how these wells are drilled by involving trained Hydrogeologist and Geologist to site the location, supervise the drilling and then the water subjected to laboratory test before being put to public use. Geophysical investigation should be undertaking in order to properly site a borehole. The high rate of failures could be attributed to lack of proper exploration which determines the type of drilling to be done and the proper borehole completion procedure to be used.

6.3 CONTRIBUTIONS TO KNOWLEDGE

- Detail geologic, groundwater configurationand hydrogeologic maps of the study area on the scale of 1: 50, 000 of the topographic sheet 78 (Funtua SE) was produced.
- Determination of Aquifer Characteristics of the aquifers in the study area.
- Determination of the geo-electric sections of the aquifer.
- Determination of the water quality of the study area.

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APPENDIX I

NIGERIA STANDARD FOR DRINKING WATER

Parameter	Unit	Maximum Permitted	Health Impact	Notes
Aluminum (Al)	mg/L	0.2	Potential Neuro-degenerative disorders	Note 1
Arsenic (As)	mg/L	0.01	Cancer,	
Barium	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	
Copper (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	Fluorosis, Skeletal tissue (bones and teeth) morbidity	
Hardness (as $CaCO_3$)	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, affect mental development in infants, toxic to the central and peripheral nervous systems	
Magnesium (Mg^{+2})	mg/L	0.20	Consumer acceptability	
Manganese (Mn^{+2})	mg/L	0.2	Neurological disorder	

CONTINUED

Parameter	Unit	Maximum Permitted	Health Impact	Notes
Mercury (Hg)	mg/L	0.001	Affects the kidney and central nervous system	
Nickel (Ni)	mg/L	0.02	Possible carcinogenic	
Nitrate (NO_3)	mg/L	50	Cyanosis, and asphyxia ('blue-baby syndrome") in infants under 3 months syndrome") in infants under 3 months	
Nitrite (NO_2)	mg/L	0.2	Cyanosis, and asphyxia ('blue-baby syndrome") in infants under 3 months	
pH	-	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	

APPENDIX II

WHO (2004) DRINKING WATER STANDARD

Parameters	**WHO standard (2004)**		**Results of Tests**	
	Highest Desirable Level	**Maxmimum Permissible**	**Range**	Mean
PH	7 – 8.5	Min 6.5 Max 9.2	6- 8	7
K^+	1.0 – 12	> 12	0.23- 16.83	17.06
Na^+	200	>200	0.67- 36.83	18.75
Mg^{2+}	50	150	7.24- 15.48	11.36
Ca^{2+}	75	200	1.51- 59.28	50.40
HCO_3^+	Variable	500	363.6- 668.8	656.6
Cl^-	200	600	21.3-127.6	74.45
SO_4^{2-}	20	400	4.3- 95.0	49.65
NO_3^-	45	50	2.2-12.8	7.5
TDS	1000	-	440.3-905.6	672.95

APPENDIX III

Gheorghe Standards for Transmissivity (T)

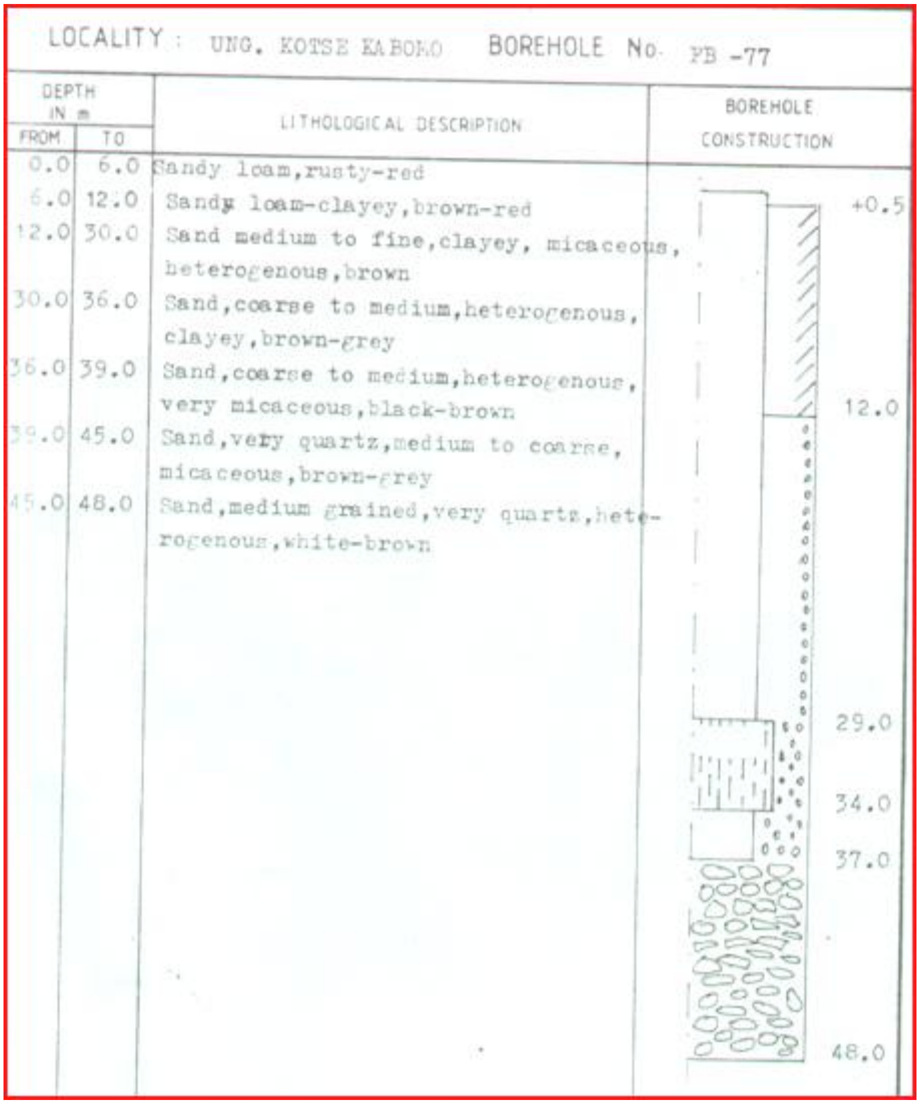
Transmissivity Range (m2/day)	**Transmissivity Potentials**
➢ 500	**Highly potential**
50 – 500	**Moderately potential**
5 – 50	**Low potential**
0.5 – 5	**Very low potential**
< 0.5	**Negligible potential**

