HYDROGEOLOGY AND GROUNDWATER QUALITY OF DUTSEN WAI SHEET 125 NE, NORTH WEST NIGERIA

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN GEOLOGY

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ZARIA

MARCH, 2017

Declaration

I declare that the work in this dissertation entitled "Hydrogeology and Groundwater quality of Sheet 125DutsenWai NE, North Westa Nigeria" has been carried out by me in the Department of Geology. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

_____ _____

Michaels, P. Segun **Date**

Certification

This dissertation entitled "Hydrogeology and Groundwater quality of DutsenWaiSheet 125 NE, North West Nigeria by MICHAELS, P. Segun meets the regulation governing the award of Master of Science Degree in Geology (Hydrogeology) of Ahmadu Bello University, and approved for its contribution to knowledge and literary presentation.

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Abstract

The hydrogeology of the DutsenWai Sheet 125 NE was studied based on the knowledge of hydrogeology, geology, Remote sensingand geophysical interpretation of VES data. This was done in order to determine the groundwater potential of the area. The geological maps and the hydrogeological maps were updated and the groundwater movement at the end ofwet and peak of dry seasons were determined.The aquifer characteristics and the water quality were determined.Theaverage value of transmissivityis 0.34m^2/day while the mean value of hydraulic conductivity and specific capacity are2.934 and 9.14 x 10^{-2} m^2/s respectively. 22 samples of groundwater were analysed using Atomic Absorbtion Spectrometry (AAS) and flame photometery to determine the major element Na,K, Ca,Mg and trace elements Cu,Zn and Pb while the anions Cl^-,SO_4^{2-}, HCO_{3-} and NO_3^{2-} were determined by spectrophotometric methods. The result obtained from field and petrographical studies show that the major rocks types of the area are migmatite,biotite granite,ignimbrite. The ground water analysis shows that the temperature has a mean annual average of 27^oC, conductivity is 21.2mS/m, pH is averaged at 9.43, Total Dissolved Solids is ranged between 2.8 to 385mg/l, Dissolved Oxygen is 3.2mg/l. Turbidity is ranged between 2.8 and 4.6 NTU. For cation analysis, sodium and potassium ranged between 2.0 to 68mg/l and 2.80 to 20mg/l respectively. Calcium and magnessium ranges between 0.6 to 59.183ppm and 0,448 to 8.572mg/l respectively. Cupper ranges from 0.00 to 0.071mg/l and Zinc has a concentration that ranges from 0.004mg/l to 0.07mg/l and Lead is below detection limit for all samples analysed. For the Anions, chloride ranges between 0.40 to 5.90mg/l, Sulphate is very small ranging between 0.5 to 13.75mg/l, bicarbonates range between 0.333 to 8.2004mg/l and nitrates concentration in water sample ranges from 6.0 to 12.0mg/l. The lineament analysis deduced were processed to generate the lineament density map, lineament length and dominant trend within the area. The results show that the groundwater in the study area is potable and suitable for domestic, agricultural and domestic uses

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CHAPTER ONE

INTRODUCTION

1.0 INTRODUCTION

Hydrogeochemistry is a field combining hydrology and mineral/rock chemistry and is at the heart of many water resource issues for three reasons. First, chemicals and isotopes dissolved in water are excellent tracers for quantifying Earth's water reservoirs and the fluxes across reservoirs in the hydrologic cycle, both globally and locally. Second, chemical knowledge is essential for understanding water-quality problems; for example, the concentrations and speciation of chemicals in water directly affect its potability and usability for agriculture and recreation. The deterioration of water quality can be either natural (geogenic) or human induced (anthropogenic). Third, possible modifications of hydrogeochemical processes that affect water quality are a key element in strategies for addressing future global warming and energy challenges. More than fifty percent of Nigeria is underlain by crystalline rocks, such as gneisses, migmatites and metasediments of Precambrian age. They have been intruded by a series of granitic rocks of late Precambrian to lower Paleozoic age (Rahaman,1976). Most of the basement areas are covered by residual deposits derived from in-situ chemical weathering. The total fresh groundwater resources in the northern Nigeria shield where the study area falls in, as estimated by Schoeneich (2007), stands at 94,979 million m^3 both in the overlying saprolite and the underlying fresh, fractured or jointed crystalline rocks. Schoeneich, (2007), this makes only 1.5 percent of the total groundwater resources of the country with most of the fresh groundwater about 98.5 % is located within the sedimentary basins.

Geochemical tracers such as Cl, the isotopes ^{14}C, ^{3}H, ^{36}Cl, ^{4}He, and ^{81}Kr, and the noble gases have been used to estimate aquifer recharge rates and to determine groundwater ages (Phillips and Castro, 2004). Trace gases and exotic isotopes have also allowed

hydrogeochemists to use old water stored in aquifers as archives of paleoenvironmental information (Siegel, 1991; Edmunds, 2001). In recent years, it has been recognized that submarine groundwater discharges into coastal ocean contribute 5–10% of freshwater inflows to oceans, as well as being a significant source of nutrients and pollutants for coastal ecosystems. These effusive fluxes to oceans are difficult to quantify with physical measurements, but geochemical tracers, such as the U/Th series radionuclides, prove to be effective tools (Swarzenski, 2007).

Water quality refers generally to various chemical, physical, and biological characteristics. The required "quality" of any water depends to a large extent on the purpose for which it is intended (e.g. drinking, swimming, or fishing), but it is mostly linked to drinking water standards (Appendix). The connection between geochemistry and water quality is direct and obvious. The most important supplies of potable freshwater occur is the shallow subsurface aquifers. Accordingly, the geochemical processes that control the chemistry of freshwater bodies are closely coupled to microbiologic activities, climatic forces, atmospheric inputs, and physical transport processes.

The influence and importance of water quality to society are illustrated by the acute human health problems related to arsenic contamination of shallow wells in Bangladesh and southern India (Charlet and Polya, 2006; Polya and Charlet, 2009). High arsenic concentrations occur naturally in the sediments of the Ganges Delta, where arsenic compounds are adsorbed onto iron oxyhydroxide and sulfide minerals. Anthropogenic processes have led to the remobilization of the arsenic into shallow groundwater. Ninety percent of the local population use groundwater for drinking. As a result, about 21 million people are currently exposed to arsenic contamination and could suffer adverse health effects. (Charlet and Polya, 2006; Polya and Charlet, 2009)

1.1 Aim and Objectives of Study

The aim of this study is to carry out geochemical investigations of groundwater and the hydrogeology of the area of study. The objectives are to;

i. determine the groundwater potential of the area

ii. the groundwater quality of the area

iii. the suitability of the water in sustaining various uses

iv. update the geological map of the area.

v. produce groundwater maps of the area

1.2 Statement of Research Problem

It has been established that the groundwater of certain parts of the northern Nigeria particularly where artesinal mining is practised is known to contain certain element above the recommended levels for human consumption. The case of lead poisoning in Zamfara State is a case in point and thus pertinent to carry out research in other parts where artesinal mining is practised to assess the risk . Dutsen Wai and Banke arears also has some relatively small scale mining activities where the artesinal miners mine for cassiterite and related metals.

1.3 Significance of the Study

The research will help to determine the suitability of the water in the study area for drinking, agricultural or domestic purposes. It will also evaluate the risk posed by artisanal mining.

Also this research will be of immense benefit to hydrogeologist in that it will provide an insight to the hydrogeology and occurrence of groundwater in the study area.

1.4 Location, Extent, Accessibility of Study Area

The study area is bounded by latitudes 8° 15'00"E to 8°30' 00"E and longitudes10°45 '00"N to 11°00' 00"N covering an area of about 770 Km^2 . It is located in the north-east part the of Dutsen Wai Sheet 125 NE. The area is accessible by various minor roads and footpaths. A major road links the area of study with the main town of Dutsen Wai. Other villages in the area are Rafin dodo, Dutse banki, Takalafiya, Anchau, Damau, Kuzuntu, Magami, Nasari, Bugau and Rikochi .

The area is drained by River Banki and its tributaries running from the northern region to the southern part

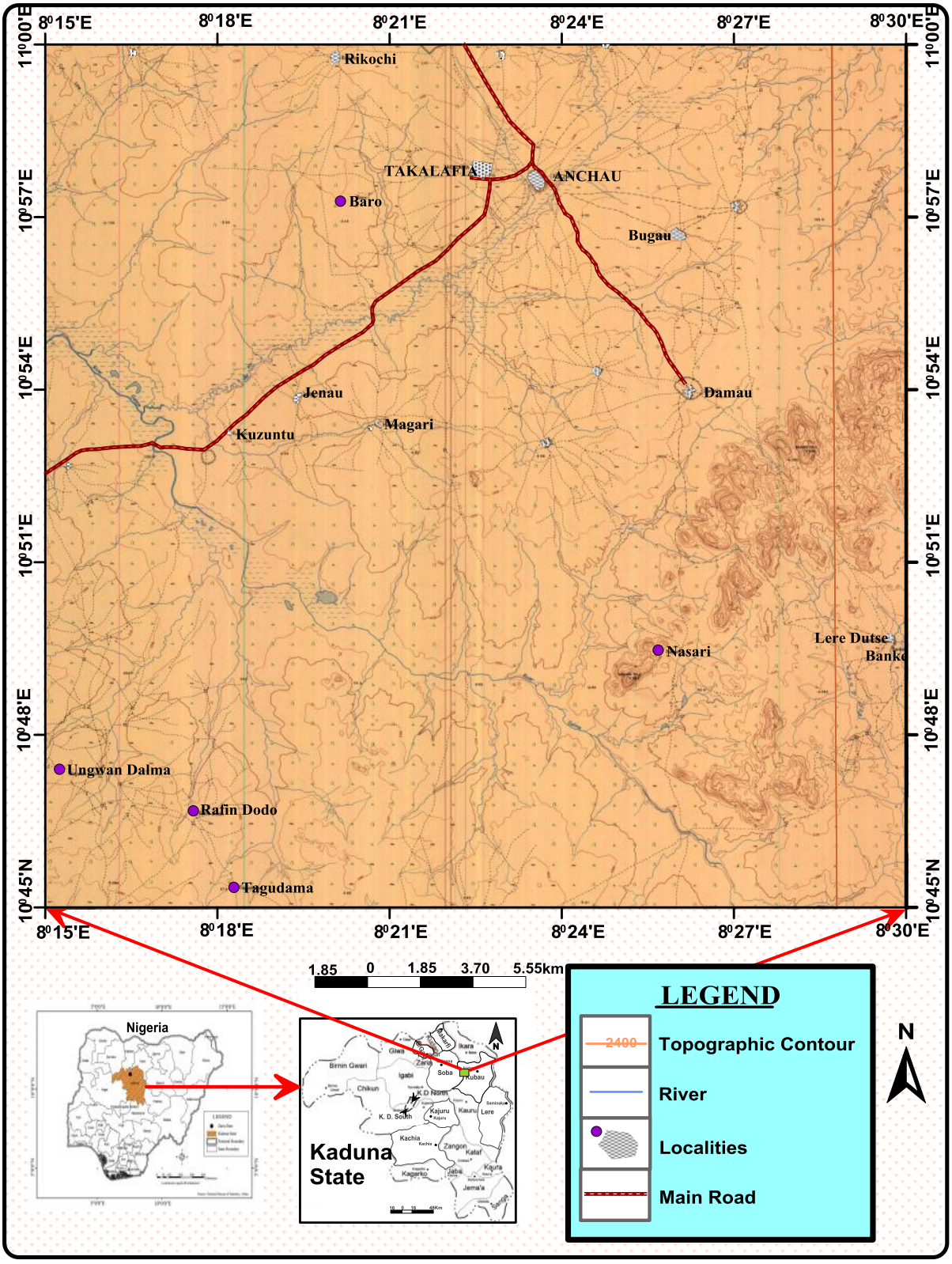


Figure 1.1: Location map of the study area; Dutsen Wai Sheet 125 NE,

1.5 Relief and drainage

The relief of the area is that of a gently undulating surface, except the eastern part of the study area, at Dutsen Wai town, where the Dutsen Wai hills form a prominent topographic feature with elevation of 853.44 m above sea level. The area is capped by the extensive hardpan lateritic cover, especially in its western and northern parts. Under this surface is gritty clay, water saturated from which hand dug wells are serving water to small rural communities. The area is well drained by River Banke and its tributaries (Figure 1.2). The drainage pattern is generally dendritic.

The Damau Hills region includes the large and remote northern arc of volcanic rocks which, because of its size and accessibility has been the least studied part of the ring complex.

The western edge of the complex is marked by the prominent hill of Dutsen Nasari rising to a height of 173 m above the surrounding plains. It is asymmetric with a very steep eastern scarp, and divided into northern and southern parts by a deep valley.

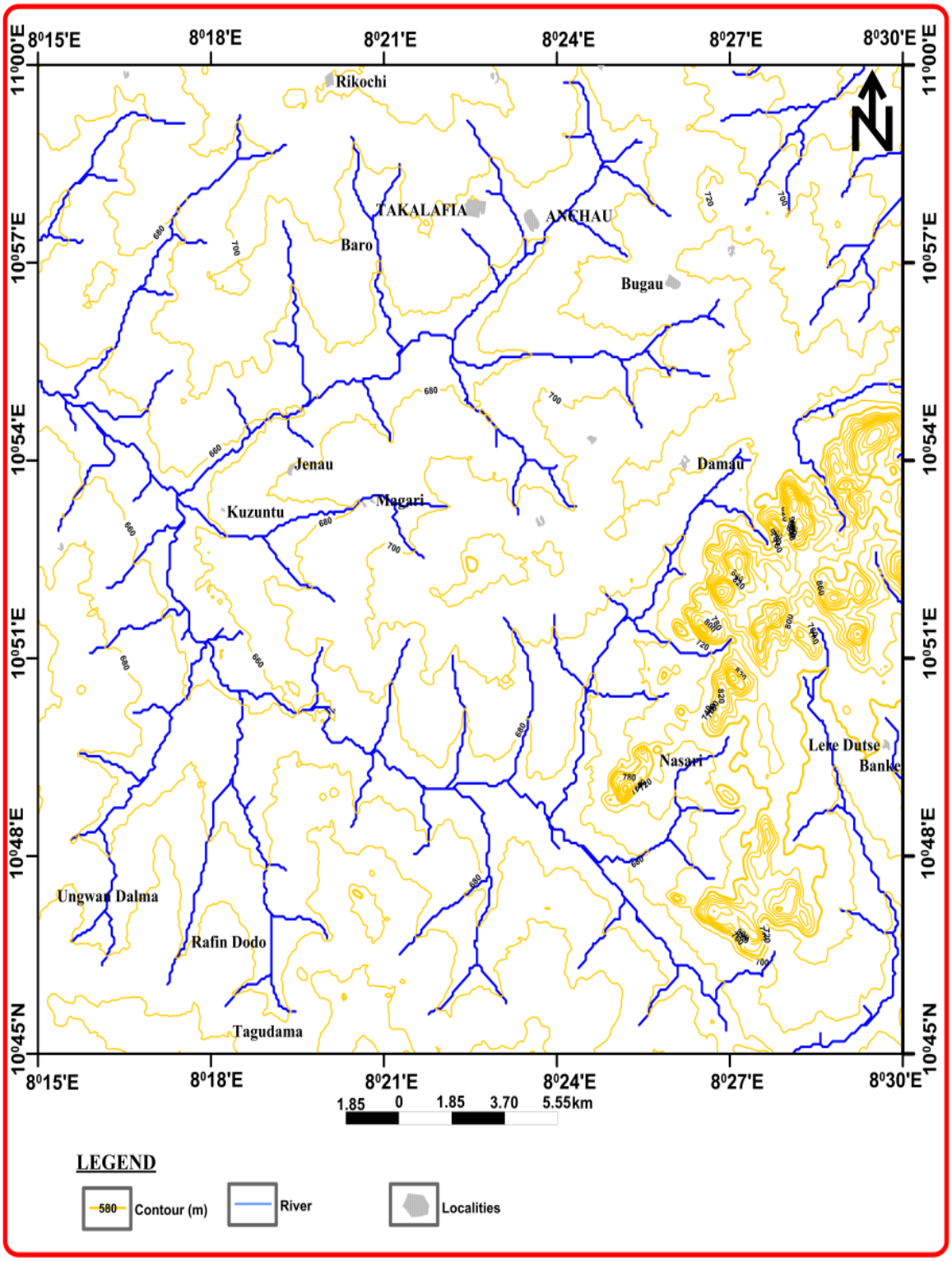


FIGURE 1.2: Drainage map of the study area

1.6 Previous works

Earlier workers, such as Raeburn *et al.* (1927), first mapped and described the Dutsen Wai ring complex during their initial surveys of the Nigerian tin fields. They recognized the principal granitic components (explosive breccias, biotite-granites and albite-riebeckite-granite) and gave an account of the distribution of tin mineralization. The granites were re-surveyed by MacLeod and Jacobson in 1960.

Du Preez (1956) described two phases of oldest erosional cycles. He stated that the first erosional phase started after the Pan – African Orogeny. After plenty of erosional cycles, a thick weathered mantle was created on a peneplain surface of which the older laterite was developed possibly in the Plio – Pleistocene. According to Barber (1965), this older laterites is said to have plunged in the northeastern part below the Chad Formation. The second phase of the oldest erosion concentrated on the older laterite reducing the formerly continuous cover on the weathered mantle to discontinuous residual hills with the result of broad depressions in which materials were deposited discordantly with the oldest paleomorphology.

Du Preez and Barber (1965), while working on the groundwater distribution in northern Nigeria noted that extractable groundwater by open wells and boreholes is located in the fractured rock and the weathered portion of the basement. These authors reported that the thickness of the weathered basement varies. They further stated that sufficient weathered material and the degree of saturation are some of the factors that affect the presence of groundwater in the basement complex.

Uzoma (1973) carried out a pumping test on a well at the Government Technical Secondary School, Soba and reported a discharge rate of 23.30 liters per minute in the weathered rock aquifer. By using Bolton's non-steady state approach for water table aquifer, he obtained

transmissivity values of approximately 15 m^2/d, 4.54 m^2/d and 1.5 m^2/d (1007 imp. gal /day/ft, 304 imp. gal/day/ft and 102 imp. gal/day/ft).

Nassef and Olugboye (1979) carried out a hydrological and hydrogeological investigation of Galma Basin. This investigation formed part of the Galma River Basin Development Project which was aimed at a systematic and scientific study of the basin with a view to developing the area for agricultural and water supply purposes, by means of irrigation scheme, dam impoundment and borehole drilling. In part of their analyses, they noted that the terrain in and around Soba town (where Uzoma carried out his well test in 1973), being at the geometric center of the basin, is considered typical of the terrain situation in most part of the basin. They however considered Uzoma's test inconclusive and stated that the ''recorded yield of the aquifer may not be the optimum for it, if the well is better developed''. Hence using Uzoma's well test data, they recalculated transmissivity using Jacob's method and obtained 2.795×10^{-5} m^2/s ($2.4m^2/d$) as apparent transmissivity claiming the average thickness of the aquifer to be 8 m. These authors estimated 0.335×10^{-5} m/s (0.289m/d) as the average permeability of the '' weathered rock aquifer underlying Galma River Basin''. They concluded, however, that since they lacked accurate knowledge of the extent, thickness and lithology of the geologic section, as well as the permeability of the aquifer, their conclusion was tentative.

Nassef and Olugboye, (1979) reported that the study area is almost entirely underlain by migmatite, with fine-medium grained biotite granites occurring at the northern and western ends with the Younger Granites extrusive into the surrounding migmatite

Plateau State Water Board (1981) carried out studies on the coefficients of total run-off, surface runoff, base flow and evapo-transpiration at the Werram River gauging station Jos. It reported that, for an area of 216 km^2 the coefficients of these components are 0.72, 0.53, 0.19, and 0.28 respectively.

Inalegwu (1986) studied the hydrology of the Forom river upstream of Barakin-Bako, for an area of 161 km^2. He found the coefficients of total run-off, surface run-off, baseflow and evapo-transpiration to be 0.566, 0.408, 0.158 and 0.434 respectively.

Malami (1986) investigated the hydrology of Tilden Fulani river drainage basin on the area of 190.5 km^2 and found the coefficients to be 0.52 (total run-off), 0.31 (surface run-off), 0.21 (baseflow), and 0.48 (evapo-transpiration).

Adegoye (1987) carried out a field hydrogeological study of the River Karami (Rahama) catchment area on Dutsen Wai sheet 125 S.E and reported that the catchment area consists of fractured crystalline rocks, covered in most parts by soft overburden. Field permeameter, sieve analysis, falling head permeameters and test pumping methods were used to determine the coefficient of permeability (K) of both the soft overburden and fractured aquifers and found that permeability ranges from 0.377 m/day to 6.862 m/day. Adegoye (1987) further reported that the geochemical and bacteriological analysis carried out indicated that the water quality in the aquifers is acceptable for domestic, agricultural and industrial uses.

Ogunjobi (2000) computed aquifer characteristics in the crystalline Basement Complex of northern Nigeria using Galma basin as a case study and concluded that, the transmissivity ranges from 0.22 m^2/ day to 42.41 m^2/day, the storage coefficient varies between 0.005 and 0.007 and average specific yield varies from 0.024 to 0.06 m^3/day within the basin and the result of the analysis indicated that the yield is highest where weathered aquifer is thickest and parent rock is coarse.

Ogwuche (1991) worked on the relationship between the coefficients of run-off and the area of the drainage basin on River Karami for hydrological stations at Jengre and upstream Saminaka, mid-stream around Lere and downstream at Kauru with an area coverage of about 2738.28 km^2. Using hydrograph separation method, she found the mean annual discharge of 31530910 m3 at Saminaka, 214292130 m3 at Lere, and 812245110 m3 at

Anchau with coefficients of run-off in the same order as 0.40, 0.15 and 0.25 respectively. She calculated the potential coefficient of run-off for Jengre which showed inconsistency in the available data and Lere which has data but suspected unreliable. The coefficients found using statistical method are 0.43 at Jengre and 0.37 at Lere, with mean annual discharges of 14251350 m^3 and 51726000 m^3 respectively.