APPENDIX IV

Bouwers Standards for Hydraulic conductivity (K)

Materials	K Ranges (m/day)
Clay soils (surface)	0.01 -0.2
Deep clay beds	10^{8} to 10^{-2}
Loam soil (surface)	0.1 to 1
Fine sand	1 to 5
Medium sand	5 to 20
Coarse sand	20 to 100
Gravel	100 to 1000
Sand and Gravel mixes	5 to 100
Clay, sand and gravel mixes (till)	0.01 to 0.1

APPENDIX V



LOCALITY : UNG. KOTSE KABOKO BOREHOLE No. FB -77

DEPTH IN m FROM	TO	LITHOLOGICAL DESCRIPTION
0.0	6.0	Sandy loam,rusty-red
6.0	12.0	Sandy loam-clayey,brown-red
12.0	30.0	Sand medium to fine,clayey, micaceous, heterogenous,brown
30.0	36.0	Sand,coarse to medium,heterogenous, clayey,brown-grey
36.0	39.0	Sand,coarse to medium,heterogenous, very micaceous,black-brown
39.0	45.0	Sand,very quartz,medium to coarse, micaceous,brown-grey
45.0	48.0	Sand,medium grained,very quartz,heterogenous,white-brown

Borehole lithology and Borehole Construction for UngwaKotseKabomo, Katsina State.

APPENDIX VI

PUMPING TEST DATA SHEET Date: 03/10/2011

Site Name: Yankwani Primary School, Bakon L.G.A. Katsina State. BH Depth: 21m Pump setting: 22m...... SWL: 2.93m

Pumping Phase						Recovery Phase				
Clock time	Time Since Pumping started (min)	Pumping Water level (ft)	Pumping Water level (m)	Draw Down (m)	Pumping Rate (l/s)	Clock time	Time since pumping stopped (min)	Recovery Water Level (ft)	Recovery Water Level (m)	Residual Draw down (m)
0 hr	0	9.61	2.93	0.00		0 hr	0	67.19	20.48	16.58
	1	10.76	3.28	0.35	0.32		1	65.75	20.04	16.14
	2	11.19	3.41	0.40			2	65.06	19.83	16.93
	3	11.42	3.48	0.55			3	57.68	17.58	13.68
	4	11.55	3.52	0.59			4	55.61	16.95	13.05
	5	12.07	3.68	0.75			5	53.25	16.23	12.33
	6	12.30	3.75	0.82			6	51.77	15.78	11.88
	7	12.70	3.87	0.94			7	49.61	15.12	11.23
	8	13.88	4.23	1.30			8	48.29	14.72	10.82
	9	14.37	4.38	1.45			9	47.15	14.37	10.47
	10	15.35	4.68	1.75			10	45.87	13.98	9.88
	12	16.14	4.92	1.99	1		12	37.50	11.43	7.53
	14	16.86	5.14	2.21			14	35.73	10.89	6.99
	16	17.29	5.27	2.34			16	33.50	10.21	6.31
	18	17.75	5.41	2.48			18	31.69	9.66	5.76
	20	18.11	5.52	2.59			20	29.95	9.13	5.23
	25	18.47	5.63	2.70			25	26.15	7.97	4.07
	30	18.70	5.70	2.77			30	23.56	7.18	3.28
	40	19.09	5.82	2.89						
	50	19.29	5.88	2.95						
1hr	60	19.35	5.90	2.97						
	70	19.35	5.90	2.97						
	80	19.32	5.89	2.96						
	90	19.32	5.89	2.96						
	100	19.29	5.88	2.95						
	120	19.29	5.88	2.95						
	140	19.29	5.88	2.95	0.59					
	141	21.35	6.51	3.58						
	142	22.70	6.93	4.00						
	143	24.20	7.38	4.45						
	144	26.27	8.01	5.08						
	145	30.87	9.41	5.90	1					
	146	32.25	9.83	6.90						
	147	33.72	10.28	7.35						
	148	35.00	10.67	7.74						
	149	35.80	10.92	8.00						
	150	37.13	11.32	8.39						
	152	39.80	12.14	9.21						
	154	41.53	12.66	9.73						
	156	42.88	13.07	10.14						
	158	45.07	13.74	10.81						
	160	46.60	14.21	11.28						
	170	50.95	15.53	12.60						
3hrs	180	52.55	16.02	13.10						
	190	54.16	16.51	13.80						
	220	57.80	17.62	14.69						
	240	58.82	17.93	15.00						
	300	59.35	18.09	15.16	0.59					
6hrs	360	59.35	18.09	15.16						

Pumping Test data for Yankwani Primary School, Bakori, Katsina State.

APPENDIX VII

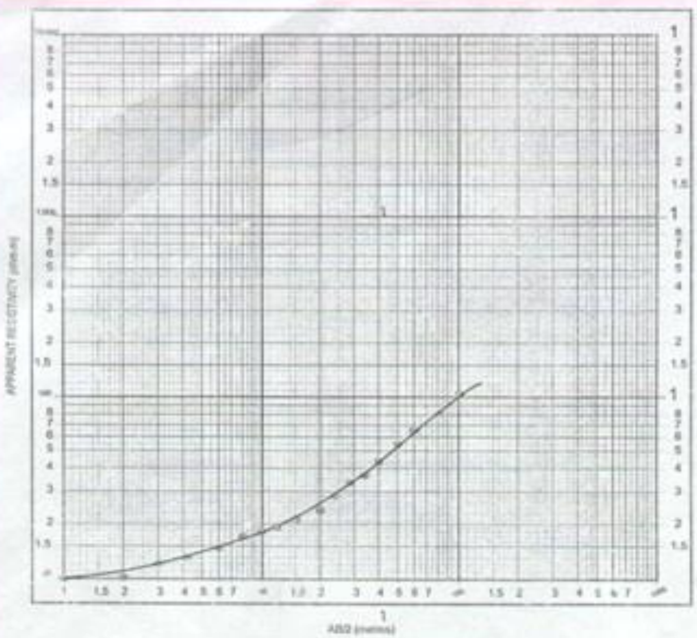
PUMPING TEST DATA SHEET Date:

Site Name: Nabukka Primary School, Bakori L.G.A, Katsina State. BH Depth...30m Pump setting: **22m**..... SWL: 3.9m

Pumping Phase						Recovery Phase				
Clock time	Time Since Pumping started (min)	Pumping Water level (ft)	Pumping Water level (m)	Draw Down (m)	Pumping Rate (l/s)	Clock time	Time since pumping stopped (min)	Recovery Water Level (ft)	Recovery Water Level (m)	Residual Draw down (m)
0 hr	0	12.80	3.90	0.00		*0 hr*	0	67.19	20.48	16.58
	1	15.72	4.79	0.86	0.29		1	65.75	20.04	16.14
	2	17.16	5.23	1.33	↓		2	65.06	19.83	15.93
	3	19.29	5.88	1.98			3	57.68	17.58	13.68
	4	20.28	6.18	2.28			4	55.61	16.95	13.05
	5	23.29	7.10	3.20			5	53.25	16.23	12.33
	6	25.75	7.85	3.95			6	51.77	15.78	11.88
	7	28.25	8.61	4.71			7	49.61	15.12	11.23
	8	31.36	9.56	5.66			8	48.29	14.72	10.82
	9	34.25	10.44	6.54			9	47.15	14.37	10.47
	10	37.34	11.38	7.48			10	45.87	13.98	9.88
	12	41.73	12.72	8.82			12	37.50	11.43	7.53
	14	45.67	13.92	10.02			14	35.73	10.89	6.99
	16	52.36	15.96	12.06			16	33.50	10.21	6.31
	18	53.54	16.32	12.42			18	31.69	9.66	5.76
	20	54.07	16.48	12.58			20	29.95	9.13	5.23
	25	59.28	18.07	14.17			25	26.15	7.97	4.07
	30	31.29	18.78	14.88			30	23.56	7.18	3.28
	40	34.12	19.99	16.09						
	50	35.40	20.31	16.41						
1hr	60	67.19	20.48	16.58						
	70	38.41	20.49	16.59	↑					
	80	39.43	20.49	16.59						
	90	39.82	20.48	16.58	0.28					
	100	39.89	20.48	16.58						

Pumping Test data for Nabukka Primary School. Bakori, Katsina State

APPENDIX VIII



AB/2	MN/2	K	dV/I	P(a) Fld	P(a) Cl	Error Dev
1	0.3	5	1.16	5.8	5.8	0.00
2	0.3	20	0.47	9.4	9.4	0.00
3	0.3	47	0.26	12.0	12.0	0.00
4	0.3	83	0.17	13.9	14.1	-0.01
4	1	24	0.59	14.2	14.2	0.00
6	1	55	0.27	15.1	14.9	0.01
8	1	99	0.17	17.0	16.8	0.01
10	1	156	0.12	18.3	18.7	-0.02
12	1	225	0.08	18.5	18.0	0.03
15	1	352	0.06	22.5	21.0	0.05
20	1	627	0.04	26.0	25.0	0.04
20	5	118	0.25	30.0	29.5	0.02
25	5	189	0.18	34.0	34.0	0.00
30	5	275	0.12	34.0	33.0	0.03
35	5	377	0.10	37.0	37.7	-0.02
40	5	495	0.08	40.0	39.6	0.01
50	5	774	0.07	54.3	54.5	0.00
60	5	1124	0.06	65.0	67.0	-0.03
80	5	2004	0.04	86.0	80.0	0.07
80	10	990	0.08	80.2	79.2	0.01
100	10	1550	0.07	103.4	108.5	-0.05