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

1.7 Climate, vegetation and landuse

The study area belongs to the tropical climate. The monthly temperature varies between 19.4^0C and 26.9^0C in August representing the wet season, and increases to 20.4^0C and 34.9^0C at the end of the dry season.

Wet season in the area begins in April and ends in October while dry season begins, in October and last until April. Dry season is subdivided into cold or harmattan dry period ending in January, and warm period of dry season in February, March and April (Walter, 1977).

The vegetation of the study area is of the Guinea Savannah type (Du Preez and Barber, 1965) which is characterized mainly by herbs and grasses with few deciduous widely scattered trees. The herbs and grasses grow very tall in some places although evergreen trees exist mainly along the perennial rivers and streams. Because of the seasonal character of rainfall, the colour of vegetation varies. It is green during the rainy season but becomes yellow or brown in the dry season.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Geology and hydrogeology of crystalline basement complex rocks of nigeria

2.1.1 Geology of Crystalline Basement Complex Rocks

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

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

- The migmatites-gneisses complex
- Metasediments and metavolcanics rocks schist belt
- The Older Granites (Pan African granitoids)

  Undeformed Acid and Basic dykes

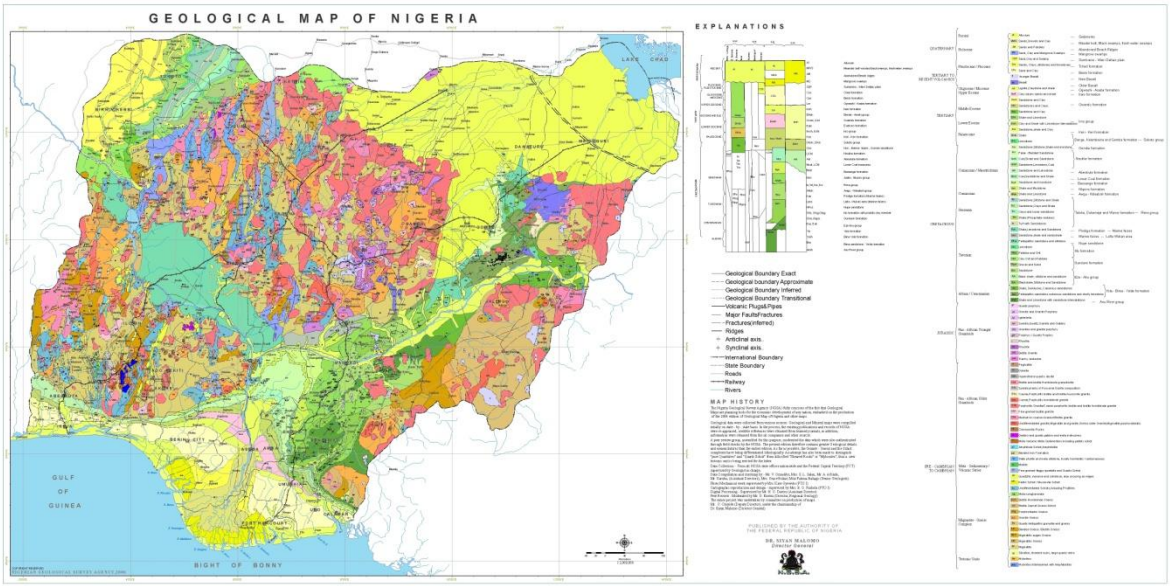


Figure 2.1: Geological map of Nigeria showing different rocks types (After Geological survey of Nigeria, 1994)

2.1.2 Hydrogeology of Basement aquifers

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

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

The aquifer systems developed are:-

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

2.2 Development of Groundwater

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

The two most important properties that explain the characteristics of aquifers are permeability and porosity. According to MacDonald *et al*., (1986), these properties vary with depth. While

permeability depends on the extent of fracturing and the clay content, porosity generally decreases with depth as shown in fig. 4 below:-

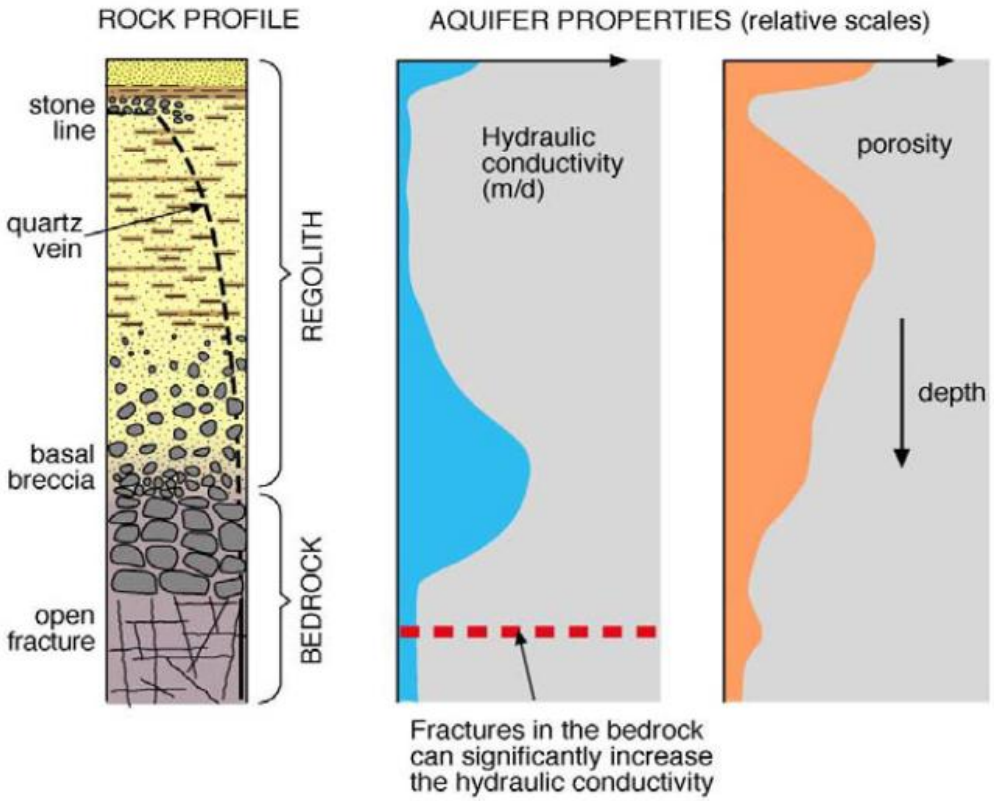


Figure 2.3: Schematic diagram of the variation of permeability and porosity with depth in the crystalline basement (After Chilton and Foster, 1995)

Fig. 2.3 shows that regolith has a high storage capacity but low permeability, whereas bedrock has a low storage capacity but high permeability. However, that is not always the case. Because there are cases where boreholes yield do not necessarily decline with depth. For example, Loiselle and Evans (1995) did not find any evidence of either decrease in fracture density or fracture yield up to a depth of about 180m in the crystalline rocks of Maine, USA. High yields from deep fracture horizons are reported from India and Sri Lanka. Data on borehole drilling in parts of the Indian shield also show an improvement in borehole productivity with an increase in depth up to 300m (Jagannathan 1993). Singhal and Gupta, (2010) observed that high discharge from deep gold mines in Karnataka, India, and Rand mines in South Africa also indicate high potentiality of deep fractured aquifer

2.2.1: Exploration Approaches

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

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

Landsat 5-TM imagery of an area can be analyzed and interpreted in order to determine the lineament trends, lineament density and groundwater potential across the area (Anudu *et al*., 2011). Rose (azimuth-frequency) diagram of the lineaments shows lineament trends. According to Boeckh (1992), depending on the resolution of the satellite, recording system can show major lineament trends. Lineament density shows number of lineaments per unit area, or total length of lineaments per unit area. Areas having high lineament density represent areas with high groundwater potentials.

In most cases, authors could not establish a direct relationship between borehole yield and lineament, due to lack of direct evidence that the structures responsible for the flow correlates with a mapped lineament. But Sander, (2007) noted that, this may be attributed to local factors such as fracture infilling, fracture connectivity etc. It is recognized that lineament mapping is often not based on facts, but rather on personal beliefs or feelings, and also depends on factors such as data quality, extraction technique, and interpretation method. But

when it is correctly interpreted, lineament in conjunction with knowledge of local geology, hydrogeology, tectonics, geomorphology etc; reveals setting and orientation of fractures for groundwater exploration at depth. These approaches to borehole siting will achieve a high success rate if properly applied.

2.2.2: Structural control of groundwater occurrence

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

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

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

However, in regional flow system, regional flow of ground water occurs within the major interconnected fracture systems.

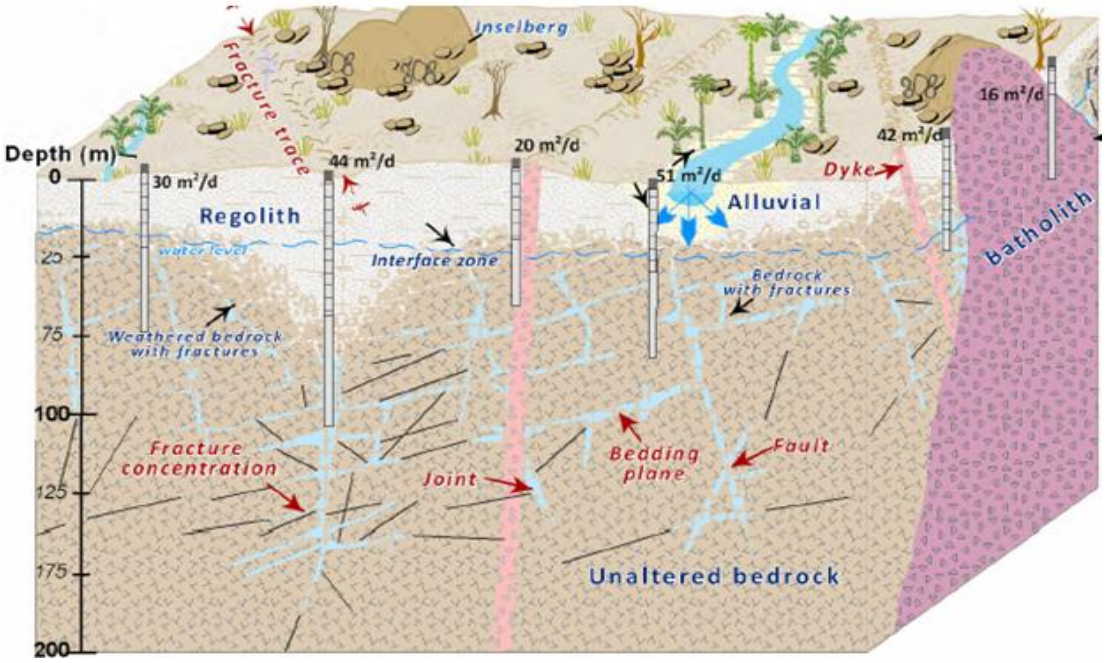


Figure 2.4: Groundwater flow in basement aquifers (After Martin. 2011)

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

CHAPTER THREE

3.0 MATERIALS AND METHODS

The hydrogeology and groundwater quality in parts of Dutsen Wai Sheet 125 NE was carried out in four stages, consisting of desk study, field work, laboratory work and evaluation of the field and laboratory data.

3.1 DESK STUDY

The desk study consisted of the assemblage and examination of all available information such as topographic map of Dutsen Wai Sheet 125 NE on a scale of 1:50,000, relevant published and unpublished data, from Federal Surveys, Kaduna State Water Board, Kaduna State Agricultural Development Project and Rural Water Supply and Sanitation Agency (RUWASSA), Kaduna. After the field work, processing of data collected both in the field and laboratory was done.

3.2 FIELD WORK

The field work was carried out both at the on-set of rainy season signifying peak dry season and the peak of rainy season signifying peak rainy season. This stage covered a period of about five months (April, 2015 to September, 2015). The field work involved locating hand dug wells, measurement of water levels in hand dug wells, water sampling, mapping and petrologic description of outcropping rocks, rock sampling. Field equipment/materials used during the fieldwork included a topographic map, a hand-held Garmin-satellite navigator, measuring tape, geological hammer, sample bag, nitric acid for sample preservation, a syringe, field note book, Hand-Held Water Quality meter model WQC-24, water sample bottles, Heron Instrument Dipper T 600rT, drawing bucket attached with rope, masking tape and marker.

3.2.1: Determination of Aquifer Characteristics

Pump test data of ten (10) boreholes were used for the determination of aquifer characteristics. The ability of an aquifer to transmit water in economic quantities in wells depends on some influencing factors. These factors are described as the aquifer characteristics and they include hydraulic conductivity (K), transmissivity (T) and storativity (S). The properties were determined using Jacob's straight line method (1947). Parts of the data obtained from the measurements were plotted on semi-log graph in order to observe the changes in drawdown for a period of pumping of the borehole. The drawdown (s) in meters on the ordinate is plotted against time (t) in minutes (Appendix-I). When there is significant change in drawdown during the period of pumping, the flow is considered unsteady, but if the change in drawdown is not significant (nearly horizontal line on the graph), the flow is regarded as steady flow. However, all the pump test data used for this study are of unsteady flow. Data used were obtained from RUWASSA Kaduna (Appendix-II)

Transmissivity was determined from the relation:

$$s2 - s1 = \left[\frac{(2.30Q)}{(4\pi T)}\right] x \left[\log 10\left(\frac{t2}{t1}\right)\right] \quad \text{(i)}$$

$$= \Delta s = \left[\frac{(2.30Q)}{(4\pi T)}\right] x \left[\log 10\left(\frac{t2}{t1}\right)\right] \quad \text{(ii)}$$

$$\text{Hence, } T = \left[\frac{(2.30Q)}{(4\pi \Delta s)}\right] x \left[\log 10\left(\frac{t2}{t1}\right)\right] \quad \text{(iii)}$$

Where: T = transmissivity (m^2/day);

Q= discharge rate (rate of pumping, m^3/day);

Δs = change in drawdown; and

t_2,t_1 = time (days) since pumping started (Figure 3.1) .

Where: T = transmissivity (m^2/day); and

D = thickness of water bearing zone

Coefficient of Storativity (storage coefficient):

$S = 2.25Tt_0/r^2$ …… (v)

Where: S = storage coefficient;

T = transmissivity (m^2/day);

t_o = time intercept on zero draw-down axis; and

r = radius of the borehole.

An overview of the methodology adapted for lineament extraction using landsat etm plus data is shown in Figure 3.1 below

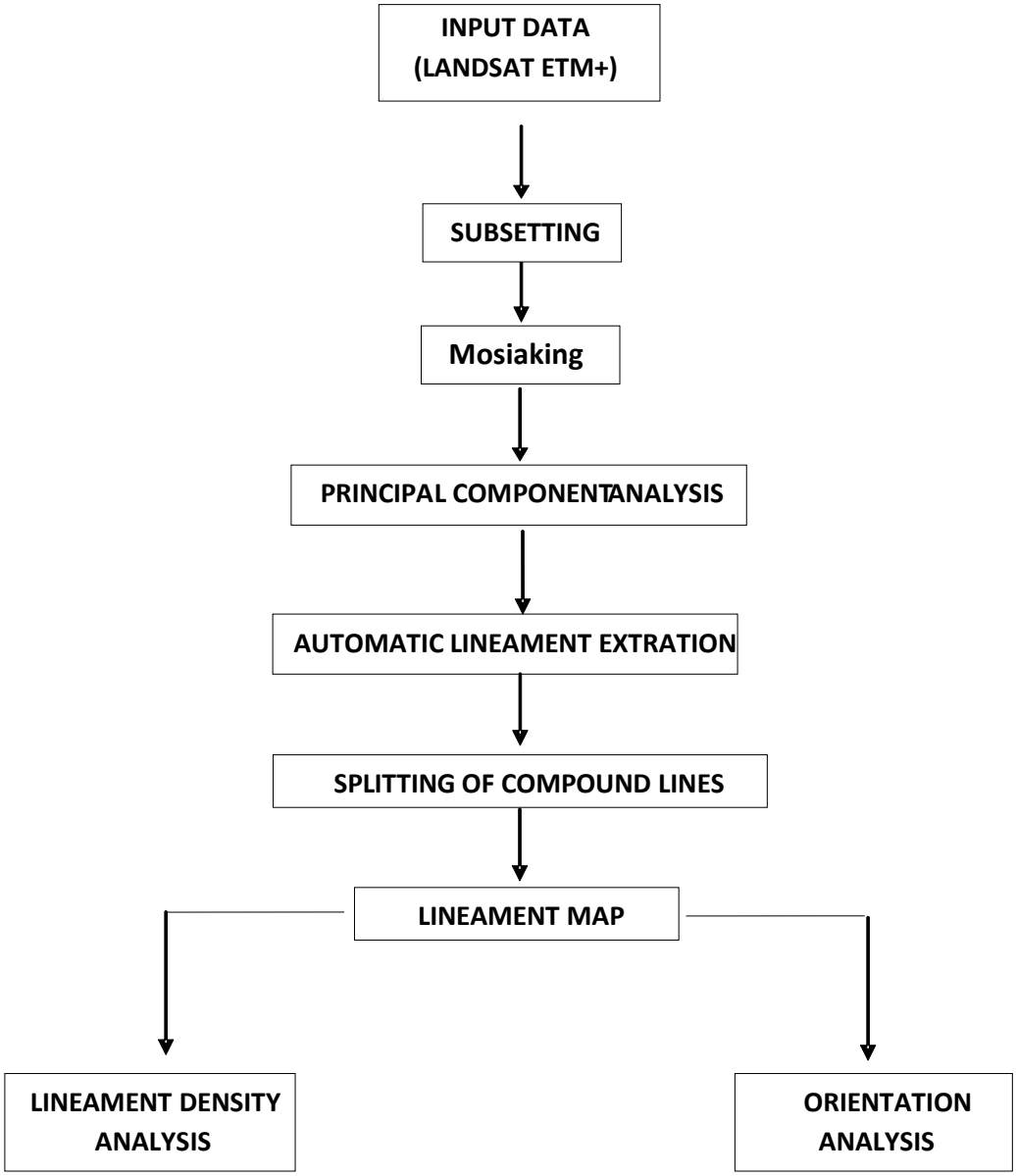


Figure 3.1: An overview of the methodology adapted for lineament extraction using landsat etm plus data

3.2.3 Principal component analysis

The first principal component image (PC1) of landsat 7 pansharpened reflected bands in 8-bit grayscale and 30 m spatial resolution was used as it carries most information and is suitable for lineament extraction purposes. This was carried out using ENVI 4.5 software on a layer stacked image of the acquired landsat scene.

3.2.4 Lineament mapping

LANDSAT ETM+ imagery of the area was downloaded from global land cover facility site. The automatic lineament extraction was carried out with the aid of the Line module of the PCI Geomatica software. The calculation of lineament related values with script files was done using ArcMap 10.1GIS environment. The extracted lineaments were taken to Rockworks 15 software where rose-diagram (azimuth-frequency) generated lineaments trends (Fig. 4.11).

3.2.5 Lineament extracton

This was done in the PCI Geomatica GIS environment using the "Line: lineament extracton module" under geological and geophysical analysis. The lineament extraction in PCI extracts lineaments from any single 8-bit image in three steps viz: edge detection, thresholding and curve extraction respectively. The parameter settings used are shown in Table 3.1

3.2.6 Splitting compound lines into simple lines

This was done in the ArcMap 10.1 GIS environment. Compound lines were splitted at the vertices. The aim was to get the accurate endpoint of straight lines which is necessary for trend/orientation analysis. The length and endpoint of lines (X coordinate of line start (X1), Y coordinate of line start (Y1), X coordinate of line end (X2) and Y coordinate of line end (Y2)) were also computed within the ArcMap 10.1 GIS environment.

Table 3.1: Software Setting for Lineament Extraction

Description	**Values**
Filter Radius (Pixels)	10
Edge Gradient Threshold	100
Curve Length Threshold (Pixels)	30
Line Fitting Error Threshold (Pixels)	3
Angular Difference Threshold (Degrees)	30
Linking Distance Threshold	20

3.3 Lineament density

Lineament density which is a measure of the degree of rock fracturing, was computed using the "Line density" feature in ArcMap leading to nine (9) classes of lineament density.

3.4 Petrological field studies

Rock outcrops were mapped, described, and sampled with their coordinates taken and plotted on the field map (Figure 4.4). Geological boundaries were used in the construction of the geological map shown in Figure 4.1. Thin sections of the rocks sampled were prepared at the Thin Section Laboratory of the Geology Department, Ahmadu Bello University, Zaria. Each of the thin section slide was observed under a petrological microscope and described as shown in plates Pates IV to X

3.5 Hydrogeological field studies

Hydrogeological field work of the study area was carried out by traversing the network of roads and footpaths to villages.

3.5.1 Collection of Water Samples

The bottles for sampling were obtained, and at each sampling point the bottle was rinsed with the water to be sampled before the water was collected. pH, Temperature, Dissolved Oxygen,Turbidity, Salinity and Conductivity were measured directly in the field using Hand held Water Quality Meter(WQC-24 (6 in 1 combined meter). This allows an initial, rapid assessment of water quality at the site of sampling. This was followed by the acidification with some few drops of Nitric acid (HNO_3) to prevent adsorption of ions on the walls of the containers, similarly to prevent bacterial activities. The sample was labeled and stored in container containing ice blocks before taken to the laboratory for analysis.

3.5.2 Equipment used:- Polyethylene bottles (for acidified and non acidified samples), disposable syringes, washing bottles, permanent drawing ink markers, ice blocks, and two

500ml polyethylene beakers for measurement of pH , EC, pH meter etc. At each of the sampling points, the following procedures were followed;

1. Labelling of sample bottles;
2. Ploting of location and sample number on the map;
3. Temperature/pH/EC meter and polyethylene beaker were rinsed in deionized water and then with water to be sampled, to remove any trace of previous sample or storage solution;
4. Measurements of temperature, pH, TDS,DO, Salinity and electrical conductivity (EC) of water using WQC-24 (6 in 1) combined meter;
5. Recording the temp/pH/EC/TDS readings on the field record sheet, the meter and beaker were rinsed with deionized water and meter kept in its cap;
6. Two samples were collected at each sampling points with some drops of nitric acid (HNO_3) added to one of the bottles for cation analysis and closed tightly;
7. The filled samples bottles were placed in the cool box;
8. Transportation of samples to the laboratory for analysis.