Data

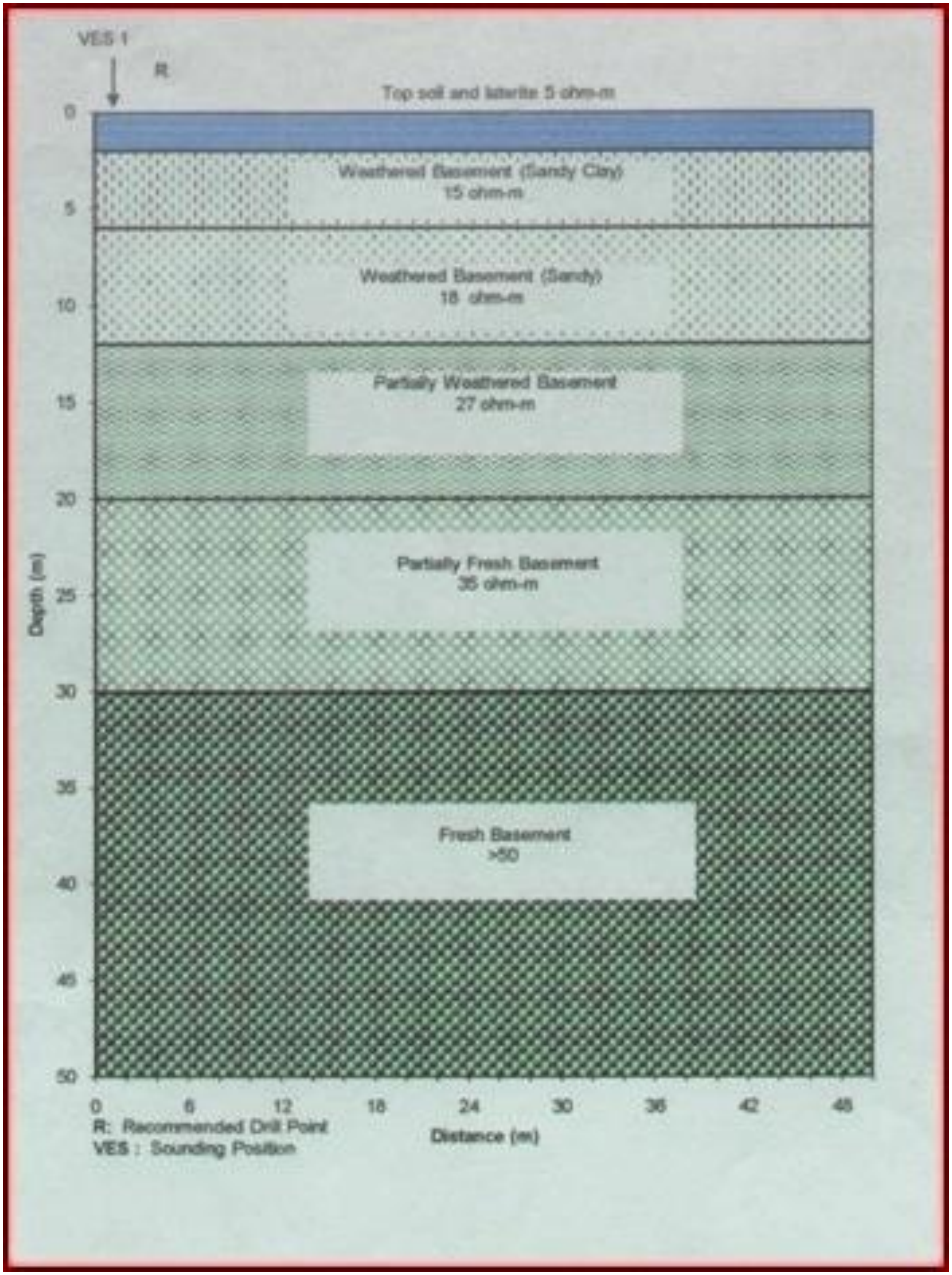
Interpreted Model

Layer	Resistivity (ohm-m)	Thickness (m)	Depth (m)
1	5	2.00	2.00
2	19	4.00	6.00
3	18	6.00	12.00
4	27	8.00	20.00
5	35	10.00	30.00

VES 1 — Interpreted; • • • Field Curve

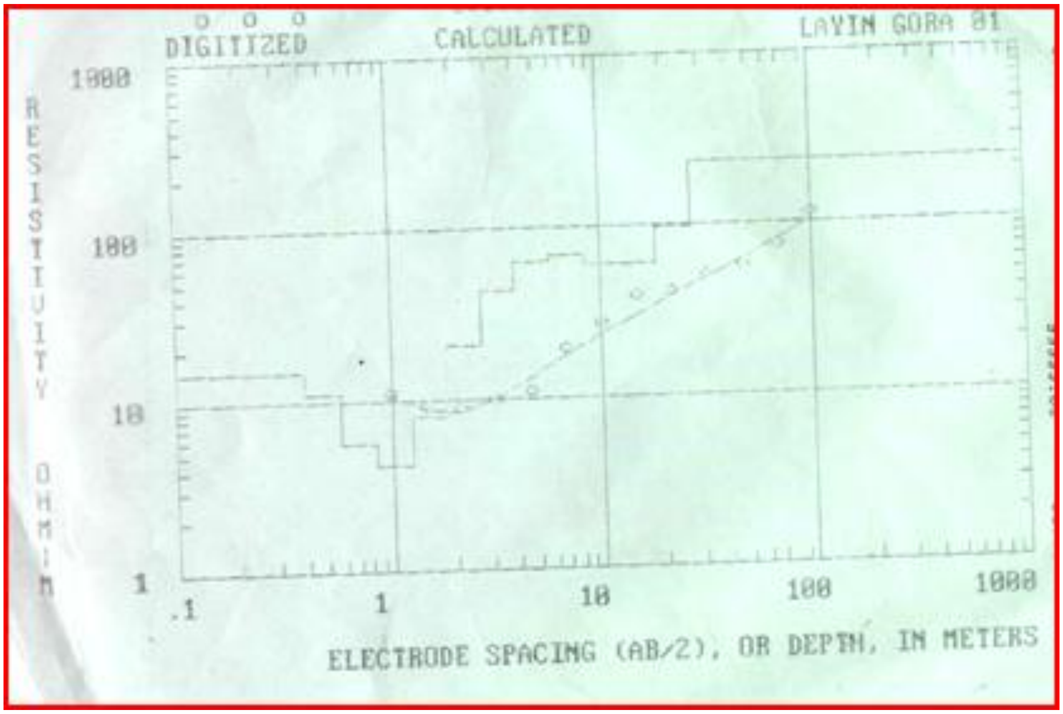
VES data and interpreted model for IslamiyaJibiri, behind KTARDA QTR. Funtua, Katsina State.

APPENDIX IX



Geo-electric Section at IslamiyaJabiri,behind KTARDA QTR, Funtua, Katsina State

APPENDIX X



APPENDIX XI

LAYIN GORA 01 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.39	14.97	3.94	42.83
0.58	11.12	5.78	63.87
0.85	5.72	8.48	67.84
1.24	4.22	12.45	59.35
1.83	8.14	18.27	60.37
2.68	20.68	26.82	96.26
		99999.00	229.54

APPENDIX XII
RAINING SEASON WELL MEASUREMENTS

Longitude	Latitude	Well Depth (Ft)	Well Elevation (Ftasl)
7˚ 19' 14.16"	11˚ 30' 1.44"	11.42	2239
7˚ 19' 6.6"	11˚ 30' 00	3.54	2247
7˚ 18' 59.04"	11˚ 30' 5.04"	4.99	2245
7˚ 18' 59.04"	11˚ 30' 5.76"	3.28	2295
7˚ 18'45"	11˚ 30' 13.68	0	2300
7˚ 15' 15.84"	11˚ 34'32.88"	14.5	2136
7˚ 16' 31.44"	11˚ 33'47.52"	16.24	2159
7˚ 16' 57.72"	11˚ 33' 18"	9.35	2191
7˚ 17' 21.84"	11˚ 33' 1.44"	6.82	2243
7˚ 17' 30.12"	11˚ 32' 54.6"	3.67	2246
7˚17' 51.36"	11˚32' 30.48"	5.12	2245
7˚ 17' 57.48"	11˚ 32' 25.44"	2.43	2248
7˚ 18' 48.24"	11˚ 32' 2.52"	4.04	2196
7˚ 18' 43.2"	11˚ 32' 16.8"	0	2225
7˚ 18' 53.64"	11˚ 31' 52.68"	6.3	2283
7˚ 18' 20.88"	11˚ 30' 53.28"	5.91	2294
7˚ 18' 8.28"	11˚ 31' 13.8"	2.82	2277
7˚ 20' 15.72"	11˚31' 44.4"	10.24	2290
7˚ 20' 17.16"	11˚ 31'23.16"	8.33	2292
7˚ 20' 26.16"	11˚ 30' 2.16"	23.59	2232
7˚20' 4.56"	11˚ 32' 43.44"	14.63	2236
7˚ 19' 56.64"	11˚ 32' 52.8"	10.66	2249
7˚ 19' 24.24"	11˚ 32' 21.12"	4.59	2251
7˚ 29' 52.08"	11˚ 39' 22.68"	36.25	2114
7˚ 28' 53.04"	11˚ 39' 1.44"	56.17	2124
7˚ 28' 45.48"	11˚ 39' 2.88"	30.05	2120
7˚ 26' 53.88"	11˚ 40' 44.04"	29.56	1985
7˚ 27' 3.24"	11˚ 40' 40.44"	20.64	2008
7˚ 25' 8.4"	11˚38' 43.8"	30.81	2069
7˚ 27' 3.96"	11˚35'43.08"	24.74	2105
7˚ 25' 39.36"	11˚ 33' 34.92"	7.22	2113
7˚ 25' 34.68"	11˚ 33' 3.6"	9.15	2116
7˚ 25' 17.04"	11˚33' 16.56"	26.67	2123
7˚ 21' 55.44"	11˚ 33' 16.56"	39.76	2235
7˚ 21' 41.76"	11˚ 32' 14.28"	27.59	2272
7˚ 21' 37.08"	11˚ 32' 7.8"	17.22	2283
7˚ 21' 5.04"	11˚ 44'9.6"	50.56	2004