3.6 Laboratory Work

The water quality of the acidified and non acidified samples from the wells were analysed at the Multi-user laboratory, Department of Water Resources and Environmental Engineering, Multi-purpose laboratory in the Department of Soil Science, Ahmadu Bello University Zaria, in order to determine the concentrations of major and some trace elements in the water. This was achieved using Atomic Absorption Spectrometer (AAS-Varian AA240Fs), Direct reading Photometer (Hanna model), titrimetric method, and Flame photometer (FPF9 Jenwy model). The method and the procedure of how these were done are as shown in table 3.3.

Table 3.3: Analytical Methods for Environmental Water Quality (After UNEP 2004)

PARAMETERS	**METHOD DESCRIPTION**	**UNITS**
ELECTRICAL CONDUCTANCE	pH/EC/TDS/Temperature model Mi 806 combined meter. Specific Conductance of a solution is the ability of the solution to carry electric current and has some relationship to the Total Ionic Concentration of the solution. The specific conductance is measured by a conductivity meter with Pt electrodes and is equilibrated to 25ºC before the sample measurement is made. The conductivity meter is calibrated on a per use basis.	µS/cm
TOTAL DISSOLVED SOLIDS	pH/EC/TDS/Temperature model Mi 806 combined meter. The Total Dissolved Solids (TDS) is measured through a calibrated conductivity meter. The resolution is 3 significant digits or 1 mg/L and the range varies between 0 and 19900 mg/L.	mg/L
TEMPERATURE	pH/EC/TDS/Temperature model Mi 806 combined meter. Both atmospheric and water temperature are measured upon sample collection. The water temperature is measured by immersing meter into the water or by measuring the temperature immediately after collection.	^{O}C
pH	pH/EC/TDS/Temperature model Mi 806 combined meter. The temperature of a sample is stabilised at 25ºC. The above meter was used for pH determination. The sample aliquot is read at 25ºC.	pH Units
BICARBONATE	Calculated If PA = 0 then HCO3= 1.219*TA If PA ≤TA/2 then HCO3= 1.219*(TA-2*PA) If PA > TA/2 then HCO3= 0 If TA < PA then no calculations If TA = PA and Not = 0 then no calculations. The method detection limit is 0.5 mg/L. Caution: These calculated results are computed from measured analytical values according to the formula indicated. The computations may be in error if the parameters used in the calculation are subsequently edited or changed.	mg/L HCO_3
NITRATE	Colourimetry A sample is filtered in the field through a 0.45 µm membrane filter and preserved at 4ºC. The sample aliquot is passed through a coil, filled with cadmium filings, to reduce the nitrates to nitrites. The resulting nitrites, plus the original nitrites, are then reacted with sulphanilamide to form a diazo compound. This compound is then reacted with N-(1-naphthyl) ethylenediaminedihydrochloride to form an azo dye. The azo dye colour intensity, proportional to the nitrate + nitrite concentration, is determined colourimetrically at 520 nm and compared to identically-prepared standard and blank solutions.	mg/L NO_3

SODIUM	Flame Photometry The sample is collected and preserved in a polyethylene bottle at 40°C. A sample aliquot is mixed with lithium nitrate and passed into the burner of a flame photometer equipped with filters to isolate the spectral lines of sodium. The intensity of light produced is proportional to the concentration of sodium in the sample and compared to identically-prepared standard and blank solutions, using propane and air flame. The method detection limit is 0.1 mg/L.	mg/L Na
MAGNESIUM	Atomic Absorption Spectrometry – direct aspiration A sample is collected and preserved in the field at 4°C. The shaken sample aliquot is mixed with a $LaCl_3$solution and aspirated in an air-acetylene reducing flame. The absorbance is measured spectrometrically at 285.2 nm and compared to identically-prepared standard and blank solutions. The method detection limit is 0.001 mg/L.	mg/L Mg
SULPHATE	Turbidimetric Method A sample is filtered in the field through a 0.45 µm membrane filter and preserved at 4°C. The sulphate in a sample aliquot is precipitated in a hydrochloric acid medium with barium chloride. The absorbance of the barium sulphate suspension is measured by a photometer and the sulphate concentration is compared to a calibration curve from identically-prepared standard and blank solutions. Interference: Colour and/or suspended matter in large amounts, silica in concentration greater than 500 mg/L will interfere. Organic matter may also interfere. The method detection limit is 1 mg/L.	
CHLORIDE – DISSOLVED	Silver Nitrate Titration A sample is filtered in the field through a 0.45 µm membrane filter and preserved at 4°C. If a sample aliquot is highly coloured, add $Al(OH)_3$suspension, mix, let settle and filter; if sulphide, sulphite or thiosulphate is present, add $H_2O_2$and stir for one minute. The pH of the sample should be between 7 and 10 (if not, adjust with diluted sulphuric acid or sodium hydroxide). Titrate with a standardised silver nitrate solution, using potassium chromate as an indicator, to a pinkish yellow end point and compare to identically-prepared standard and blank solutions. Interference: Bromide, cyanide and iodide interfere as equivalent chloride concentrations; soluble reactive phosphorusin excess of 25 mg/L precipitates as silver phosphate; iron greater than 10 mg/L masks the end point. Calculation: mg/L Cl = (A – B) x N x 35.450 mL sample A = mL of titrant for sample B = mL of titrant for blank N = normality of silver nitrate (mg/LNaCl = mg/L Cl x 1.65). The method detection limit is 5 mg/L.	mg/L Cl

POTASSIUM	Flame Photometry A sample is preserved in the field at 4°C. The sample aliquot is mixed with a lithium nitrate solution, as an internal standard, and passed through the burner of a flame photometer equipped with interference filters isolating the spectral lines of potassium. The intensity of light produced is proportional to the amount of potassium present in the sample and is compared to identically-prepared standard and blank solutions, using propane and oxygen flame. The method detection limit is 0.1 mg/L.	mg/L K
CALCIUM	Atomic Absorption Spectrometry A sample is preserved in the field at 4°C. A LaCl3 solution is added to the sample aliquot, mixed and aspirated. The absorbance is measured spectrometrically at 422.7 nm, and compared to identically-prepared standard and blank solutions. The method detection limit is 0.002 mg/L.	mg/L Ca
TOTAL IRON	Spectrophotometry A sample is preserved in the field with nitric acid. The sample aliquot is digested with nitric acid, mixed with HCl, followed by hydroxylamine hydrochloride ($NH_2OH.HCl$) solution (reducing ferric to ferrous ions). This solution is mixed with TPTZ (2,4,6-tripyridyl-s-triazine) solution and buffered at pH 4.75. The absorbance of the resulting violet colour is measured spectrometrically at 588 nm and compared to identically-prepared standard and blank solutions. Interference: Precipitable organic compounds. The method detection limit is 0.001 mg/L.	mg/LFe

3.7: Geophysical Investigation

A vertical electrical sounding (VES) of electrical resistivity method was carried out using Ohmega resistivity meter with Schlumberger configuration. According to Macaulay (2008), the VES principle is based on the fact that sub-strata is a resistor to the flow of electric current and that any sub-surface variation in conductivity will alter the current which affects the electrical resistivity of overburden and bedrock varies considerably in relation to moisture content.

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

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

The electrode spacing was progressively increased keeping the centre point of the electrode array fixed. The maximum half current electrode separation (AB/2) was between 1 and 80m while the half- potential electrode separation (MN/2) was maintained between 0.5 and 8m. The apparent resistivity measured at each point was plotted on a log-log paper. The plots gave a rough idea of position and forms of the interface. A total of ten (10) VES points were collected.

CHAPTER FOUR

4.0 RESULTS

This chapter presents the results of the interpreted geological and hydrogeological data, acquired on the field

4.1 Petrographic description of collected rocks from the Area

The study area is underlain largely by migmatite and granite. Most of the north eastern and south western parts of the area is underlain by migmatite while the rest of the portion is mainly granite and gneiss.

At the western end of the area is part of the banke complex. It covers a very large area of about 205 km^2 of which over a third consists of basement rocks enclosed within the ring fault. There are notably two hills, the Damau hills and the Dutsen Nasari.

4.1.1:FerroHedenbergite granite porphyry

They are iron formations and are brownish green in colour. They are found to occur at the southern end of the Damau Hills. They are most commonly found in syenite and alkali granites.

4.1.2:Biotite-granite

The rocks are exposed at the north-western part of the area. Field examination shows that they are mostly porphyritic and nearly equigranular and coarse grained. This belongs to the younger granite series.



Plate I: Hand specimen of biotite granite collected at Kawa ($N10^{0}50.516$, $E8^{0}21.246$)

4.1.3:Crystal rich ignimbrite in feeder cone

These are homogenous and appear to be well stirred and contain strong eutaxitic foliation oriented parallel to the contacts and their features is thought to result from inwardly-directed pressure exerted by the dyke walls during a collapse which follows eruption of the ash flow. Vents of this type are believed to originate by permissive intrusion through the roof of a shallow seated magma chamber.

4.1.4:Intra caldera crystal-rich Ignimbrite

Ignimbrites occur typically as light coloured rocks. In hand specimen the phenocrysts are basically biotite, quartz and alkaline feldspars. It is seen that a caldera forms as a result of large ignimbrite eruption



Plate II: Hand specimen of an ignimbrite at Nasari

4.1.5:Fine to medium grained biotite granite

It covers a large portion of the study area and extends to the middle part. They are fine to medium grained rock dominated by phenocryst of perthite feldspars in a groundmass of quartz, plagioclase and orthoclase with biotite. They belong in the older granite series

4.1.6: Migmatite

This covers more than half of the area under study. They are mixtures of gneissic-schistose rocks with more or less foliated gneisses or granites. They are also seen to be highly weathered. Field examination shows that they are fine to medium grained rocks



Plate III: Migmatite outcrop around Ungwan Dalma($N10^0$47.218, $E8^0$16.420)

4.2: Superficial deposits

In areas where fresh bedrocks are not exposed, decomposed weathered bedrock are overlain by varied thicknesses of laterites, weathered clayey zones. The laterite covers the top of the remnants of some pediment low flat – topped lateritic mesas . The lateritic cover is a thin layer of ironstone believed to be erosion remnants of a lateritic sheet on an extensive peneplain and are possibly of Pliocene age, according to Du Preez (1956). The laterites are dark brown to reddish and sometimes yellowish in colour, hard crusted and

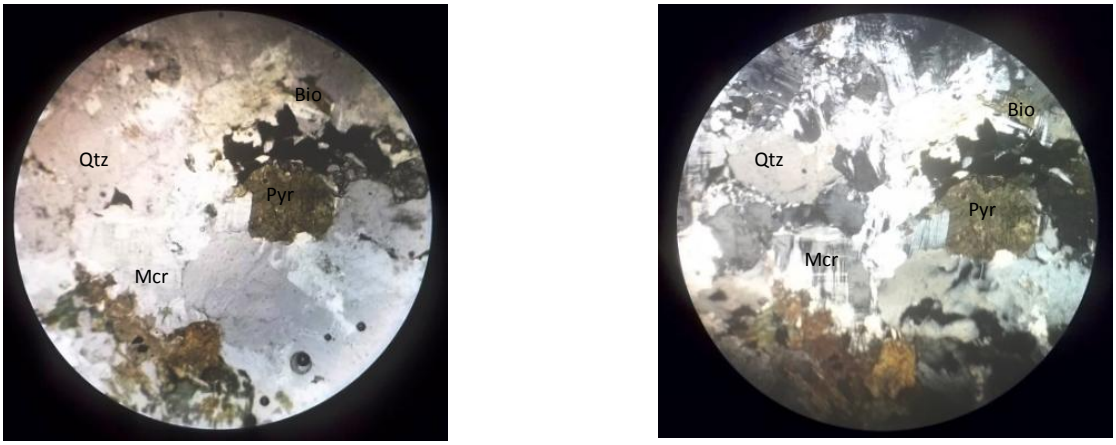
gravelly. These layers are followed by the weathered clayey zone. The stream alluvial deposits found in the study area are mostly derived from the weathering of basement rocks. They are fine to coarse grained sand, silts, clays and unconsolidated gravels made up of quartz. Along River Galma, white coloured alluvium was found and brown to brownish red sands, silts and clays were seen along the river valley, with gravelly texture in few places. These alluvium deposits are often saturated with water and where thick enough, like some points in river Galma, they constitute good aquifers in the area for fadama farming in the dry season.

4.3 Results of Laboratory Analysis.

The thin section analysis of these rock types revealed the various minerals that constitute these rocks and their optical characteristics.

4.3.1:Fine to medium grained Biotite Granite

It is medium to fine grained and porphyritic in places(or porphyroblastic) . Main minerals include Quartz=35%, Orthoclase=10%, Microcline=15%, Biotite=25%,Pyroxene=8%, the biotite have perfect based cleavage and moderate relief. The pyroxene is brown and and green in plane polarised light. It is green in cross polarized light and have two sets of cleavage intersecting at 90^0

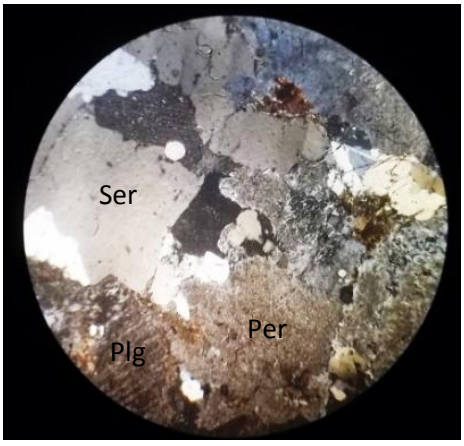


PPL XPL

Plate IV:Photomicrograph of biotite granite showing Mcr=Microcline, Qtz= Quartz,Bio= Biotite and Pyr=Pyroxen with green false colour.

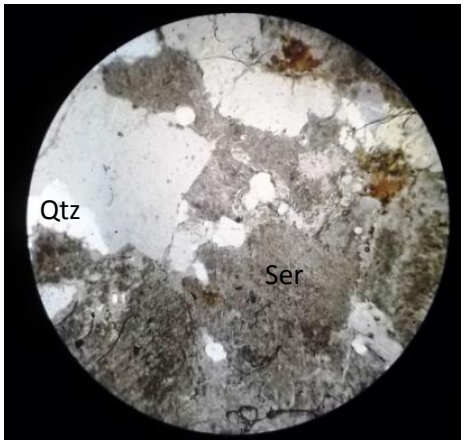
4.3.2 Biotite granite

Nearly equigranular and coarse grained. Plagioclase 20%, Orthoclase 30%, Sericite10 Perthite 10%, Quartz 25%, Accessory biotite is less than 5%.



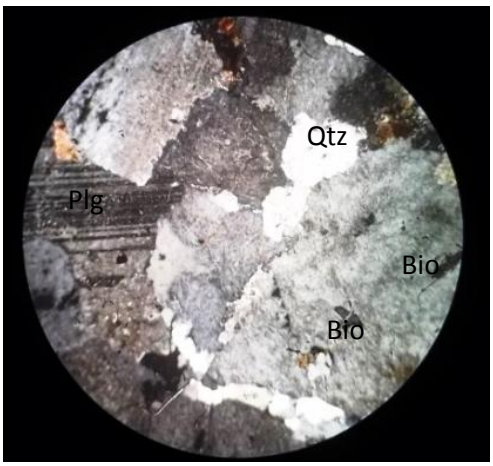
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Plate V:Biotite granite Shows Plg= plagioclase getting altered to Per= perthite and orthoclase completely altered



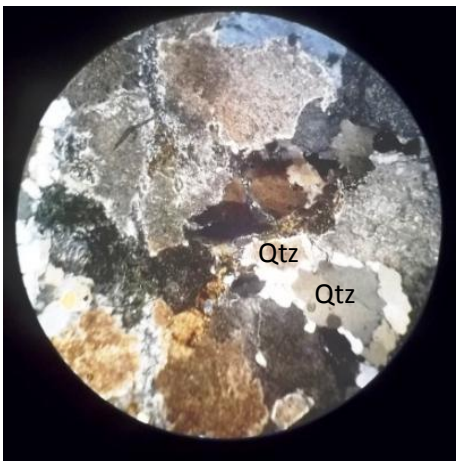
XPL

Plate VI: Shows cloudy view of feldspar due to alteration. Ser=sericite, Qtz=quartz



XPL

Plate VII: photomicrograph of biotite granite showing specks of biotite poikilitically included in the felsic minerals. Bio= biotite, Plg=plagioclase, Qtz=quartz.



XPL

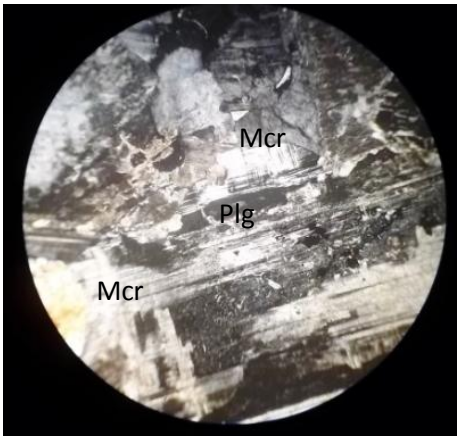
Plate VIII: Photomicrograph showing undulose extinction in quartz. Qtz=quartz.

NOTE:

Field of view = 4mm, Magnification = x 40

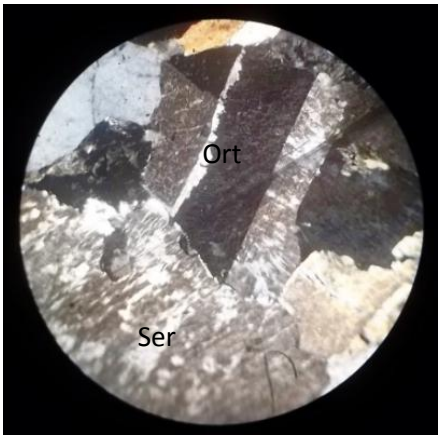
4.3.3 Migmatite

Nearly equigranular and coarse grained but the microcline is also part of the feldspar. It is porphyritic and has a low level of alteration.



PPL

Plate IX: Photomicrograph showing microcline and other felsic. Mcr=microcline, Plg=plagioclase.



PPL

Plate X: Photmicrograph showing Carlsbad twinning in orthoclase. Ort=orthoclase, Ser=sericite.

NOTE:

Field of view = 4mm

Magnification = x 40

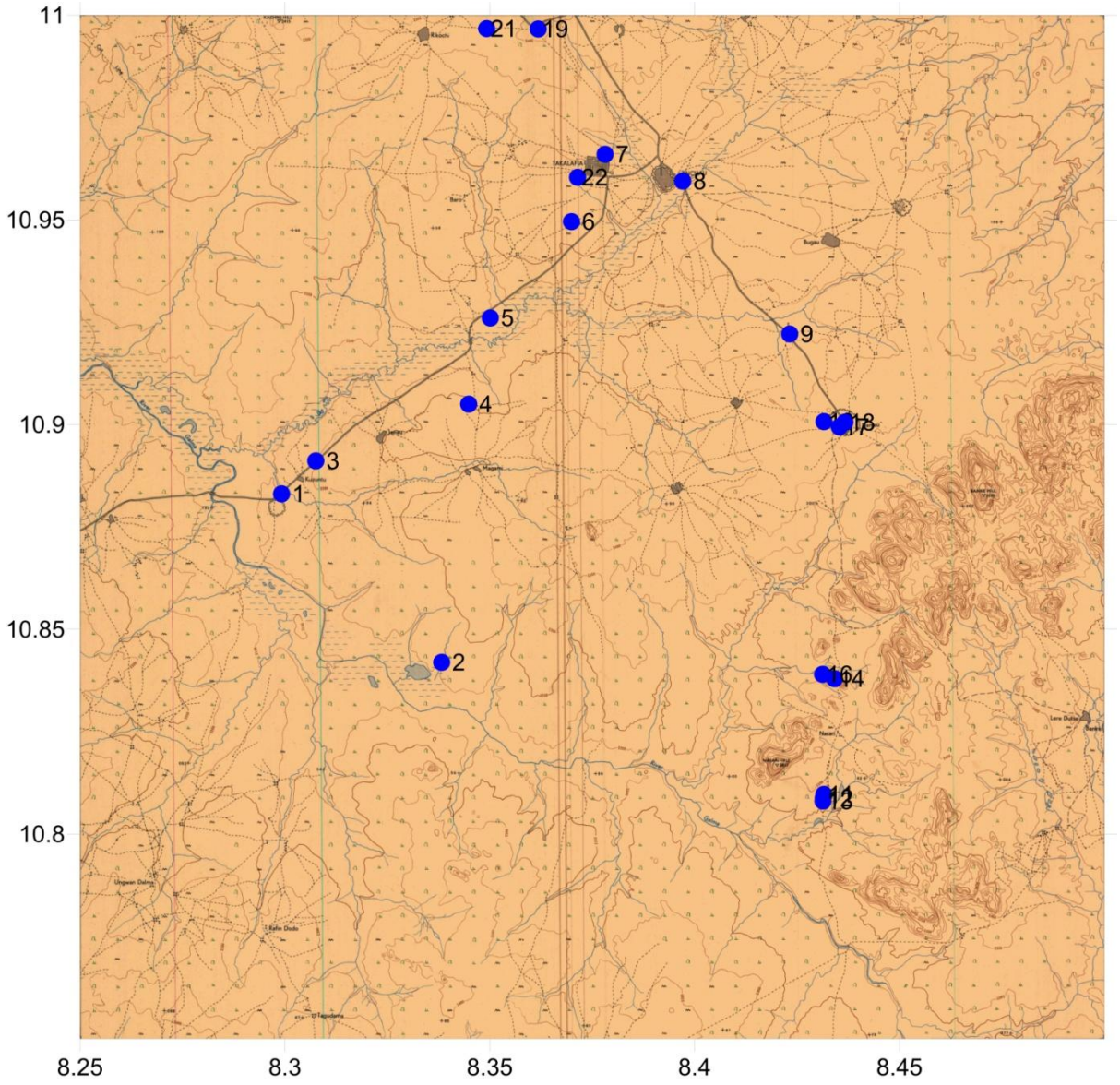


FIGURE 4.1: Map of sample collection

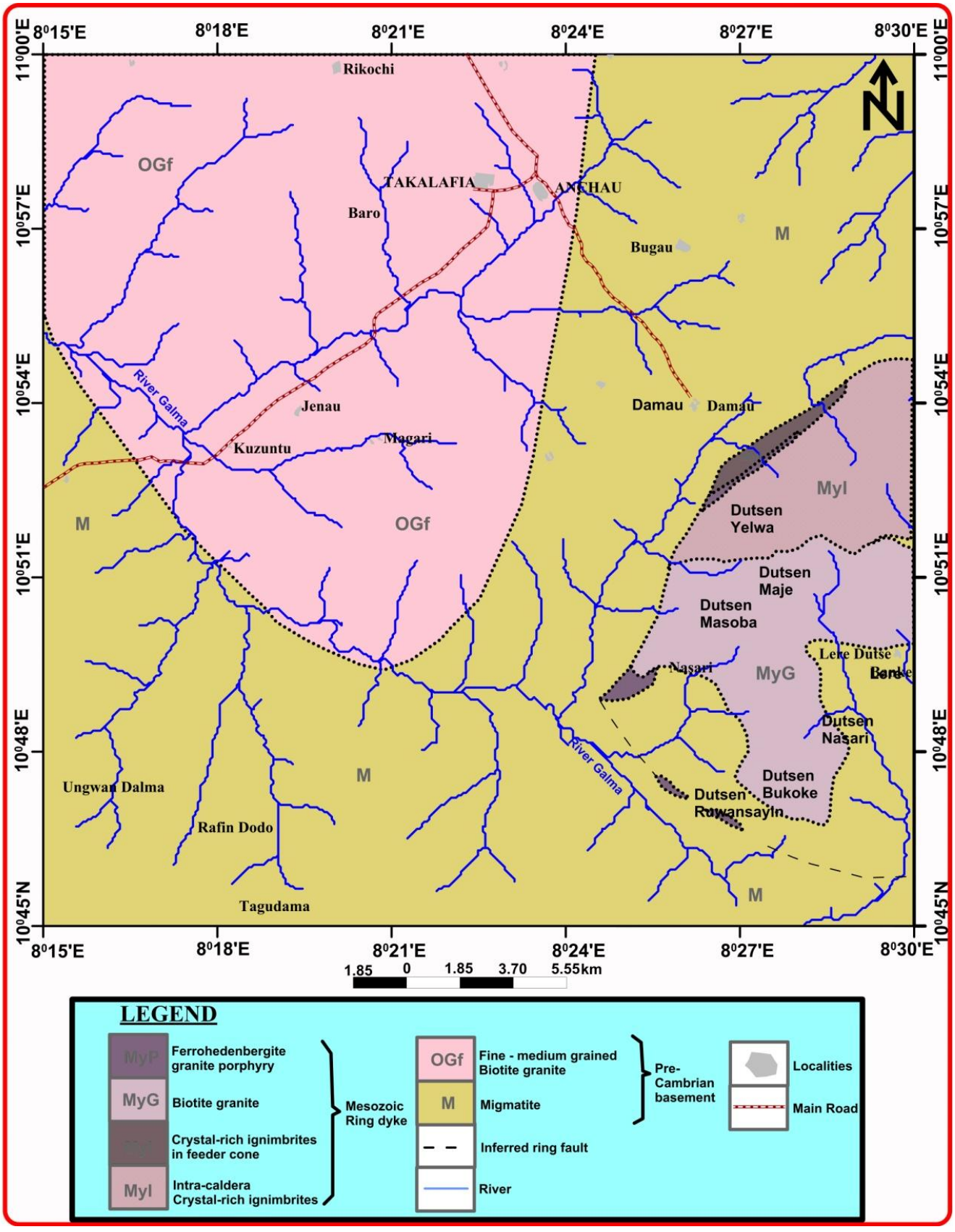


FIGURE 4.2:Geological map of study area

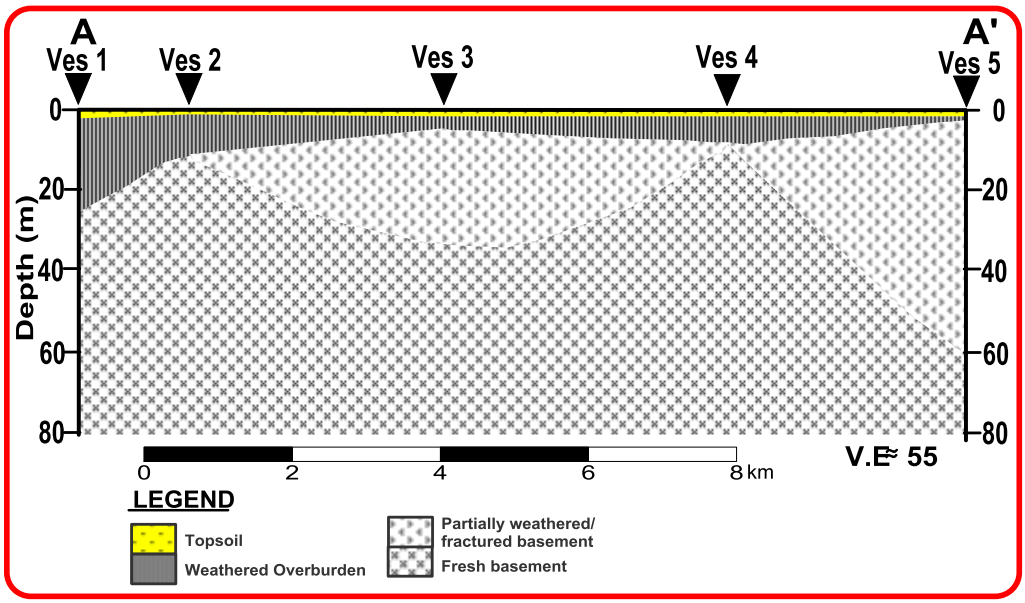


FIGURE 4.2: Geophysical cross sectional view line A-A’

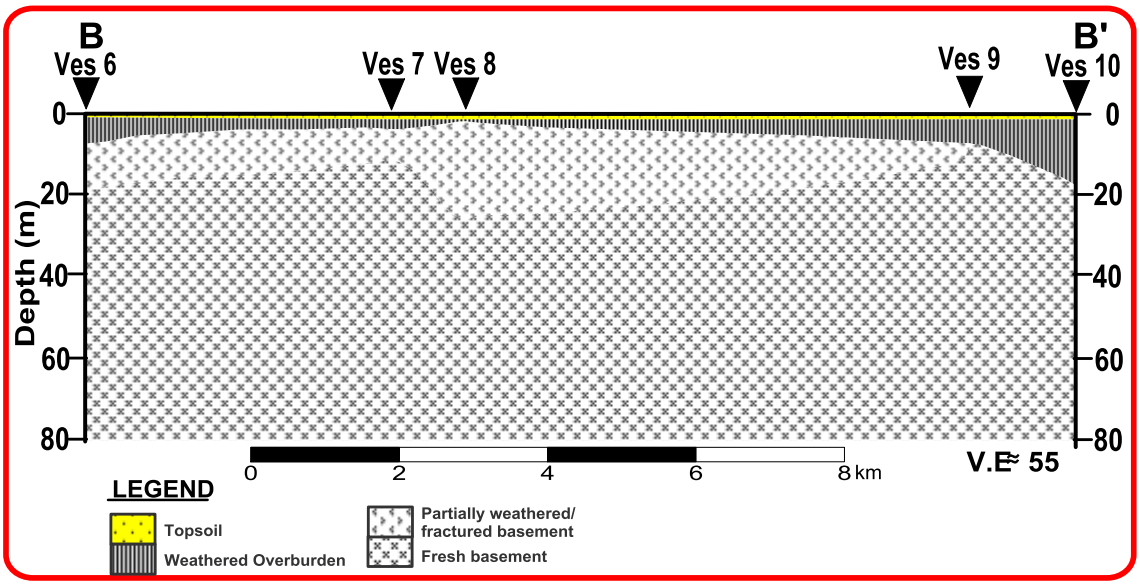


FIGURE 4.3: Geophysical cross sectional view of line B-B’

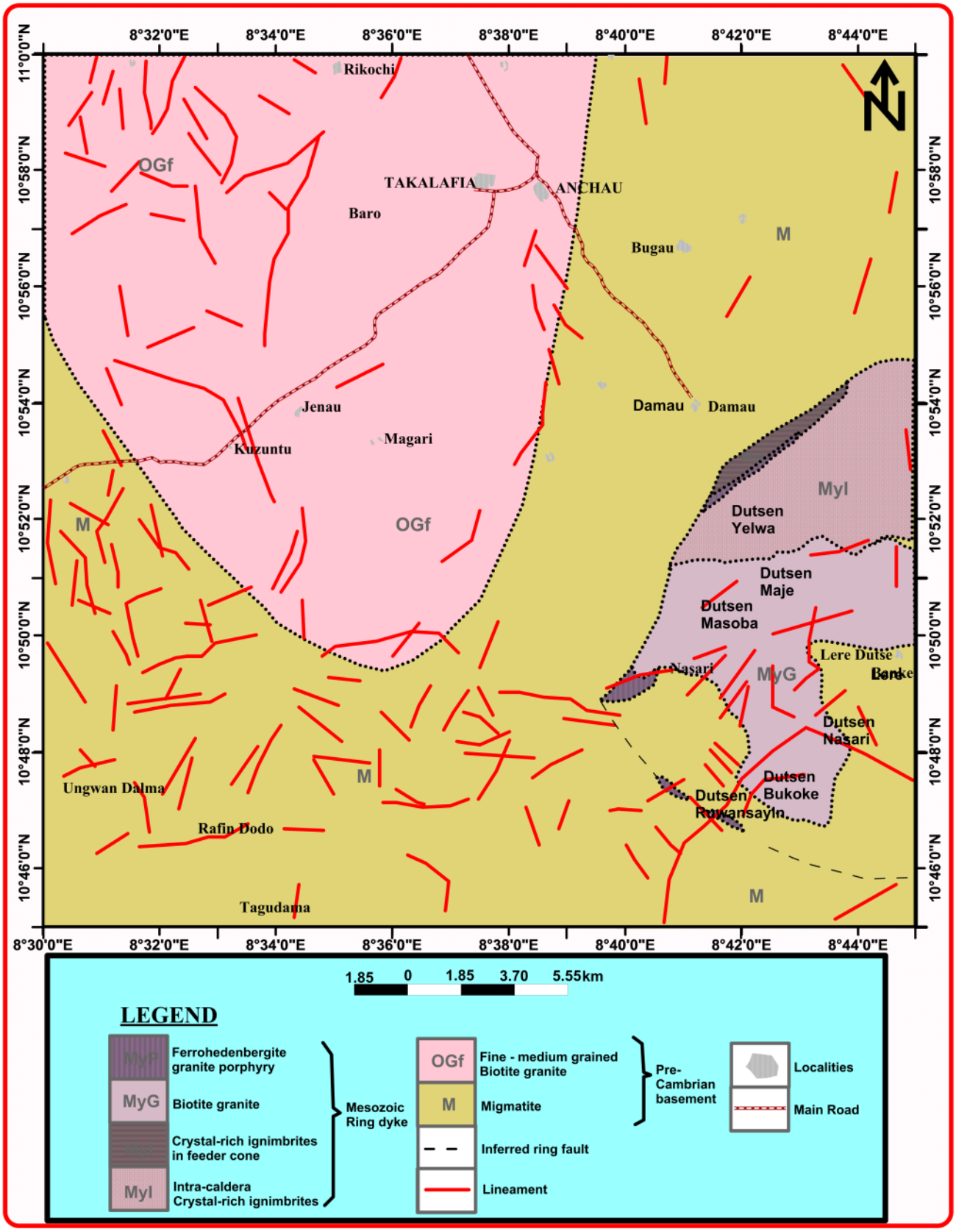


FIGURE 4.4: Geological map of the study area showing lineaments

4.3: Hydrogeological maps

The field data (Table 4.3) evaluates for hand dug wells in the study area were plotted on topographical base map and the following hydrogeological maps were prepared:

1. Map of peak wet season groundwater configuration (Figure 4.6),
2. Map of peak dry season groundwater configuration (Figure 4.5),
3. Map of geological cross–section perpendicular to the main watershed (Figure 4.7),
4. Hydrogeological cross-section parallel to the main watershed (Figure 4.8).

4.3.1: Groundwater configuration maps

The elevation of water levels (Table 4.3) above sea level measured at the field was used to construct groundwater configuration maps for both the peak of dry and wet seasons. Fig 4.5 and 4.6 show the peak of dry and wet season's groundwater elevation maps respectively constructed using combination of manual and software tools. They were done by placing the groundwater level elevation (difference between surface elevation and groundwater level measured from the hand dug wells with reference to sea level) on the map of the study area. Directions of groundwater flow were drawn, usually from higher elevations to lower elevations and perpendicular to groundwater contours, thereby joining the second order streams of the area on the map. The last stage was digitization and other necessary manipulations of the maps using global mapper software.

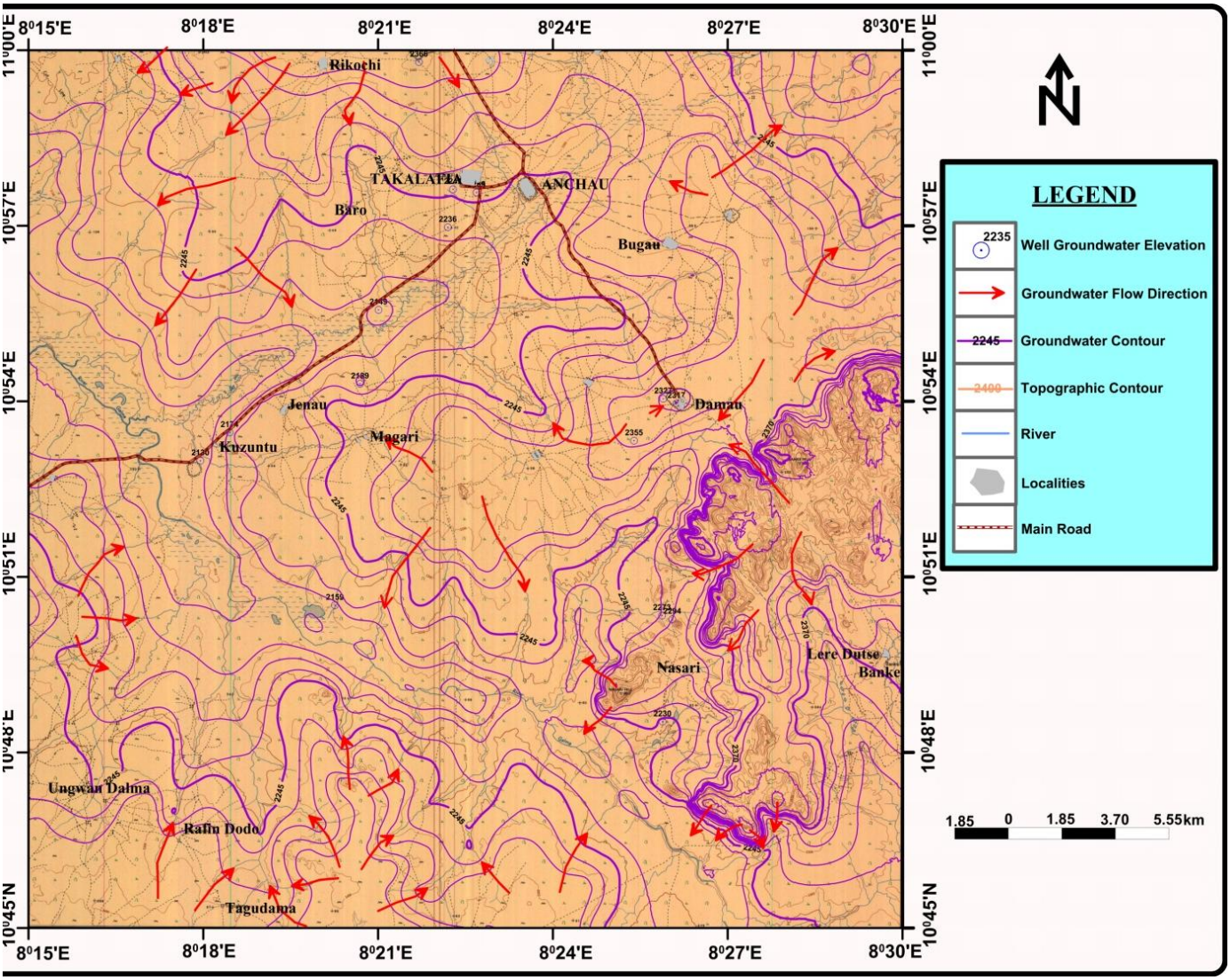


Figure 4.5: Peak Dry Season Groundwater Configuration Map of Dutsen Wai Sheet 125NE

4.3.2: Static water level at peak of Dry Season

The measured water level in hand dug wells at peak of dry season range from 2.00 to 21.20 mbgl. The maximum water levels elevation was 2290 masl and minimum was 2212 masl, this gave a range of 78m.

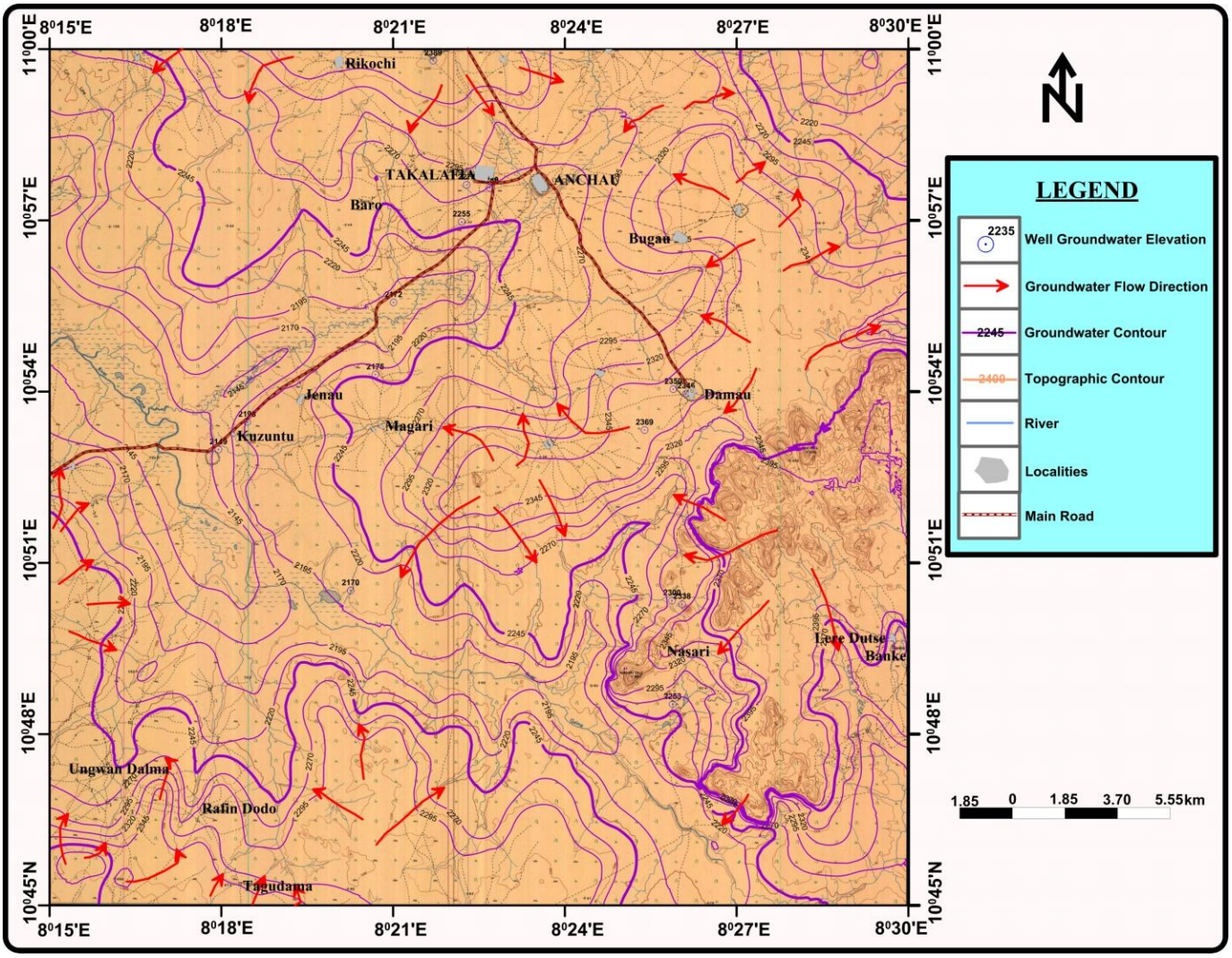


Figure. 4.6: Peak of wet season groundwater configuration map of Dutsen Wai Sheet 125NE

4.3.3 Static water level at peak of Wet Season

The water level measurement in hand dug wells at peak of wet season range from 0.50 to 12.0 mbgl. The maximum water levels elevation was 2296 masl and minimum was 2218 masl.

4.3.4 Hydrogeological cross-section perpendicular to the main watershed

These were constructed from all the maps (Figures 4.7 and 4.8). It was done by drawing equal length of line of cross-sections A-B perpendicular to the watershed and C- D parallel to the streams. The beginning and the end of the line of cross- section was indicated on a plain sheet, after which the plain sheet was placed on the cross-section profiles on all the maps to mark out each contour value on the sheet. The contour values were used to

graduate a vertical axis while the horizontal axis was drawn using line of the cross – section, on another plane sheet. Points of the contour values were marked out from the vertical axis, and finally hydrogeological cross sections were drawn across profiles AB as shown on Figures 4.5 and 4.6 respectively.