7˚ 20'53.52"	11˚ 43' 56.28"	49.25	2006
7˚ 21' 32.76"	11˚ 43' 36.12"	40.49	2040
7˚ 21' 5.76"	11˚ 43' 51.96"	52.76	1997
7˚ 16' 29.28"	11˚ 44' 33.72"	46	1909
7˚ 20' 48.48"	11˚ 43' 6.6"	36.58	2023
7˚ 20' 53.16"	11˚ 41' 44.52"	16.01	2284
7˚ 26' 35.16"	11˚ 35' 33.36"	4.99	2095
7˚ 23' 37.68"	11˚ 35' 33.36"	11.09	2197
7˚ 22' 7.68"	11˚ 35' 3.84"	15.01	2285
7˚ 16' 55.2"	11˚ 37' 19.62"	33.69	2176
7˚ 16' 53.76"	11˚ 37' 10.56"	19.09	2159
7˚ 17' 2.76"	11˚ 41'53.16"	22.18	1976
7˚17' 5.28"	11˚ 42' 6.48"	22.24	1988
7˚ 18' 33.84"	11˚ 40' 19.56"	16.99	2063
7˚ 18' 42.48"	11˚ 37' 12.72"	21.65	2208
7˚ 18' 31.32"	11˚ 36' 10.8"	7.41	2218
7˚ 16' 4.44"	11˚ 34' 51.96"	10.01	2140
7˚ 18' 44.64"	11˚ 31'19.92"	6	2294
7˚ 18' 54.36"	11˚ 30' 43.2"	3.18	2307
7˚ 29'51.36"	11˚ 33' 28.44"	9.09	2041
7˚ 29' 55.68"	11˚ 33' 23.04"	29.36	2021
7˚ 29' 32.64"	11˚ 31' 23.52"	23.62	2046
7˚ 29' 24.72"	11˚ 31' 21.36"	54.59	2015
7˚ 28' 44.76"	11˚ 31' 26.04"	6.3	2094
7˚ 28' 49.44"	11˚ 30' 39.6"	12.07	2087
7˚ 26' 51"	11˚ 30' 14.76"	24.38	2176
7˚ 26' 15.36"	11˚ 30' 17.28"	2.62	2202
7˚ 24' 24.12"	11˚ 31' 5.88"	46.1	2117
7˚ 19' 0.48"	11˚ 30' 8.28"	4.66	2295
7˚ 17' 1.32"	11˚ 32' 13.56"	7.19	2243
7˚ 17' 23.64"	11˚ 31' 0.12"	2.49	2248
7˚ 16' 16.32"	11˚ 30' 42.12"	26.21	2124
7˚ 15' 14.76"	11˚ 30' 40.32"	11.52	2139
7˚ 15' 48.6"	11˚ 30'33.84"	9.15	2166
7˚ 25' 33.24"	11˚ 33' 26.28"	23	2127
7˚ 25' 40.08"	11˚ 33' 33.84"	12	2113
7˚ 25' 17.04"	11˚ 33' 17.28"	28.41	2123
7˚ 18' 50.76"	11˚ 31' 38.64"	10.21	2290
7˚ 18' 29.98"	11˚ 31' 51.24"	23	2277
7˚ 17' 29.4"	11˚ 32' 54.96"	7	2243
7˚ 17' 21.84"	11˚ 33' 1.8"	14.25	2243

7˚ 20' 18.24"	11˚ 31' 51.24"	20	2280
7˚ 20' 35.52"	11˚ 31' 54.84"	10	2290
7˚ 21' 37.8"	11˚ 32'10.68"	24	2283
7˚ 22' 12.36"	11˚ 32' 19.68"	18.08	2234
7˚ 22' 42.24"	11˚ 36' 50.04"	26.91	2258
7˚ 22' 48.36"	11˚ 39' 55.44"	21.08	2154
7˚ 21' 24.12"	11˚ 40' 5.88"	26.08	2124
7˚ 21' 20.88"	11˚ 39' 30.96"	20	2095
7˚ 20' 53.88"	11˚ 43' 58.8"	52.5	1999
7˚ 20' 53.88"	11˚ 43' 56.64"	56.41	2006
7˚ 20' 49.92"	11˚ 43' 55.92"	41.71	1989
7˚ 20' 57.84"	11˚ 43' 40.8"	52.08	1988
7˚ 20' 48.48"	11˚ 43' 6.6"	36.29	2023
7˚ 20' 53.52"	11˚ 41'7.44"	29.25	2071
7˚ 23' 37.68"	11˚ 35' 33.72"	27.91	2197
7˚ 22' 43.68"	11˚ 35' 35.88"	26.08	2224
7˚ 22' 8.4"	11˚ 34' 47.28"	16.17	2259
7˚ 22' 10.92"	11˚ 34' 54.48"	16.25	2274
7˚ 23' 33.72"	11˚ 33' 50.4"	28.87	2196
7˚ 23' 37.68"	11˚ 33' 53.28"	27.46	2198
7˚ 29' 49.2"	11˚ 39' 33.12"	43.08	2094
7˚ 29' 53.16"	11˚ 39' 33.48"	43	2112
7˚ 28' 53.76"	11˚ 39' 1.08"	59.75	2124
7˚ 28' 45.12"	11˚ 39' 2.88"	36.42	2120
7˚ 27' 32.4"	11˚ 40' 40.44"	27.83	2212
7˚ 27' 0.36"	11˚ 39' 43.92"	31	2219
7˚ 26' 53.88"	11˚ 40' 44.04"	36.42	1985
7˚ 28' 17.04"	11˚ 39' 43.2"	20.42	2080
7˚ 27' 3.96"	11˚ 35' 43.08"	49	2076
7˚ 26' 59.28"	11˚ 35' 37.68"	24	2012
7˚ 24' 11.88"	11˚ 33' 7.92"	19.17	2141
7˚ 24' 24.12"	11˚ 31' 4.8"	34.91	2117
7˚ 24' 26.28"	11˚ 32' 0.96"	28.58	2091
7˚ 16' 24.24"	11˚ 40' 40.8"	42.5	2008
7˚ 17' 3.12"	11˚ 41' 54.24"	24.81	1988
7˚ 17' 2.4"	11˚ 42' 6.48"	23	1977
7˚ 17' 1.68"	11˚ 42' 7.92"	27	1988
7˚ 25' 45.48"	11˚ 32' 4.56"	82.35	1988
7˚ 25' 27.84"	11˚35' 6.36"	46.26	2154

APPENDIX XIII

DRY SEASON WELL MEASUREMENTS

Latitude	Longitude	Well dept (Ft)	Well Elevation (Ft asl)
7˚ 20' 45.8"	11˚ 32' 55.5"	12.79	2254.69
7˚ 22' 20.35"	11˚ 30' 31.2	9.1	2215.9
7˚ 21' 18.08"	11˚ 30' 56"	25.6	2268.15
7˚ 21' 08.9"	11˚ 31' 42.1"	26.52	2306.81
7˚ 21'42.7"	11˚ 32' 06.8	33.2	2266.8
7˚ 22' 16.6"	11˚31' 26.37"	23.2	2201.8
7˚ 23' 11.2"	11˚ 32' 10.01"	23	2155
7˚22' 52.98"	11˚ 31' 00.36"	15.1	2184.9
7˚ 22' 20.3"	11˚ 32'21.2"	31.6	2187.84
7˚ 22' 15.08"	11˚ 32' 44.46"	24	2203.27
7˚ 22' 06.79"	11˚ 30' 36.29	15.4	2234.6
7˚ 26' 40.52"	11˚ 40' 52.1"	41.01	1958.99
7˚26' 57.1"	11˚40' 50.1"	26.083	1983.3
7˚ 26' 10.4"	11˚ 40' 43.7"	35.696	1990.87
7˚ 25' 06.5"	11˚ 42' 52.7"	55.118	1936.55
7˚ 26' 50.9"	11˚ 30' 14.6"	16.404	2147.88
7˚ 23' 34.36"	11˚ 30' 24.96"	22.966	2158.85
7˚ 24' 46.88"	11˚ 30' 32.65"	32.808	2167.19
7˚ 24' 46.93"	11˚ 31' 09.0"	49.213	2123.64
7˚ 17' 01.89"	11˚ 35' 59.1"	6.234	2230.86
7˚ 17' 04.2"	11˚35' 54.2"	39.042	2200.96
7˚ 17' 09.4"	11˚ 35'27.8"	35.761	2204.24
7˚ 17' 7.6"	11˚ 35' 44.5"	11.155	2238.85
7˚ 17' 36.0"	11˚ 31' 51.5"	18.701	2255.66
7˚ 23'22.3"	11˚ 31' 30.4"	19.685	2130.315
7˚23' 48.6"	11˚ 32' 49.7"	26.903	2073.097
7˚ 23' 51.1"	11˚ 34' 35.5"	18.701	2181.3
7˚ 24' 30.2"	11˚ 33' 46.4"	28.543	2171.46
7˚ 23' 27.5"	11˚ 33' 46.0"	23.95	2147.48
7˚ 20' 18.5"	11˚ 41' 32.2"	28.871	2055.06
7˚ 18' 6.2"	11˚ 37' 40.8"	20.013	2164.99
7˚ 18' 30.5"	11˚ 40' 19.9"	50.525	2027.6
7˚ 26' 10.04"	11˚41' 47.3"	29.2	2010.27
7˚27' 55.02"	11˚ 40'34.40"	25.9186	2024.08
7˚ 28' 03"	11˚38' 33"	27.559	2096.25
7˚ 17' 7"	11˚35'49.3"	34.4488	2213.55