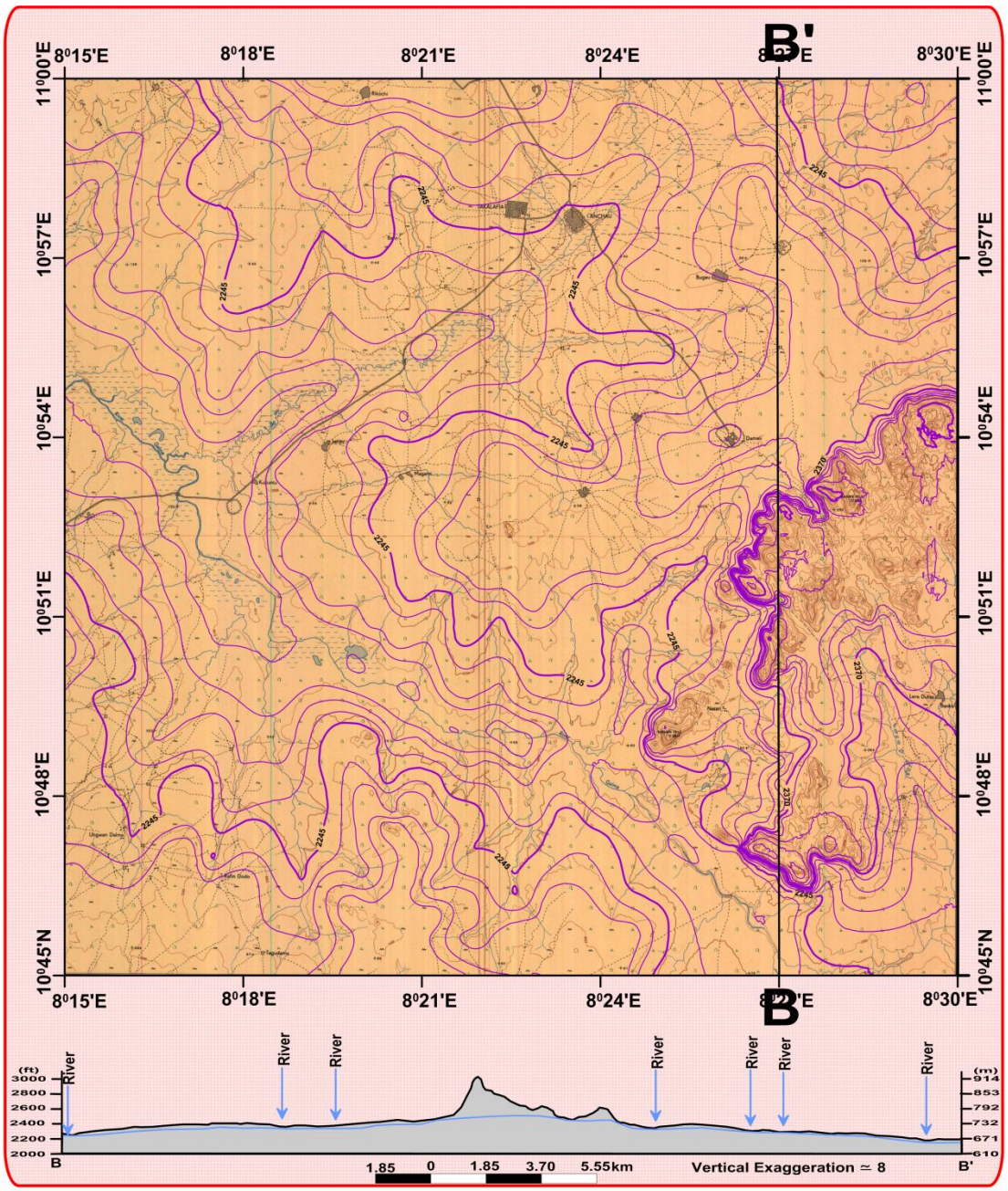


FIGURE 4.7: Hydrogeological cross-section perpendicular to main watershed of Dutsen Wai Sheet 125NE

4.3.5 Hydrogeological cross-section parallel to the main watershed

This hydrogeological cross section A-A’ was constructed from the values of water table measured in hand dug wells in table 4.3.

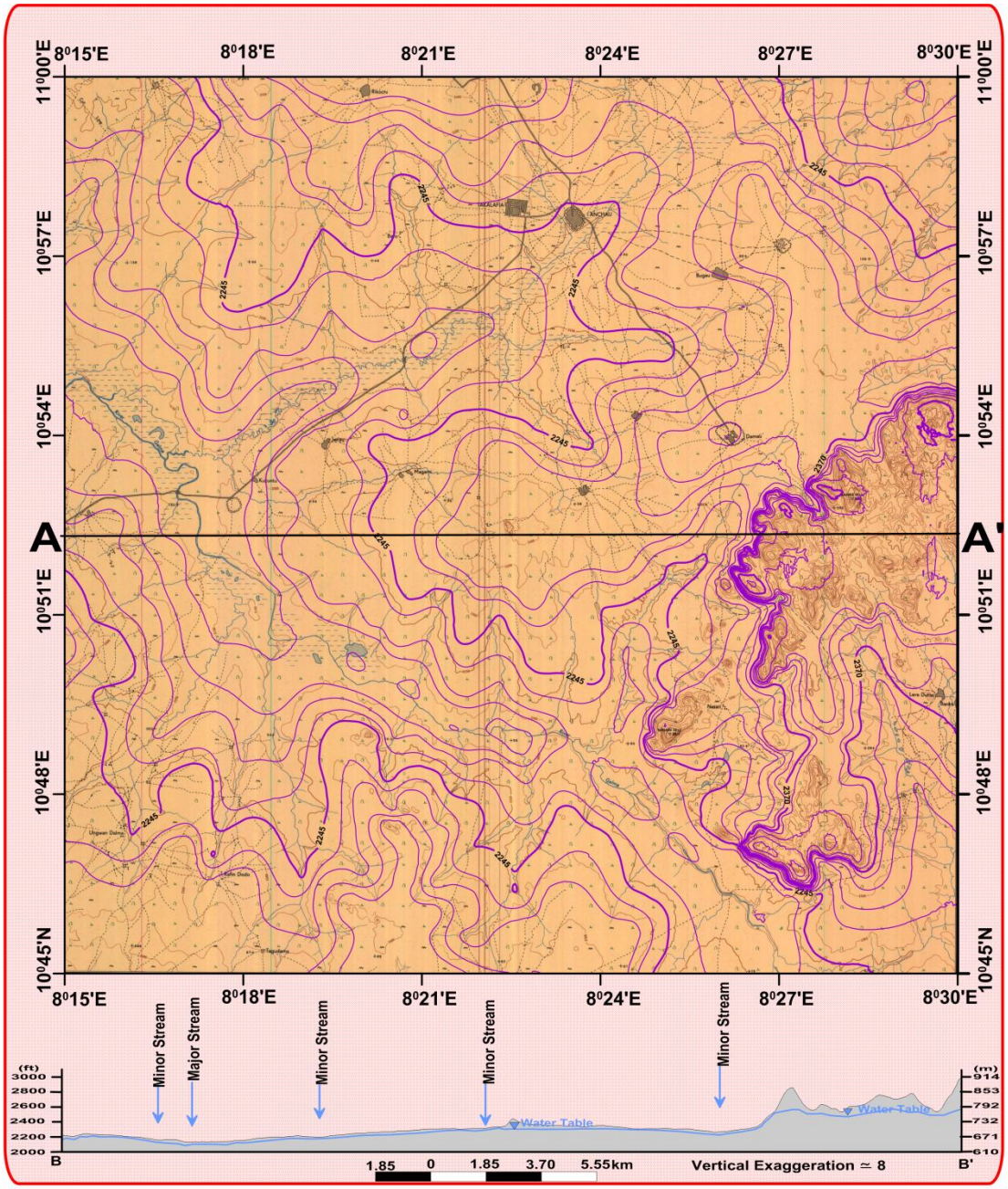


FIGURE 4.8:Hydrogeological cross-section parallel to the main watershed of Dutsen Wai Sheet 125NE

The results of the physical parameters measured on site at the peak dry season period is as shown in the table below:

TABLE 4.1: THE RESULTS OF THE PEAK DRY SEASON(APRIL,2015) TEST OF THE PHYSICAL PARAMETERS ARE AS FOLLOWS:

WELL NO	VILLAGE	LAT.	LONG.	pH	COND. µS/cm	TEMP. ^{o}C	TDS mg/l	TURB. (NTU)	DISSOLVED OXYGEN (mg/L)	WELL TYPE	DEPTH TO WATER (m)
1	Kuzuntu 1	10^{o}52.985	8^{o}17.950	9.46	106.0	26.3	67.84	438.3	49.97	Not lined	8
2	Kawa	10^{o}50.516	8^{o}20.259	9.35	136.0	28.8	87.04	55.0	43.88	Not lined	5
3	Kuzuntu 2	10^{o}53.468	8^{o}18.452	9.36	101.0	26.9	64.64	76.9	48.45	Lined	8
4	Magami	10^{o}54.299	8^{o}20.691	9.48	103.0	27.5	65.92	158.0	24.84	Lined	21.2
5	Kugawa	10^{o}55.563	8^{o}21.008	9.12	334.0	26.8	213.76	119.9	46.56	Not lined	10
6	Anchau 1	10^{o}56.974	8^{o}22.197	9.21	75.0	26.6	48.00	109.9	30.17	Not lined	8
7	Anchau 2	10^{o}57.568	8^{o}22.689	9.20	136.0	27.6	87.04	39.5	31.22	Not lined	10
8	Anchau 3	10^{o}57.568	8^{o}22.689	9.21	418.0	28.0	267.52	14.9	40.10	Not lined	2
9	Kajurgo	10^{o}53.327	8^{o}25.393	9.20	105.0	28.9	67.20	121.4	43.49	Not lined	6
10	Damau 1	10^{o}54.043	8^{o}25.894	9.39	172.0	27.9	110.08	37.2	8.40	Not lined	9
11	Jangaba 1	10^{o}48.580	8^{o}25.829	9.05	236.	27.7	151.04	262.8	26.95	Not lined	8
12	Jangaba 2	10^{o}48.524	8^{o}25.882	9.18	315.0	27.9	201.6	50.5	45.77	Stone	10

							0			line	
13	Jangaba 3	10^{o}48.483	8^{o}25.879	9.16	463.0	27.1	296.32	90.3	38.36	Notlid	6
14	Nasari 1	10^{o}50.277	8^{o}26.049	9.05	437.0	28.0	279.68	432.7	45.06	Not lined	15
15	Nasari 2	10^{o}50.321	8^{o}26.041	9.32	201.0	27.6	128.64	71.1	46.72	Lined	10.6
16	Nasari 3	10^{o}50.340	8^{o}25.873	9.29	394.0	27.1	252.16	136	23.63	Not lined	9
17	Damau 2	10^{o}53.965	8^{o}26.120	9.32	540.0	26.6	345.60	17.3	39.76	Not lined	11
18	Damau 3	10^{o}54.034	8^{o}26.202	9.40	484.0	26.7	309.76	16.7	41.62	Lined	12.8
19	Mararaba Rikochi	10^{o}59.797	8^{o}21.701	9.27	155.0	25.9	99.20	22.9	48.93	Not lined	13
20	Gidan Mai auduga	11^{o}00.081	8^{o}22.573	9.27	41.0	26.0	26.24	176.3	27.30	Not lined	8.2
21	Rikochi	10^{o}59.802	8^{o}20.954	9.16	74.0	26.4	473.6	155.7	41.59	Not lined	14
22	Anchau	10^{o}57.623	8^{o}22.286	9.12	64.0	27.8	409.6	59.4	25.44	Not lined	12.6

TABLE 4.2: THE RESULTS OF THE PEAK WET SEASON(SEPT,2015) TEST OF THE PHYSICAL PARAMETERS ARE AS FOLLOWS

WELL NO	VILLAGE	LAT.	LONG.	pH	COND mS/m	TEMP. ^{o}C	TDS(mg/l)	TURB. (NTU)	DISSOLVED OXYGEN (mg/l)	WELL TYPE	DEPTH to WATER (m)
1	Kuzuntu	10^{o}52.985	8^{o}17.950	9.62	65.0	26.6	41.60	10.47	47.44	Not lined	2.2
2	Kawa	10^{o}50.516	8^{o}20.259	9.56	134.0	27.2	85.76	21.8	35.69	Not lined	1.6
3	Kuznu	10^{o}53.468	8^{o}18.452	9.86	167.0	27.1	106.88	39.4	35.5	Lined	2.1
4	Magami	10^{o}54.299	8^{o}20.691	988	954.0	27.3	610.56	47.3	37.8	Lined	5.0
5	Kugawa	10^{o}55.563	8^{o}21.008	9.51	192.0	26.4	122.88	17.7	49.74	Not lined	3.1
6	Anchau	10^{o}56.974	8^{o}22.197	9.64	30.0	27.7	19.20	17.7	40.05	Not lined	2.2
7	Anchau	10^{o}57.568	8^{o}22.689	9.83	46.0	27.9	2944	28.2	5.76	Not lined	3.8
8	Anchau	10^{o}57.568	8^{o}22.689	9.59	454.0	27.8	290.56	11.1	9.12	Not lind	1.1
9	Kajurgo	10^{o}53.327	8^{o}25.393	9.77	47.0	28.3	30.08	18.5	4.06	Not lined	1.8
10	Damau	10^{o}54.043	8^{o}25.894	9.95	174.0	28.6	111.36	37.2	8.40	Not lined	2.0
11	Jangaba	10^{o}48.580	8^{o}25.829	9.48	289.0	26.0	184.96	3.50	34.84	Not lned	2.3
12	Jangaba	10^{o}48.524	8^{o}25.882	9.27	188.0	27.4	120.32	5.6	47.47	Stone line	3.0
13	Jangaba	10^{o}48.483	8^{o}25.879	9.57	505.0	27.7	323.20	8.4	40.15	Not lined	4.0
14	Nasari	10^{o}50.277	8^{o}26.049	9.66	837.0	26.8	535.68	11.9	16.44	Not lined	1.5
15	Nasari	10^{o}50.321	8^{o}26.041	9.97	714.0	26.9	456.96	9.9	48.85	Lined	1.2
16	Nasari	10^{o}50.340	8^{o}25.873	9.36	962.0	27.7	615.68	19.9	2.82	Not lined	1.0
17	Damau	10^{o}53.965	8^{o}26.120	9.52	254.0	27.4	162.56	9.7	47.2	Not lined	2.2
18	Damau	10^{o}54.034	8^{o}26.202	9.50	327.0	27.8	209.28	5.0	33.65	Lined	8.1
19	Mararaba Rikochi	10^{o}59.797	8^{o}21.701	9.71	322.0	26.9	206.08	15.1	17.52	Not lined	6.0
20	Gidan Mi auduga	11^{o}00.081	8^{o}22.573	9.85	42.0	28.8	26.88	42.2	8.60	Not lined	0.25
21	Rikochi	10^{o}59.802	8^{o}20.954	9.75	54.0	26.7	34.56	109.5	3.28	Not lined	3.0
22	Anchau	10^{o}57.623	8^{o}22.286	9.62	142.0	27.5	90.88	9.0	41.08	Not lined	3.6

TABLE 4.3: WATER LEVELS MEASURED IN HAND-DUG WELLS IN THE STUDY AREA

		COORDINATES			PEAK DRY SEASON DATA(APRIL,2015)		PEAK WET SEASON DATA	
Well No	Location	Latitude (N)	Longitude (E)	Elevation of well in (m) asl read from map	Depth to water table (m) bgl	Elevation of water table (m) a.s.l	Depth to water table (m) b.g.l	Elevation of water table (m) a.s.l
1	Kuzuntu	$10^{o}52.985$	$8^{o}17.950$	2230	8	2222	2.2	2228
2	Kawa	$10^{o}50.516$	$8^{o}20.259$	2250	5	2245	1.6	2248
3	Kuzuntu	$10^{o}53.468$	$8^{o}18.452$	2220	8	2212	2.1	2218
4	Magami	$10^{o}54.299$	$8^{o}20.691$	2250	21.2	2228	5.0	2245
5	Kugawa	$10^{o}55.563$	$8^{o}21.008$	2240	10	2230	3.1	2237
6	Anchau	$10^{o}56.974$	$8^{o}22.197$	2220	8	2212	2.2	2218
7	Anchau	$10^{o}57.568$	$8^{o}22.689$	2300	10	2290	3.8	2296
8	Anchau	$10^{o}57.568$	$8^{o}22.689$	2250	2	2248	1.1	2249
9	Kajurgo	$10^{o}53.327$	$8^{o}25.393$	2280	6	2274	1.8	2278
10	Damau	$10^{o}54.043$	$8^{o}25.894$	2230	9	2220	2.0	2228
11	Jangaba	$10^{o}48.580$	$8^{o}25.829$	2230	8	2222	2.3	2228
12	Jangaba	$10^{o}48.524$	$8^{o}25.882$	2240	10	1130	3.0	2237
13	Jangaba	$10^{o}48.483$	$8^{o}25.879$	2230	6	2224	4.0	2226
14	Nasari	$10^{o}50.277$	$8^{o}26.049$	2280	15	2265	1.5	2278
15	Nasari	$10^{o}50.321$	$8^{o}26.041$	2290	10.6	2280	1.2	2289
16	Nasari	$10^{o}50.340$	$8^{o}25.873$	2280	9	2270	1.0	2279
17	Damau	$10^{o}53.965$	$8^{o}26.120$	2240	11	2230	2.2	2238
18	Damau	$10^{o}54.034$	$8^{o}26.202$	2230	12.8	2218	8.1	2222
19	Mararaba Rikochi	$10^{o}59.797$	$8^{o}21.701$	2380	13	2265	6.0	2274
20	Gidan Mai auduga	$11^{o}00.081$	$8^{o}22.573$	2360	8.2	2271	0.25	2359
21	Rikochi	$10^{o}59.802$	$8^{o}20.954$	2340	14	2226	3.0	2337
22	Anchau	$10^{o}57.623$	$8^{o}22.286$	2240	12.6	2228	3.6	2236

TABLE 4.4: RESULTS FOR CHEMICAL ANALYSIS DATA FOR PEAK DRY SEASON(APRIL,2015)

S/N	Carbonate (mg/l)	Bicarbonate (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Sulphate (mg/l)	K (mg/l)	Na (mg/l)	Ca (mg/l)	Zn (mg/l)	Pb (mg/L)	Cu (mg/l)	Mg (mg/l)	Hg (mg/l)
1	0.00	0.3334	0.6500	6.000	2.67	7.60	5.10	0.068	0.061	0.00	0.013	1.133	1.202
2	000	0.8667	0.5500	7.0000	4.83	4.30	14.00	4.593	0.005	0.00	0.00	1.701	1.164
3	0.00	0.8667	0.4500	6.0000	13.75	5.20	2.00	7.174	0.109	0.00	0.00	1.290	1.006
4	0.00	8.2004	18.0000	15.0000	5.00	120.00	68.00	59.183	0.129	0.00	0.00	8.572	1.25
5	0.00	0.3334	1.2000	10.0000	1.50	18.00	17.00	8.481	0.031	0.00	0.00	2.946	1.105
6	0.00	0.6000	0.6000	12.0000	0.50	4.10	3.40	5.302	0.014	0.00	0.00	0.660	0.824
7	0.00	1.0000	9.0000	8.0000	2.00	5.60	3.40	20.052	0.013	0.00	0.00	0.448	0.990
8	0.00	1.5334	2.0500	8.0000	9.17	12.00	36.00	32.991	0.015	0.00	0.00	4.435	1.019
9	0.00	0.5334	0.7000	8.0000	13.67	4.50	9.40	13.773	0.012	0.00	0.00	1.528	1.060
10	0.00	0.8667	0.9000	10.0000	0.67	8.50	8.30	26.289	0.035	0.00	0.00	1.310	1.093
11	0.00	0.4667	1.2000	6.0000	2.67	13.0	19.00	3.639	0.034	0.00	0.00	2.700	1.273
12	0.00	0.6001	1.1500	10.0000	0.67	7.40	23.00	19.826	0.020	0.00	0.00	3.441	1.063
13	0.00	0.4667	1.8000	26.0000	2.67	14.0	41.00	21.805	0.028	0.00	0.00	5.786	1.283
14	0.00	0.3334	1.4000	25.0000	2.33	14.00	33.00	19.865	0.034	0.00	0.00	3.012	1.301
15	0.00	0.7334	0.9500	12.0000	2.17	7.20	23.00	5.993	0.034	0.00	0.00	1.354	1.278
16	0.00	1.4667	2.0000	10.0000	7.17	18.00	41.00	6.821	0.022	0.00	0.025	2.786	1.482
17	0.00	2.8001	1.6500	5.0000	2.50	20.00	30.00	60.678	0.040	0.00	0.00	5.246	1.350
18	0.00	2.0668	1.3500	7.0000	1.83	33.00	19.00	47.784	0.057	0.00	0.007	5.391	1.583
19	0.00	0.4000	1.0500	11.0000	0.67	3.00	18.00	5.491	0.012	0.00	0.00	1.633	1.266
20	0.00	0.5334	0.4500	7.0000	10.50	3.10	6.00	1.410	0.013	0.00	0.002	0.625	1.655
21	0.00	0.8000	0.4500	6.0000	9.17	3.50	14.00	1.855	0.005	0.00	0.00	0.665	1.676
22	0.00	0.4667	0.5500	5.0000	4.67	2.80	6.40	2.742	0.004	0.00	0.00	0.961	1.674

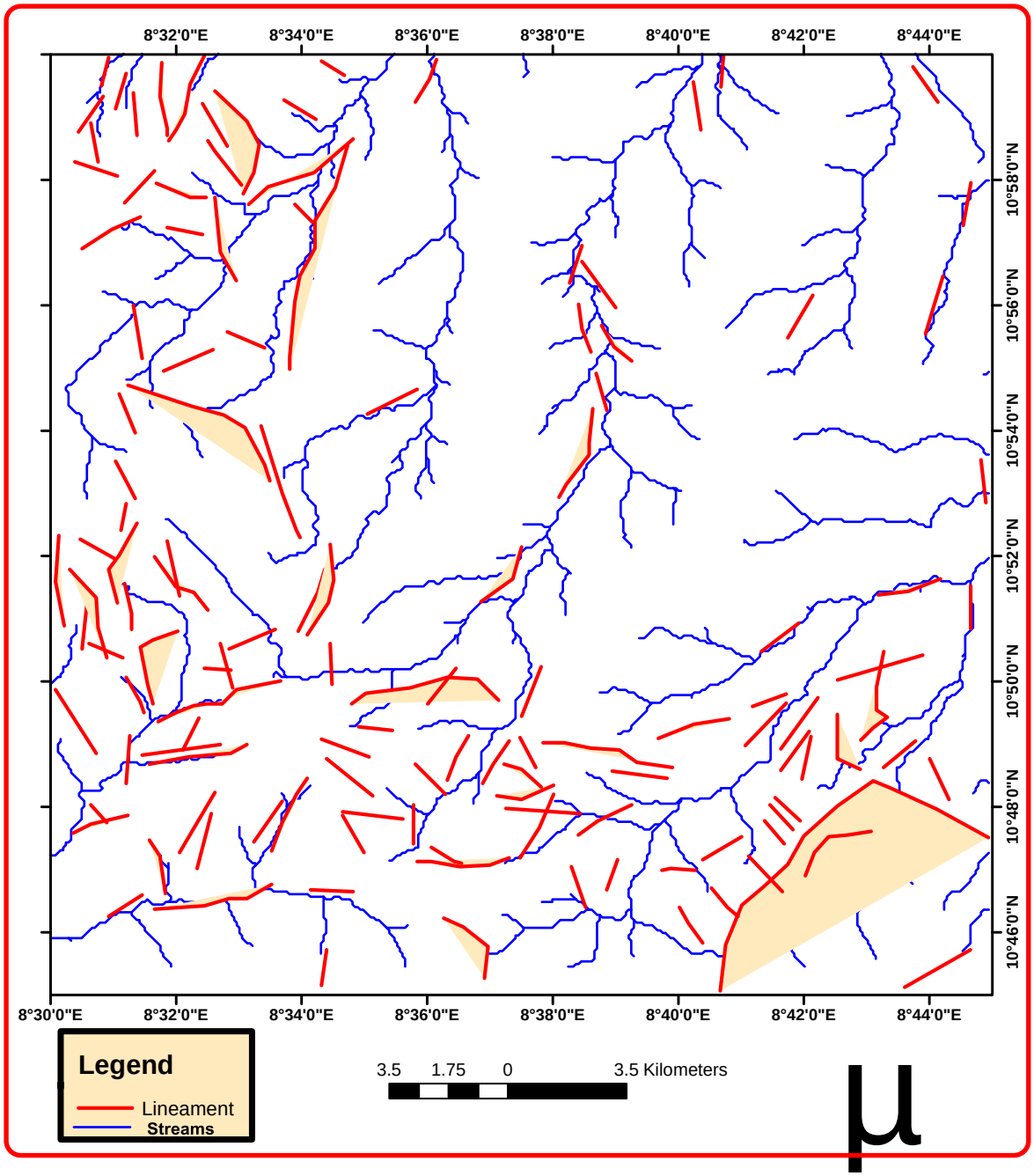


Figure 4.9:Superimposed Lineament map on Drainage of the study area

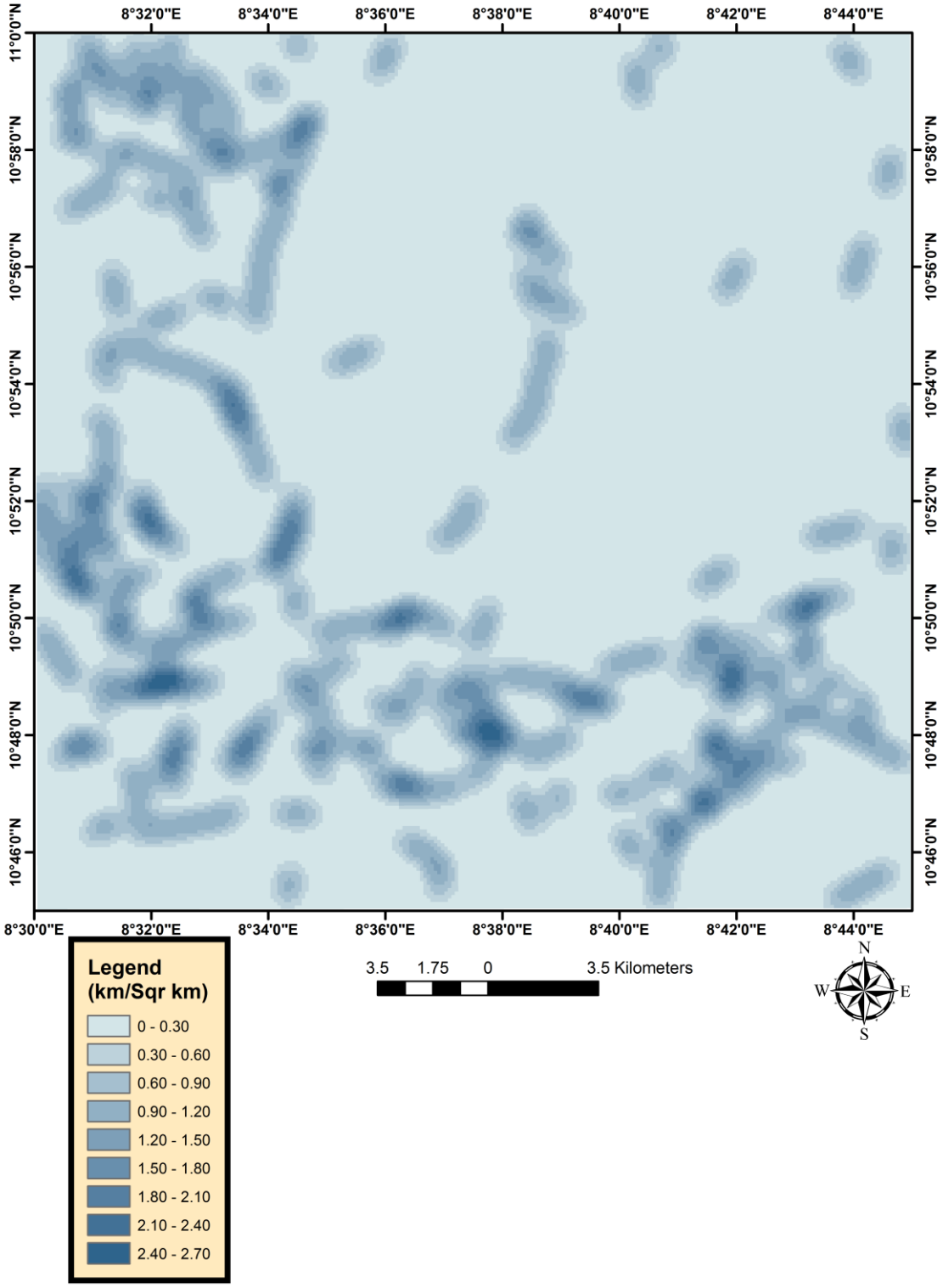


Figure 4.10: Map showing lineament density of the study area

4.5:Hydraulic properties of the Aquifers

Appendix II shows pump test data and recovery period phases. The aquifer properties of the boreholes were derived using the following procedure. A drawdown time graph was plotted using the data obtained from the pumping test as shown in appendix I.Based on the values obtained in Appendix I(VES plots) and Appendix II(Pumping test data), Transmissivity, Hudraulic Conductivity and Specific Capacity of the various boreholes in the 10 locations were determined.

Table 4.5: Locations and Hydraulic Properties of Various boreholes

S/No	Location	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Specific Capacity (m^2/s)
1	Ungwan Goburuwa	0.314	2.934	$9.14x10^{-2}$
2	Hayin Ade	0.216	2.72	$9.12x10^{-2}$
3	Ungwankudu kudumi	0.418	2.66	$9.62x10^{-3}$
4	Sabon gari wudu	0.717	3.10	$9.11x10^{-2}$
5	Ashema	0.611	3.72	$9.24x10^{-2}$
6	Kawankari	0.224	3.44	$8.16x10^{-2}$
7	Rafin Busa	0.819	4.26	$9.17x10^{-2}$
8	Ungwar Kaji	0.518	3.16	$9.16x10^{-2}$
9	SabonGari Kuzuntu	0.618	2.88	$9.21x10^{-2}$
10	Ungwar Worobaso	0.336	2.981	$9.24x10^{-3}$

1. Transmissivity

$T=2.3Q/4\pi\Delta s$;

T=transmissivity, Q=discharge, s=drawdown

2. Hydraulic Conductivity
   k = T/b; where b =aquifer thickness
3. Specific Capacity of a well is the ratio of the yield to its drawdown usually expressed in m^3/day/m.
   Specific capacity =Q/s

4.6: Geophysical Results

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

1st layer - Top soil/laterite/clay

2nd layer – Weathered layer

3rd layer – Fractured layer

4th layer – Bedrock.

I. Top soil

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

II. Weathered layer

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

Dan Hassan and Olurenfemi (1994) identified this layer to be the major aquifer unit. If the depth of weathering is sufficiently thick as exhibited by most of the VES points in the study area; the weathered mantle could contain water in storage large enough to produce a successful borehole.

III. Fractured layer

The resistivity value ranges from 26.13 ohm m to 9779.3 ohm m. The thickness varies from 23.18 m to 68.60 m. In some places, fractured zones occur immediately beneath the weathered horizon. The fractured zones are difficult to detect geophysically, unless it is of

greater thickness. Where the fractured zone is saturated, a high groundwater yield can be obtained from borehole penetrating such a sequence.

IV. Bedrock

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

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

TABLE 4.5: SHOWING BOREHOLE DEPTH, DRAWDOWN AND YIELD OF BOREHOLE IN STUDY AREA(SEPT,2015)

S/N	LOCATION	BOREHOLE DEPYTH(m)	DWL(m)	SWL(m)	DRAWDOWN	YIELD(l/s)
1	Hayin Ade	47	12.84	5.6	7.24	1
2	Ungwar Kudu	47.8	15.42	2.2	13.22	0.86
	Kudumi					
3	Ungwar Goburuwa	48.6	11.9	5.8	6.1	0.86
4	Ashema	46	31.8	5.8	26.12	0.37
5	Kawankari	37.8	37	5.8	31.2	0.3
6	Rafin Busa	45	15.72	7.2	8.5	0.4
7	Sabon Gari Wudu	46.8	19.88	6.2	13.68	0.5
8	Ungwar Kaji	47	13.69	5.5	8.19	0.9
9	Sabon Gari Kuzuntu	45	14.55	5	9.55	0.4
10	Ungwar Worobaso	47	13.69	5.5	8.19	0.9

TABLE 4.6: RESULT OF VES INVESTIGATION IN THE STUDY AREA USING

SCHLUMBERGER ARRAY

S/No	LOCATION VES (VES)	S	1st Layer Resistivity (ohm-m)	1st Layer Thickness (m)	2nd Layer Resistivity (ohm-m)	2nd Layer Thickness (m)	3rd Layer Resistivity (ohm-m)	3rd Layer Thickness (m)	4^{th} layer Resistivity (ohm-m)	4^{th} layer Thickness (m)	5^{th} layer Resistivity (ohm-m)	5^{th} Layer Thickness (m)
1	Gudami		43.04	0.084	35.65	0.104	50.52	0.099	41.42	12.23	12.42	0
	Kudu-Hakiya											
2	Goboruwa		98.5	0.107	50.8	0.117	492.3	0.259	49.29	26.78	19.25	0
	Haskiya											
3	Angwan Ade		359.6	0.988	134.8	0.859	71.75	1.05	189.4	2.91	9.87	8.88
4	Ashema		13.3	0.719	91.1	0.0879	384.7	1.9	78.24	25.05	157.4	0
5	Kawankari		27.05	1.25	169.4	0.621	46.82	0.962	10.08	5.15	522.1	0
6	Rafin busa		47.31	0.359	61.46	0.51	146.1	18.6	907.8	0	0	0
7	Ungwan Yelwa		35.14	1.26	67.76	1.32	24.66	3.15	149.9	2.37	118.14	0
	Daumaliki											
8	Wudu Sabon											
	Gari		1241	0.974	1616.6	0.537	124.1	6.64	81.62	9.75	115.13	0
9	Ungwar-kaji		49.29	0.314	127.8	1	119.86	6.31	61.25	6.72	173.8	0
10	Goboruwa Haskiya		48.93	0.097	9.34	0.216	328.8	0.202	26.37	16.28	18168.8	0

TABLE 4.7: RESULT SHOWING THE VARIOUS VES CURVE TYPE(Appendix 1)

s/nO	VES Station	Curve Type
1	VES1	H
2	VES 2	H
3	VES 3	KH
4	VES 4	A
5	VES 5	K
6	VES 6	QH
7	VES 7	KH
8	VES 8	KH
9	VES 9	H
10	VES 10	H

CHAPTER FIVE

5.0 DISCUSSION OF RESULTS

5.1 Discussion of Groundwater Configuration maps

Analysis of the water level configuration indicated that the maximum and minimum water level elevations at the peak of rainy season were 8.1m and 0.5m higher than those of the peak of dry season. The flow in the area is from areas of recharge to those of discharge. Along rivers or streams; the static water level is found to be shallow (i.e. within few meters from the surface) as observed in the south western and north western parts of the study area. In areas of higher elevations e.g. north western part of the study area the static water level is deeper. The depth to water table is more at the recharge area and shallower at the discharge areas (river or stream channels). Groundwater recharge is a function of rainfall, vegetation, relief and characteristics of regolith. The aquifers are usually recharged by infiltration directly from rainfall or by fractures directly connected to a major river or stream.

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

5.2: Physical Properties

5.2.1:Temperature

The temperature of water samples were measured on the spot and range between 25.9^0C and 28.9^0C with average mean of 27.4^0C. These values relatively keep ionization and dissolution at low level.

Drinking water standards are based on two criteria:

(1) The presence of objectionable tastes, odours, or colours, and

(2) The presence of substances with adverse physiological effects.

5.2.2 Conductivity

The electrical conductivity measured from the wells in the study area ranges from 3.0-39.4 mS/cm, with an average of 21.2 mS/cm (Table 3.1 and 3.2). The range falls within the maximum permissible limit of the 2003 WHO standard for Drinking Water (Appendix 4)

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

According to Schoeniech (2001), conductivity can be used as an index of salinity hazard in assessment of water quality for irrigation.

5.2.3 Hydrogen-ion exponent (pH)

At the pick of wet season the pH ranged from 9.27 to 9.97 and at the peak of dry season it ranged from 9.05 to 9.48(Table 4.2). This shows a lower value in the dry season. Sources of acidity in the study area is probably as a result of solution of volcanic gases or gaseous. (USDA, 2007).

5.2.4 Total Dissolved Solids

The palatability of water with a TDS level less than 600 mg/l is generally considered to be good; drinking water becomes significantly unpalatable at TDS levels greater than about 1000 mg/l. the TDS concentration values in the study area range between 28 and 385 mg/l which is less than the WHO desirable level(see appendix 4). Also the TDS can be obtained from the values of conductivity x 1000x 0.64

5.2.5 Dissolved Oxygen

The dissolved oxygen in the wet season ranges from 2.82mg/l as recorded in Nasari 3 to 47.44 mg/l in Kuzuntu(Table 4.2). The dry season ranges are from 8.40 in Damau 1 to 49.97 in Kuzuntu. This is relatively high as compared to the WHO acceptable limit of 0mg/l to 5mg/l. High Dissolved Oxygen level in a community water supply is good because it makes drinking water taste better. The amount of oxygen water can hold depends upon temperature (more oxygen can be dissolved in colder water) and for salinity (more oxygen can be dissolved in water of lower salinity).

5.2.6 Turbidity

This is the cloudiness or haziness of a fluid caused by suspended solids that are usually invisible to the naked eye. As expected water is usually more turbid during the dry season due to the less availability of water as shown by the results. Turbidity ranges from 14.9 to 438.3 NTU in the dry season and 3.5 to 109 NTU in the wet season. Organisms like phytoplanktons can contribute to turbidity in groundwater. The WHO permissible limit is 0.1 to 5.0 NTU

5.3 Chemical Characteristics

5.3.1 Cations

5.3.1.1:Sodium (Na+) and Potassium (K+)

The sodium ion concentration in the water varies from 3.00 to 68 mg/l with a mean value of 35.00, and is less than the maximum permissible level (table 4.1).

The primary source of most sodium in natural water is from the release of soluble products during weathering of plagioclase feldspars. Less important sources of sodium in natural waters are minerals nepheline, sodalite, stilbite, natrolite, jadeite, arfvedsonite, glaucophane,

and aegirite. The minerals are locally abundant in some igneous and metamorphic rocks, but are quantitatively of minor importance in comparison with the feldspar (Foster, 1942). The reason for the low value is the relative distance from the source rock.

Common source of potassium are the products formed by the weathering of orthoclase, microcline, biotite, leucite, and nepheline in igneous and metamorphic rocks. Potassium concentration range from 3.00 to 33.0 mg/l. This value is within the WHO standard limit.

5.3.1.3 Calcium (Ca++) and Magnesium (Mg++)

The calcium concentration and magnesium concentrations range between 0.68 to 59.183 mg/l and 0.448 to 8.572 mg/l respectively, and they both fall within the WHO 2003 permissible limits. The reason for the relatively accepted values is that most of the locations where samples are taken from is relatively far from the source rock.

In igneous and metamorphic rocks, weathering also releases calcium from such minerals as apatite, wollastonite, fluorite, and various members of the feldspars, amphibole, and pyroxene groups. While the common sources of magnesium is similar to that of calcium and can be obtained through weathering of igneous and metamorphic rocks from olivine, hornblende and augite, serpentine, talc, diopside, and tremolite (Hall, 1963).

5.3.1.4 Copper

In the study area, the concentration of Cupper ranges from 0.00mg/l to 0.071mg/l with an average of 0.03 mg/l. The highest value of 0.071 mg/l is not above the maximum permissible limit of WHO 2003 and 2005 with permissible limits of <0.05mg/l and 0.1mg/l respectively. This makes the water suitable for human consumptions. At levels above 5 mg/litre, copper also imparts a colour and an undesirable bitter taste to water. Although copper can give rise to taste, it should be acceptable at the health-based guideline value. However, according to

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

5.3.1.5 Zinc

The concentration of zinc in groundwater of the study area ranges from 0.004 mg/l to 0.07 mg/l with an average of 0.45 mg/l. The permissible limits of WHO 2003 and 2005 are <5.0mg/l and 5mg/l respectively. The maximum permissible limits of WHO 2005 and SON 2007 are; 5mg/l and 3mg/l respectively. In addition to that, SON 2007 did not report any health hazard associated with concentration of >3mg/l. zinc is present in low values because it usually presnt in small amount in igneous rocks.

Zinc is an essential trace element found in virtually all food and potable water in the form of salts or organic complexes. Drinking-water seldom contains zinc at concentrations above 0.1 mg/litre.

5.3.1.6 Lead

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

The 2011 WHO Standards for Drinking-water recommended a maximum allowable concentration of 0.01 mg/litre for lead, based on health concerns. The concentration of Lead in groundwater of the study area is below detection limit.

5.3.2 Anions

5.3.2.1 Chloride (Cl -)

The concentration of chloride varies between 0.40 to 5.90 mg/l and small in concentration, which falls below the WHO and Nigerian standard Sodalite and apatite are the only common minerals in igneous and metamorphic rocks which contain chloride as an essential constituent; although micas, hornblende, and natural glass may also contain significant amounts. Liquid inclusions in rocks and minerals are another source of chloride from igneous rocks.

5.3.2.2 Sulphate (SO4--)

The concentration of sulfate is very small ranging between 0.53 to 13.75 mg/l with a mean value of 6.403 mg/l, and it falls within the WHO and Nigerian standard acceptance limits.

Despite a relatively large amount of sulfur, mostly in the form of sulfates, in water and in sedimentary rocks, sulfur is only a minor constituent of igneous rocks (Junge, 1963).

5.3.2.3 Bicarbonate (HCO_{3-})

The concentration of bicarbonate range between 0.333 to 8.2004 mg/l and all the values falls within the WHO standards.

Most bicarbonate and carbonate ions in groundwater are derived from the carbon dioxide in the atmosphere, carbon dioxide in the soil, and solution of carbonate rocks.

5.3.2.4. Nitrate**:**

Nitrate concentration in the water samples ranges from 6.0 to 12.0 mg/l and most values are greater than 10 mg/l. These high values might be due to agricultural activities in the study area coming from agricultural chemicals such as fertilizers, insecticides and pesticides. But they are less than Nigerian drinking water standard maximum allowable limits

Although igneous rocks contain small amount of soluble nitrate or ammonia, most nitrate in natural water comes from organic sources or from industrial and agricultural chemicals (Waring, 1949).

5.4 Water Classification

The water classification in the study area is based on the classification system suggested by Gorrell (1985) which considers the total concentration of the main dissolved solids. The total dissolved solids ranges according to Gorrell (1985) as follows: Freshwater ranges from 0 – 1000 mg/l, brackish water from 1000 – 10,000 mg/l, salty water from 10,000 – 100,000 mg/l and brine greater 100,000 mg/l

The TDS concentration based on the above classification falls far below the upper limit of the freshwater classification and the water is considered as freshwater.

5.7 Interpretation of groundwater chemistry

The chemical parameters of water samples from the 22 hand dug wells analysed were plotted using AquaChem; a software package developed specifically for graphical and numerical analysis and modeling of water quality data. The plot types used in this work includes:

- Summary plot: Schoeller
- Trilinear plot: Piper.

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

In Piper plots, major ions are plotted as cation and anion percentages of milliequivalents in two base triangles. The total cations in mg/l, and the total anions in mg/l, are set equal to 100%. The data points in the two triangles are then projected onto the diamond grid. The projection reveals certain useful properties of the total ion relationships. Every sample is represented by three data points; one in each triangle and one in the diamond grid. Schoeller (1955) developed semi-logarithmic plots to represent major ion analyses in milliequivalents per liter and to demonstrate different hydrochemical water types on the same plot.