7˚ 16' 59.4"	11˚ 35' 37.4"	13.1234	2224.97
7˚ 16' 27.8"	11˚ 34' 48.51"	18.045	2150.288
7˚ 25' 34.0"	11˚33' 17"	39.042	2143.3
7˚ 24' 46.88"	11˚ 30' 32.65"	25.919	2172.08
7˚ 25' 8.3"	11˚ 32' 2.2"	46.916	2053.08
7˚ 25' 34.36"	11˚ 30' 24.96"	20.997	2166.5
7˚ 26' 50.9"	11˚ 30'14.6"	28.871	2171.13
7˚ 26'50.2"	11˚ 32' 50.0"	31.496	2082.14
7˚ 23' 25.4"	11˚ 42' 36.4"	29.2	2097.47
7˚ 23' 3 5.5"	11˚ 41' 41.9"	34.449	2065.55
7˚ 23' 0"	11˚ 40' 48"	55.446	2119.55
7˚ 17' 39.2"	11˚ 31' 51.1"	10.171	2239.83
7˚ 17' 35.9"	11˚ 35' 54.9"	10.499	2229.5
7˚ 25˚ 11.9"	11˚ 33' 16.8"	38	2102.61
7˚ 25' 33.2"	11˚ 33' 26.4	23.92	2100
7˚ 25' 40.2"	11˚ 33' 33.8"	12	2088
7˚ 25' 17.1"	11˚ 33' 17.3"	28.54	2108.23
7˚ 18' 50.9"	11˚ 31' 38.7"	10.21	2263.47
7˚ 18' 29.8"	11˚ 31' 51.1"	23	2237.94
7˚ 17' 29.3"	11˚ 32'55.0"	7.83	2242.17
7˚ 17' 21.7"	11˚ 33'01.8"	14.25	2235.75
7˚ 20' 18.8"	11˚ 31' 51.3"	20	2280
7˚ 20' 35.6"	11˚ 31' 54.8"	10	2290
7˚ 21' 37.9"	11˚ 32' 10.5"	24.83	2252.07
7˚ 22' 12.2"	11˚ 32' 19.5"	18.21	2249.74
7˚ 22' 42.2"	11˚ 36' 50.2"	26.92	2242.13
7˚ 22' 48.3"	11˚ 39' 55.6"	26.08	2149.73
7˚ 21' 24"	11˚ 36' 30.0"	26.08	2111.42
7˚ 21' 20.7"	11˚ 39'31.1"	20	2100.31
7˚ 20' 53.8"	11˚ 43' 58.9"	52.5	1980.83
7˚ 20' 49.8"	11˚ 43' 56.0"	41.71	1992.77
7˚ 20'57.7"	11˚ 43' 40.7"	52.08	1991.189
7˚ 20' 48.4"	11˚ 43' 06.5"	36.29	2025.55
7˚ 20' 07.4"	11˚ 41' 07.4"	29.25	2029.08
7˚ 21' 15.3"	11˚ 39' 48.5"	35.37	2094.63
7˚ 23' 37.6"	11˚ 35' 33.6"	27.92	2199.58
7˚ 23' 43.6"	11˚ 35' 35.7"	26.08	2197.25
7˚ 22' 08.5"	11˚ 34' 47.7"	13.17	2252.46
7˚ 22' 10.9"	11˚ 34' 54.6"	16.24	2251.62
7˚ 23' 33.6"	11˚ 33'50.4"	28.87	2152.95
7˚ 23' 37.5"	11˚ 33' 53.2"	27.46	2137.542

7˚ 29' 48.9"	11˚ 39' 30.0"	43.08	2126.92
7˚ 29' 53.2"	11˚ 39' 33.3"	56	2103.374
7˚ 30' 00.1"	11˚ 39' 32.3"	25.67	2124.33
7˚ 28' 53.7"	11˚ 39' 01.2"	59.75	1940.25
7˚ 28' 45.1"	11˚ 39' 02.9"	36.42	2113.58
7˚ 27' 03.3"	11˚ 40' 40.5"	27.83	1988.17
7˚ 27' 00.2"	11˚ 40' 43.7"	31	1978.09
7˚ 26' 53.7"	11˚ 40' 43.9"	36.42	1968.58
7˚ 28' 16.9"	11˚ 39' 43.1"	20.42	2079.58
7˚ 27' 04.0"	11˚ 35' 43.1"	49	2067.67
7˚ 27' 01.7"	11˚ 35' 37.8"	26	2084
7˚ 26' 59.4"	11˚ 35' 34.3"	24.167	2079.17
7˚ 24' 11.7"	11˚ 33' 08"	19.167	2139.72
7˚ 24' 25.1"	11˚ 31' 04.7"	34.9167	2125.08
7˚ 24' 20.1"	11˚ 31' 5.0"	34	2116
7˚ 24' 26.1"	11˚ 32' 01.1"	28.583	2083.32
7˚ 16' 24.1"	11˚ 40' 39.9"	42.5	2017.5
7˚ 17' 03"	11˚ 41' 54.2"	23.17	1987.43
7˚ 17' 2.3"	11˚ 42' 6.6"	23	1983.06
7˚ 17' 1.7"	11˚ 42' 7.9"	27	1976.03