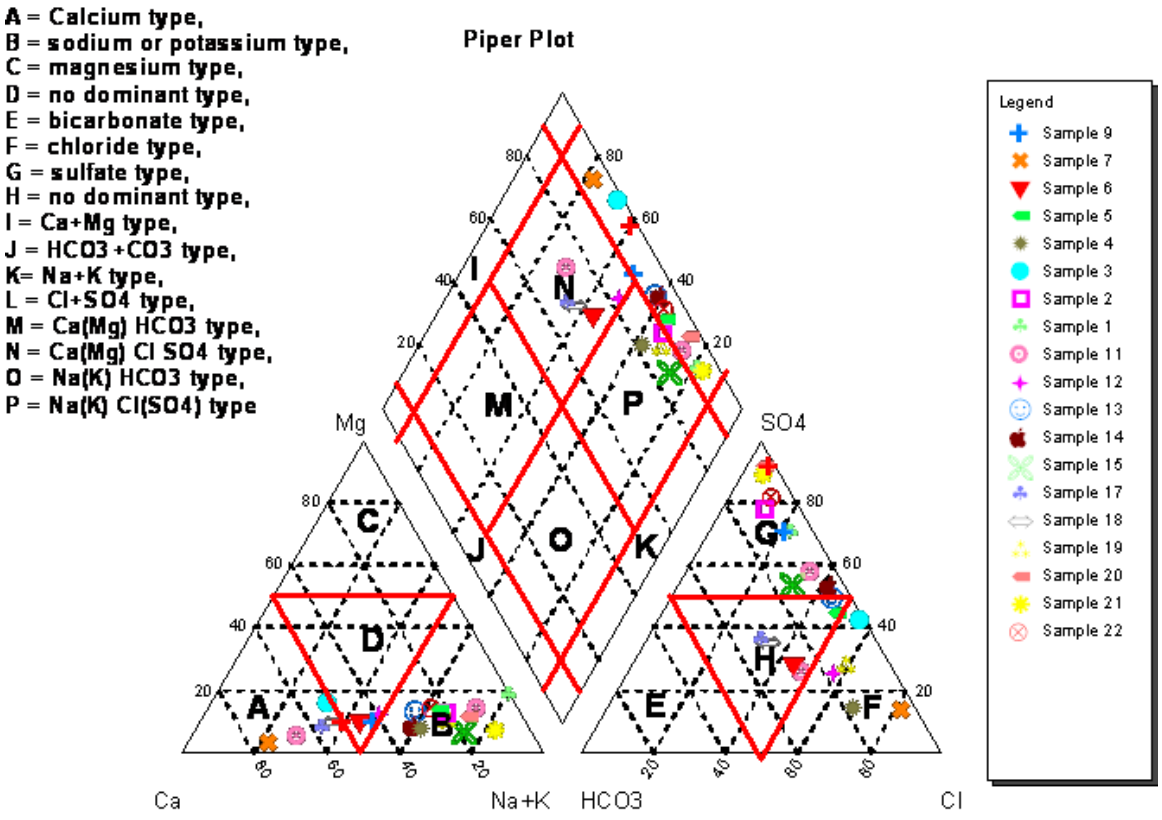


Figure 5.1: Piper trilinear diagram showing variation of milliequivalent percentages of major ions in water samples.

The Piper's trilinear diagram (Figure5.1) shows that the groundwater here contains dominant Cations Na and anions SO_4^{2-} and it falls within group P and can be called a Na-SO_4^{2-} water type and group M which is the Ca(Mg) HCO_3 water type and belongs to freshwater. The interpretation is based on (Back and Hanshaw, 1965) water types

Using Schoeller's semi – logarithmic diagram, an attempt have been made to subdivide the water into groups according to the various ionic concentrations (Fig.4.10). On the average, the water belongs to the same group. On the whole, the ionic concentration of the groundwater here is typical of crystalline and magmatic rock regions

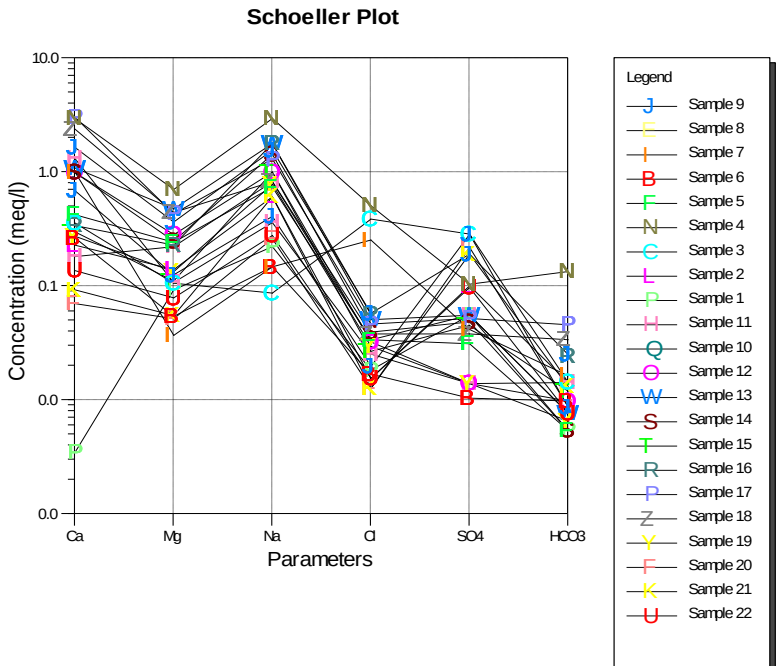


Figure 5.2: Schoeller semi-logarithm plot of groundwater-chemistry data

5.5 ORIENTATION/TREND ANALYSIS

The trend of the lineaments was computed directly from the endpoints earlier obtained using the linears - rose diagram - endpoint feature of Rockworks 15 software.

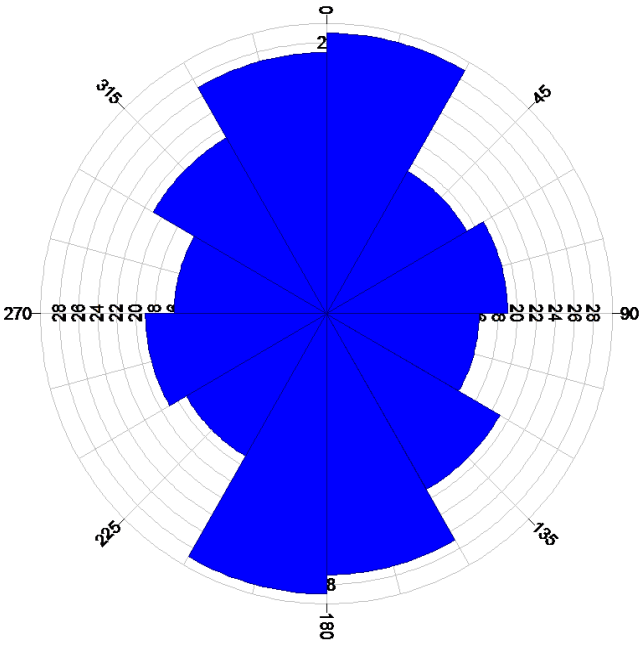


Figure. 4.11: Rose diagram (Azimuth-frequency) showing Lineaments trends

5.6: Lineament Analysis and Groundwater Potential

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

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

The NE-SW is the major trend of lineaments in the area, as observed from Rose diagram of fig.4.11. The zones of high lineaments density shown in (Fig. 4.11) could probably be feasible zones for groundwater prospecting in the study area.

5.8: Factors Controlling Groundwater Composition of the Basement Aquifers

In the course of undertaking this research, factors controlling groundwater composition were evident. To be able to identify the controlling hydrogeochemical reactions, one must know the present and past geological, biological, soil chemical, meteorological, and human factors that affect the chemistry of water. The input of chemical or biological species in the unsaturated zone of the recharge area is largely controlled by atmospheric deposition, land use (incuding vegetation and soil cover), the freguency, amount and duration of precipitation and irrigation, the mineralogy of the soil, the air temperature, the soil gas/air exchange rate and transport properties.

The quality of infiltrating surface water is controlled by the composition of the surface water together with the temperature, the composition of the surface water bottom sediments and the residence time of water within these bottom sediments. Factors that affect chemistry of ground water in the saturated zone are chemical reaction rate, residence time within the saturated zone, and mineralogy of the rock matrix. Here, the residence time and flow path

are determined by factors like aquifer thickness, permeability, porosity and amount of recharge. Superimposed on all these primarily natural factors are anthropogenic effects leading to chemical and physical stresses on the hydrogeological system that may be dominant in some areas. To be able to formulate and carry out regional studies, the following scientific and technical aspect with hydrologeology must be understood.

- The consequences of surface water/ groundwater interaction or soil moisture/groundwater interaction on groundwater quality.
- The effect of land use on water quality; and application of geochemical principles to regional aquifer system;
- Salt water intrusion; and specific contamination problems in karst aquifers

5.9: Ground Water Chemistry

The goal of evaluating groundwater quality is also to determine if the resource meets the requirements for its many different uses. Groundwater quality can be adversely affected or degraded as a result of human activities that introduce contaminants into the environment.
It can also be affected by natural processes that result in elevated concentrations of certain constituents in the groundwater. For example, despite that soil provides a protective "filter" or "barrier" that immobilized the downward migration of contaminants released on the land

5.10: Discussions of Geophysical Results

The aim of Vertical electrical Sounding is to determine the different geoelectric layers in the subsurface, the aquifer units and their characteristics, as well as general hydrogeological condition. Four layers were obtained from the VES points in the study area. They have

varying geologic characteristics, showing different degree of weathering and other second porosity in form of fracturing of the bedrock. Plots of calculated apparent resistivity in ohm-m against electode spacing with geoelectric sections showing resistivity and depth of the subsurface layer are presented in appendix I and II. These layers could be grouped as follows:-

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I. Top soil

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

Dan Hassan and Olurenfemi (1994) identified this layer to be the major aquifer unit. If the depth of weathering is sufficiently thick as exhibited by most of the VES points in the study

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The resistivity value ranges from 26.13 ohm m to 9779.3 ohm m. The thickness varies from 23.18 m to 68.60 m. In some places, fractured zones occur immediately beneath the weathered horizon. The fractured zones are difficult to detect geophysically.

IV. Bedrock

This has a very high resistivity with infinite thickness. The area has a good potential for groundwater development, especially in places underlain by porphyritic granite because of its thick regolith and extensive fractures.

CHAPTER SIX

6.0 CONLUSION AND SUMMARY

6.1 SUMMARY

The study area is underlain by migmatite which covers more than half of the study area, biotite granite, ferrohedenbergite granite porphyry and ignimbrite, fine to medium grained biotite. Older Granites of Upper Precambrian age occurring at the northern eastern part, and the Mesozoic ring dykes

Recharge to the area is by direct infiltration from rainfall water. The results of the chemical analysis of 22 water samples showed that Ca^{2+} ranges between 0.068 – 60.678 mg/l, Na^{2+} 2.00 – 68.00 mg/l, K^{+} 2.80 – 33.00 mg/l, Mg^{2+} 0.448 – 8.572 mg/l, $S0_4^{-}$ 0.50 – 13.75 mg/l, $N0_3^{-}$ 5.000 – 26.000 mg/l, HCO_3^{-} 0.333 – 8.2004 mg/l, Cl^{-} 0.4500– 18.000 mg/l.

Lineament analysis of the area indicates a predominantly NE-SW trend of lineaments. The zones of high lineaments density is the feasible zones for groundwater prospecting.

Deep boreholes tap from fractures.The Piper's trilinear diagram shows that the groundwater in the study area is of Na-SO_4^{2-} and Ca-HNO^3 water types, while Schoeller's semi – logarithmic plots also show the dominance of sodium and Bicarbonate ionic concentration. It is also established that the lineament follows the drainage pattern of the study area.

6.2 Conclusion

This study reveals that the rocks in the area have undergone relatively deep weathering and fracturing producing various thicknesses of the soft overburden and fractured crystalline aquifers.

The depth of the water table is highly variable in the area, and from the elevations mapped and studied in detail, the water level in wells coincides with the water table. Its pattern is usually a subdued replica of the surface topography, reaching its highest elevations beneath the watersheds and then flows towards the valleys into streams.

The result of water analysis showed the water in the study area is of meteoric origin and is potable for both domestic and agricultural use based on the W.H.O and Nigeria drinking water standards.

6.3 Contribution to knowledge

This study has contributed to knowledge in the following ways;

(I) Updated the geological and hydrogeological maps of the study area

(II) Determined the groundwater movement at end of wet season and at peak of dry season

(III) Determined the water quality of the area

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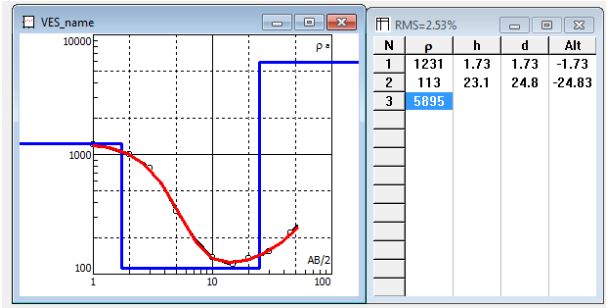
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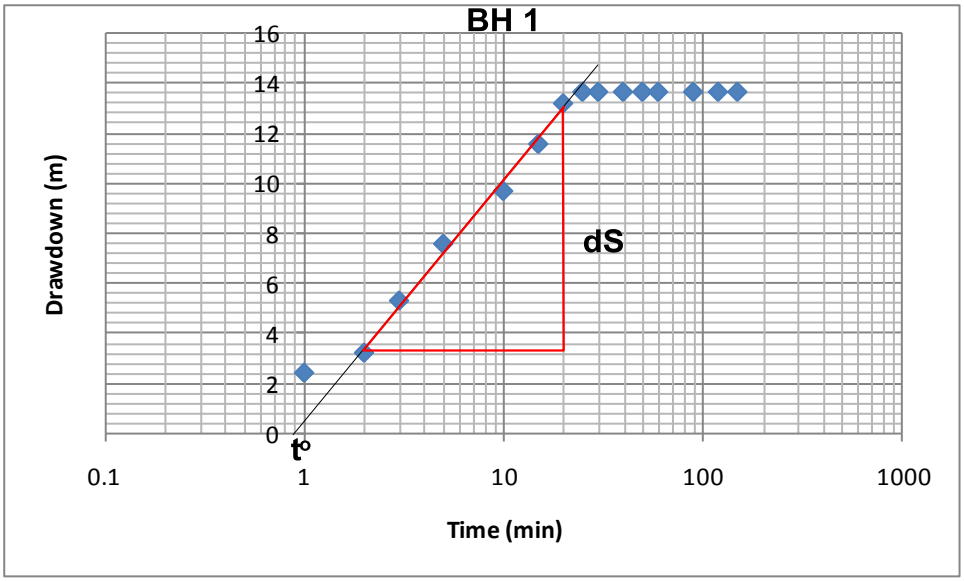
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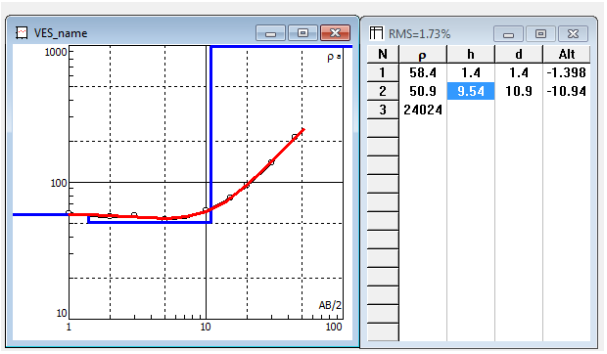
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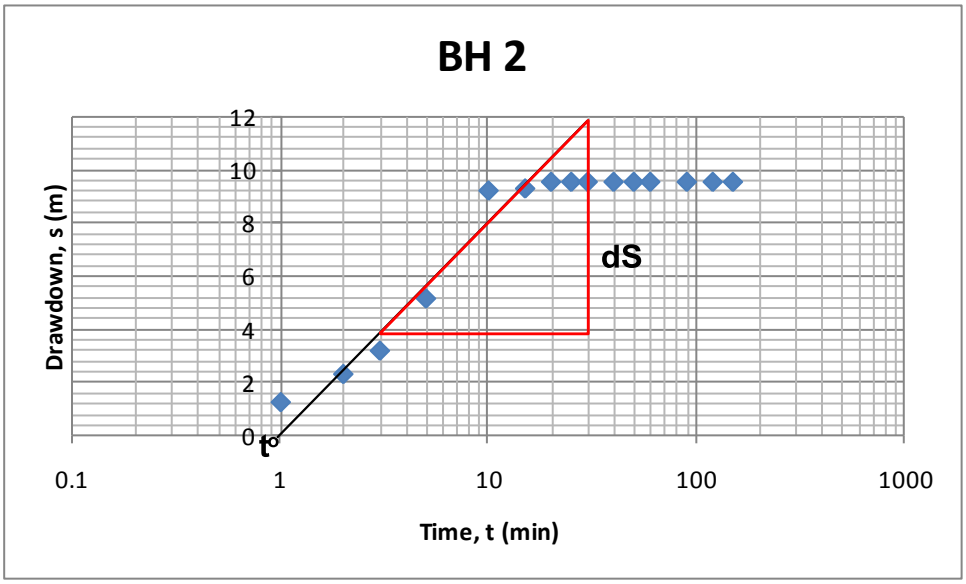
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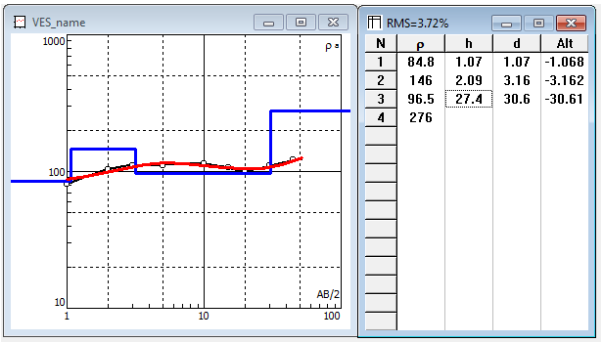
APPENDIX I- VES AND DRAWDOWN V S TIME PLOTS

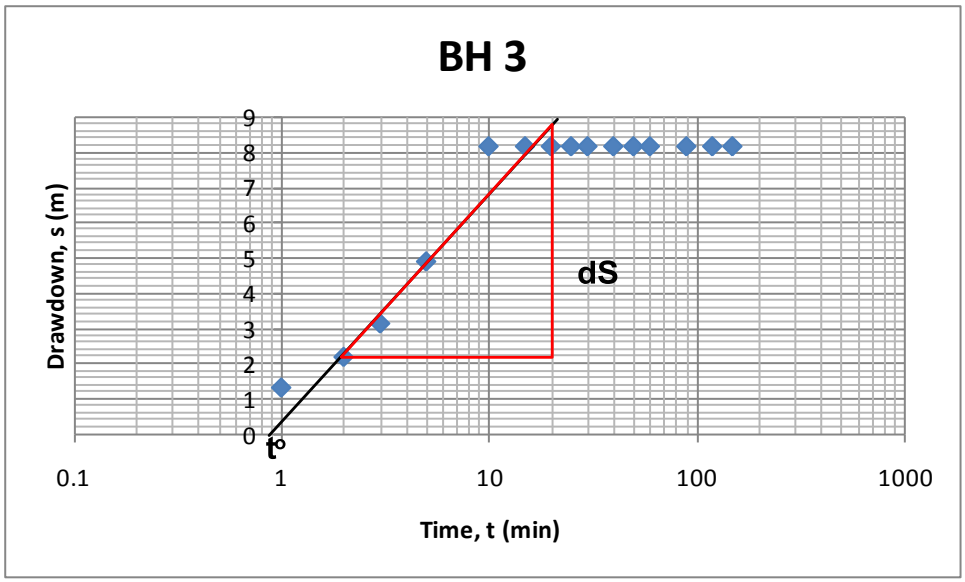


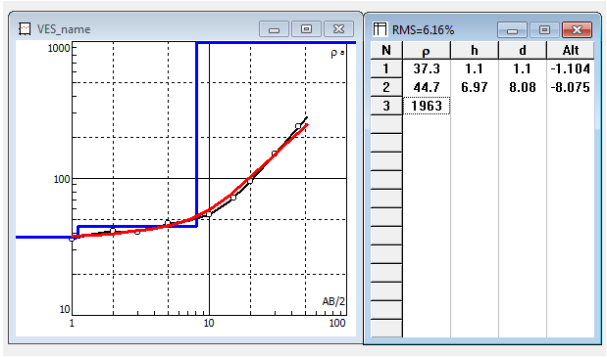


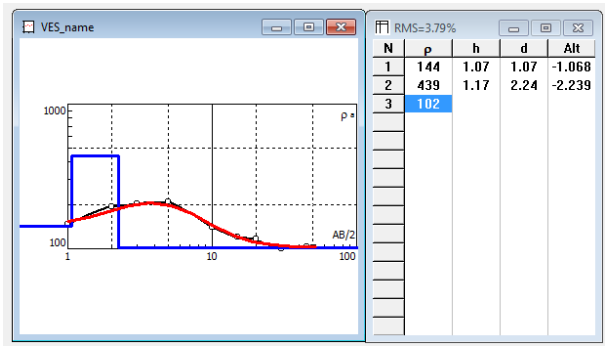

VES_name
RMS=1.73%
N ρ h d Alt
1 58.4 1.4 1.4 -1.398
2 50.9 9.54 10.9 -10.94
3 24024
AB/2

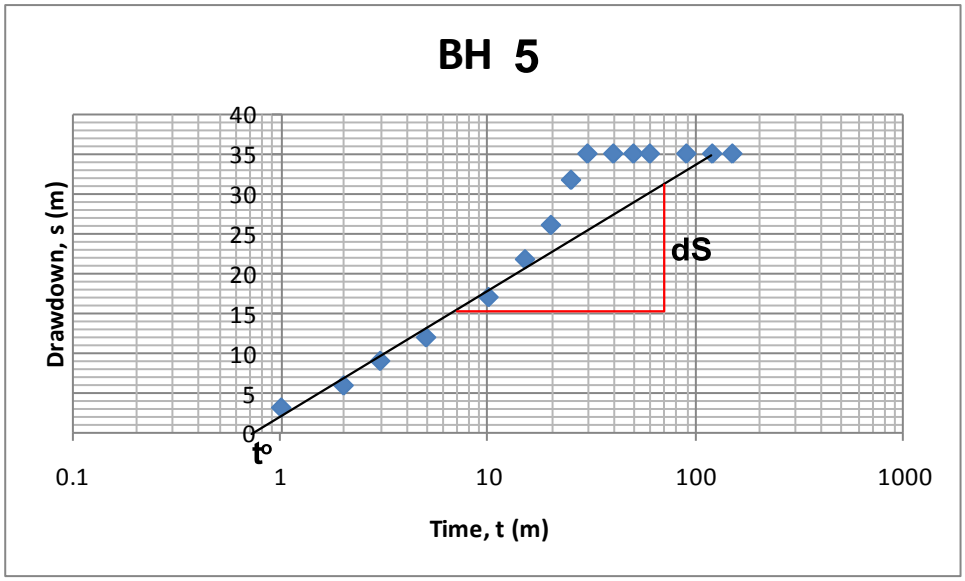

BH 2
Drawdown, s (m)
Time, t (min)
dS
t₀
0.1
1
10
100
1000

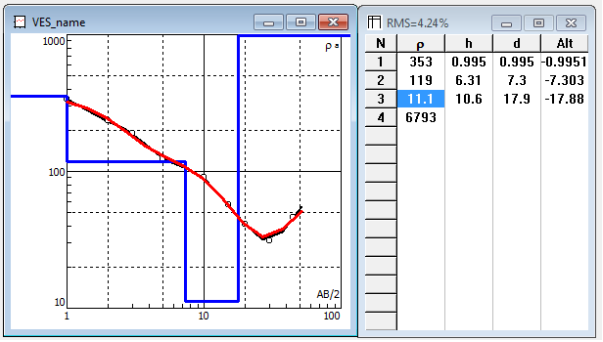

VES_name
RMS=3.72%
N ρ h d Alt
1 84.8 1.07 1.07 -1.068
2 146 2.09 3.16 -3.162
3 96.5 27.4 30.6 -30.61
4 276
AB/2

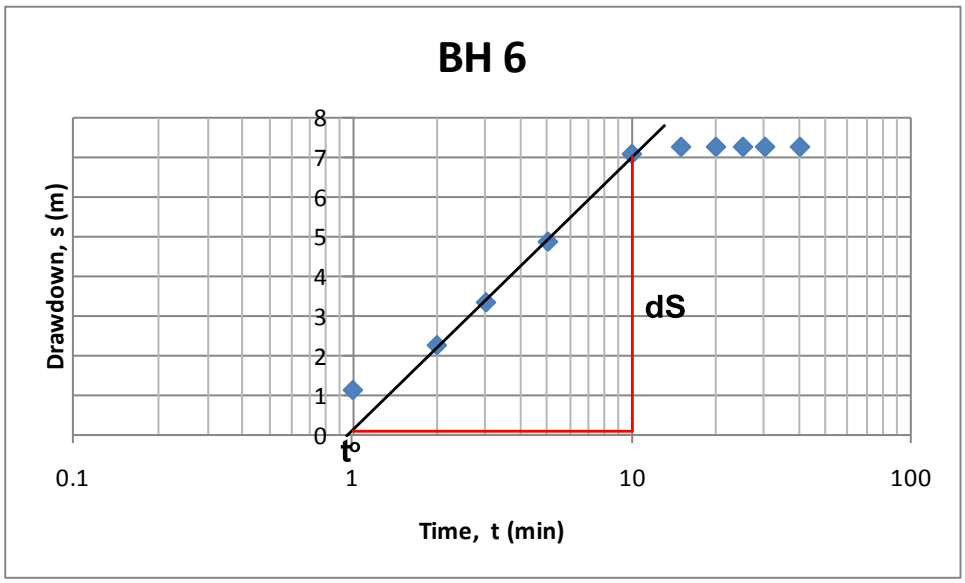

BH 3
Drawdown, s (m)
9
8
7
6
5
4
3
2
1
0
dS
t°
0.1
1
10
100
1000
Time, t (min)

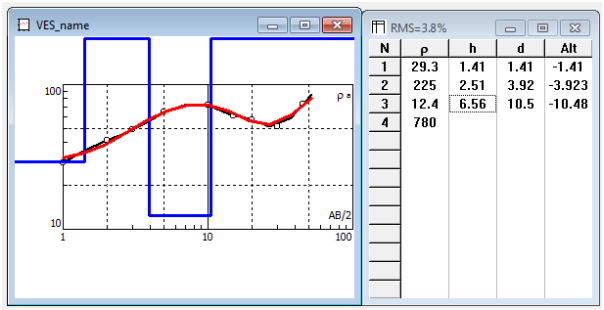

VES_name
1000
100
10
ρ a
AB/2
1
10
100
RMS=6.16%
N ρ h d Alt
1 37.3 1.1 1.1 -1.104
2 44.7 6.97 8.08 -8.075
3 1963


VES_name
1000
100
ρ a
AB/2
1
10
100
RMS=3.79%
N ρ h d Alt
1 144 1.07 1.07 -1.068
2 439 1.17 2.24 -2.239
3 102

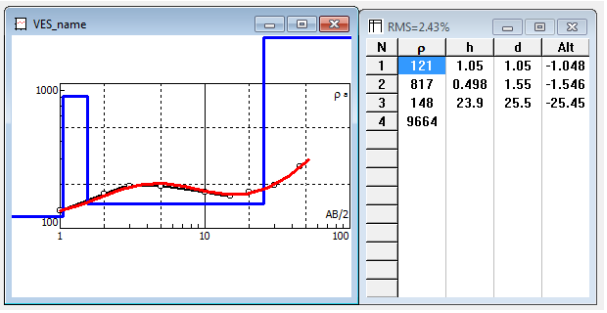

BH 5
Drawdown, s (m)
40
35
30
25
20
15
10
5
0
t°
dS
0.1
1
10
100
1000
Time, t (m)


VES_name
RMS=4.24%
N ρ h d Alt
1 353 0.995 0.995 -0.9951
2 119 6.31 7.3 -7.303
3 11.1 10.6 17.9 -17.88
4 6793
AB/2

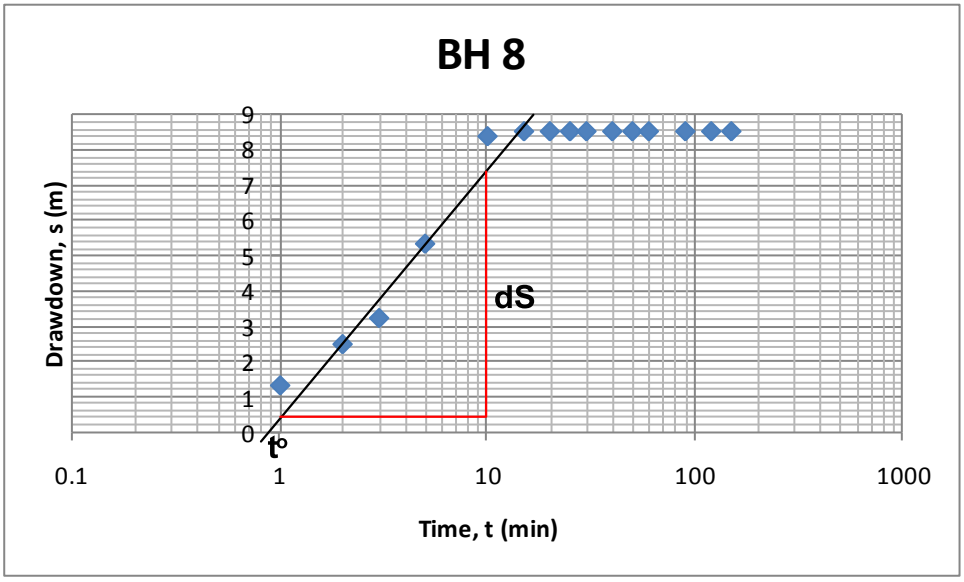

BH 6
Drawdown, s (m)
8
7
6
5
4
3
2
1
0
t°
dS
0.1
1
10
100
Time, t (min)

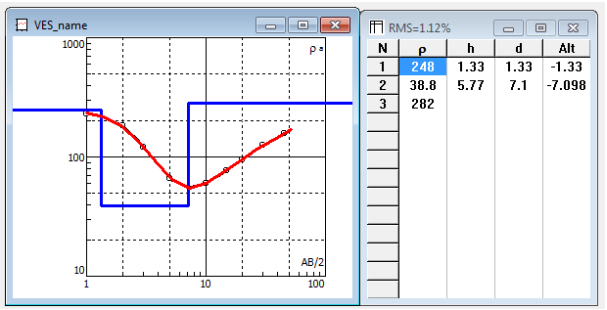


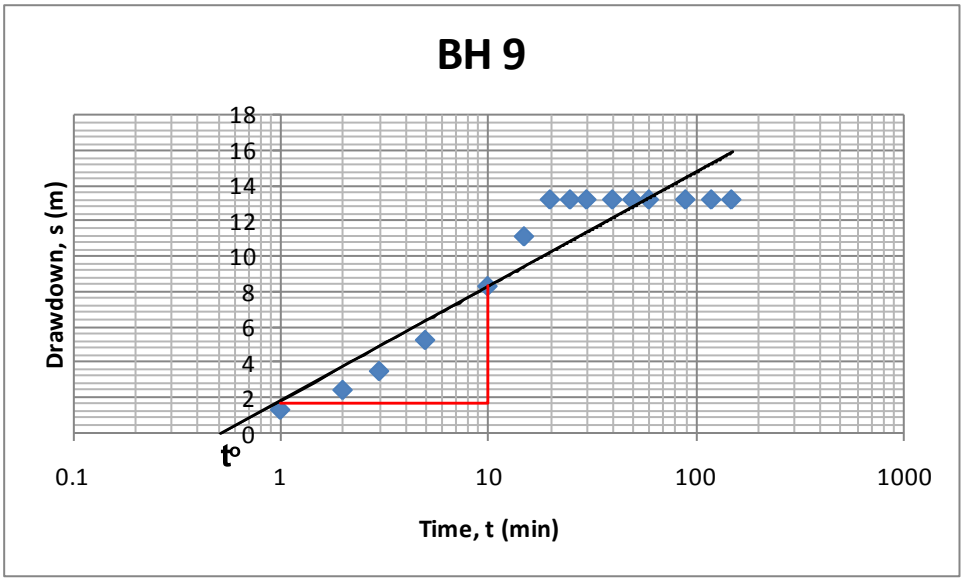
N	ρ	h	d	Alt
1	29.3	1.41	1.41	-1.41
2	225	2.51	3.92	-3.923
3	12.4	6.56	10.5	-10.48
4	780			

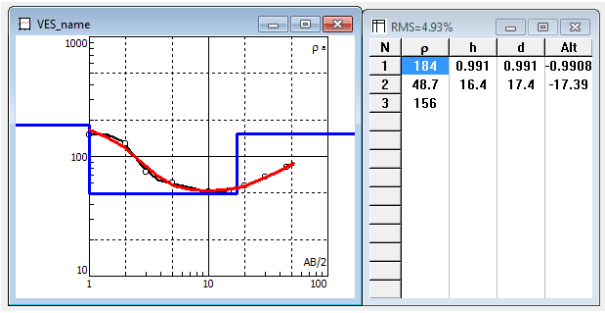


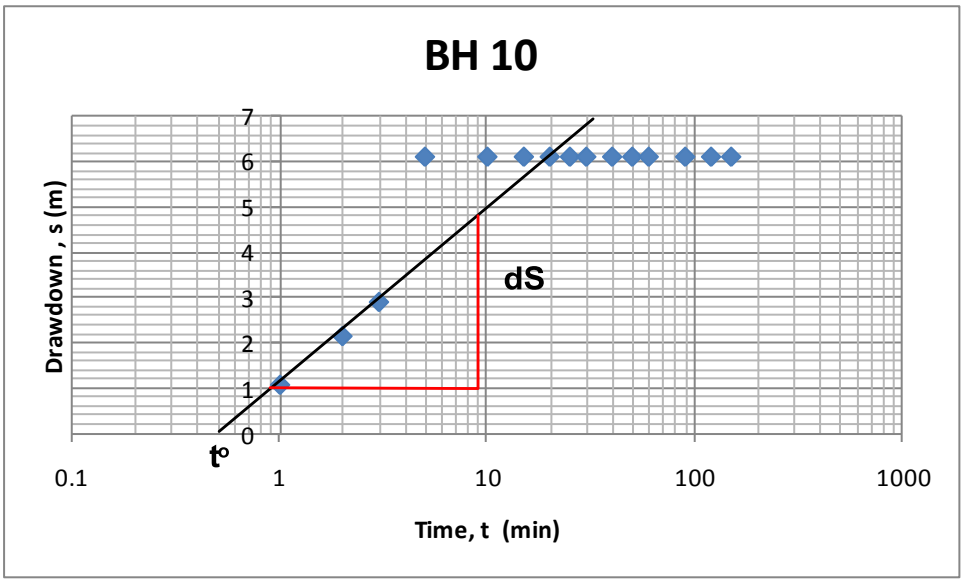
N	ρ	h	d	Alt
1	121	1.05	1.05	-1.048
2	817	0.498	1.55	-1.546
3	148	23.9	25.5	-25.45
4	9664			




VES_name
RMS=1.12%
N ρ h d Alt
1 248 1.33 1.33 -1.33
2 38.8 5.77 7.1 -7.098
3 282
AB/2


BH 9
Drawdown, s (m)
Time, t (min)
0.1
1
10
100
1000
0
2
4
6
8
10
12
14
16
18


VES_name
RMS=4.93%
N ρ h d Alt
1 184 0.991 0.991 -0.9908
2 48.7 16.4 17.4 -17.39
3 156
AB/2


BH 10
Drawdown , s (m)
0
1
2
3
4
5
6
7
dS
t°
0.1
1
10
100
1000
Time, t (min)

B

GUDIMI KUDU-HAKIYA VES 5

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	81.21	81.26	-0.0642		
2	2.00	0.400	64.38	64.94	-0.879		
3	3.00	0.600	54.74	52.61	3.88		
4	5.00	1.00	41.75	45.34	-8.60		
5	10.00	2.00	47.45	47.30	0.308		
6	15.00	3.00	61.21	56.17	8.21		
7	20.00	4.00	72.26	68.87	4.68		
8	30.00	6.00	93.19	99.34	-6.60		
9	45.00	9.00	144.6	147.8	-2.24		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	43.04	0.0848	-0.0848	0.00197	3.65
2	35.65	0.104	-0.189	0.00292	3.71
3	505.2	0.0998	-0.288	1.977E-04	50.46
4	41.12	12.23	-12.52	0.295	506.6
5	12423.6		-12.52		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

B

YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Maihali Nigeria Limited.

LOCATION: Unguwar Kudu Kudumi LGA: Kubau

STATE: Kaduna State SCHEME: Handpump Borehole

BOREHOLE DEPTH: 47.80m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 2.20m PUMP SETTING: 30m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
02.30	0	"	2.20	0.00	06.00	0	15.42	13.22
	1	"	3.51	1.31	06.01	1	12.69	10.49
	2	"	4.63	2.43	06.02	2	1075	8.55
	3	0.96	5.70	3.50	06.03	3	8.84	6.64
	5	0.96	7.46	5.26	06.04	4	6.92	4.72
	10	0.96	10.51	8.31	06.05	5	5.69	3.49
	15	0.86	13.33	11.13	06.06	6	4.77	2.57
	20	0.86	15.42	13.22	06.07	7	3.86	1.66
	25	0.86	15.42	13.22	06.08	8	2.71	0.51
	30	0.86	15.42	13.22	06.09	9	2.20	0.00
04.10	40	0.86	15.42	13.22				

YIELD: 0.86L/S = 51.60L/Min = 3096L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Nasiru Abubakar

Sign/Date: Abdullah 18/01/2016

B

YOKE ENGINEERINMG SERVICES NIG. LTD.

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BOREHOLE DEPTH: 47.80m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 2.20m PUMP SETTING: 30m

ME IN)	CONSTANT DISCHARGE				RECOVERY PERIOD			
	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
20	50	0.86	15.42					
	60	0.86	15.42					
	90	0.86	15.42					
	120	0.86	15.42					
00	150	0.86	15.42					

YIELD: 0.86L/S = 51.60L/Min = 3096L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Nasiru Abubakar

Sign/Date: 18/01/2016

D

GOBURAWA-HASKIYA VES 1

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	129.4	138.7	-7.15		
2	2.00	0.400	139.9	116.5	-16.68		
3	3.00	0.600	74.29	85.59	-15.22		
4	5.00	1.00	59.77	59.45	0.527		
5	10.00	2.00	51.07	51.58	-0.999		
6	15.00	3.00	51.82	52.22	-0.775		
7	20.00	4.00	56.27	54.69	2.79		
8	30.00	6.00	67.43	63.73	5.48		
9	45.00	9.00	81.12	84.53	-4.20		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	98.54	0.107	-0.107	0.00109	10.58
2	50.80	0.117	-0.225	0.00232	5.97
3	492.3	0.259	-0.484	5.269E-04	127.7
4	49.29	26.78	-27.27	0.543	1320.3
5	19256.4		-27.27		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

GOBURAWA-HASKIYA VES 2

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	28.36	30.12	-6.23		
2	2.00	0.400	44.76	40.90	8.60		
3	3.00	0.600	42.09	42.22	-0.308		
4	5.00	1.00	36.54	37.58	-2.85		
5	10.00	2.00	29.64	30.91	-4.31		
6	15.00	3.00	32.25	31.87	1.17		
7	20.00	4.00	37.72	35.76	5.18		
8	30.00	6.00	50.69	47.78	5.73		
9	45.00	9.00	64.49	69.79	-8.21		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	48.93	0.0970	-0.0970	0.00198	4.74
2	9.34	0.216	-0.313	0.0231	2.02
3	328.8	0.202	-0.516	6.165E-04	66.66
4	26.37	16.26	-16.78	0.616	428.9
5	18168.8		-16.78		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

D

YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Maihali Nigeria Limited.

LOCATION: Unguwar Goburawa LGA: Kubau

STATE: Kaduna State SCHEME: Handpump Borehole

BOREHOLE DEPTH: 48.60m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 5.80m PUMP SETTING: 30m

	CONSTANT DISCHARGE				RECOVERY PERIOD			
IME MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
07.00	0	"	5.80	0.00	09.30	0	11.90	6.10
	1	"	6.89	1.09	09.31	1	10.80	5.00
	2	"	7.96	2.16	09.32	2	9.73	3.93
	3	0.96	8.71	2.91	09.33	3	8.84	3.04
	5	0.90	11.90	6.10	09.34	4	7.96	2.16
	10	0.86	11.90	6.10	09.35	5	6.71	0.91
	15	0.86	11.90	6.10	09.36	6	5.80	0.00
	20	0.86	11.90	6.10				
	25	0.86	11.90	6,10				
	30	0.86	11.90	6.10				
07.40	40	0.86	11.90	6.10				

YIELD: 0.86L/S = 51.60L/Min = 3096L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Nasiru Abubakar

Sign/Date: 18/01/2016

D

YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Maihali Nigeria Limited.

LOCATION: Unguwar Goburawa LGA: Kubau

STATE: Kaduna SCHEME: Handpump Borehole

BOREHOLE DEPTH: 48.60m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 5.80m PUMP SETTING: 30m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
07.50	50	0.86	11.90	6.10				
	60	0.86	11.90	6.10				
	90	0.86	11.90	6.10				
	120	0.86	11.90	6.10				
09.30	150	0.86	11.90	6.10				

YIELD: 0.86L/S = 51.60L/Min = 3096L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Nasiru Abubakar

Sign/Date: Abdullahi 18/01/2016

UNGUWAN ADEVES 1

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	338.2	329.8	2.47		
2	2.00	0.400	233.3	244.9	-4.97		
3	3.00	0.600	191.0	179.1	6.24		
4	5.00	1.00	123.8	126.5	-2.14		
5	10.00	2.00	89.90	88.91	1.09		
6	15.00	3.00	56.87	57.46	-1.05		
7	20.00	4.00	40.97	39.79	2.87		
8	30.00	6.00	30.89	33.20	-7.49		
9	45.00	9.00	45.87	43.50	5.14		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	359.6	0.988	-0.988	0.00275	355.6
2	134.8	0.859	-1.84	0.00637	115.8
3	71.75	1.05	-2.89	0.0146	75.39
4	189.4	2.91	-5.81	0.0154	552.4
5	9.87	8.88	-14.69	0.899	87.75
6	403.9		-14.69		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

UNGUWAN ADE VES 2

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	438.2	448.6	-2.37		
2	2.00	0.400	334.8	317.7	5.10		
3	3.00	0.600	234.8	242.7	-3.37		
4	5.00	1.00	200.8	209.8	-4.47		
5	10.00	2.00	189.8	166.1	12.49		
6	15.00	3.00	98.09	107.3	-9.47		
7	20.00	4.00	68.90	71.40	-3.63		
8	30.00	6.00	56.89	50.52	11.19		
9	45.00	9.00	50.90	54.97	-8.00		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	502.9	0.932	-0.932	0.00185	468.9
2	136.2	0.657	-1.58	0.00482	89.52
3	119.0	0.561	-2.15	0.00472	66.84
4	342.2	3.39	-5.54	0.00993	1163.1
5	17.18	7.33	-12.88	0.426	126.1
6	95.22		-12.88		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

)KE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

OF CONTRANCTOR: Maihali Nigeria Limited

TION: Haying Ade LGA: Kubau

: Kaduna State SCHEME: Handpump Borehole

HOLE DEPTH: 47m PUMP CAPACITY: 0.75Hp

C WATER LEVEL: 5.60m PUMP SETTING: 30m

CONSTANT DISCHARGE				RECOVERY PERIOD			
ME NCE JMPIMG EGIN Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
0	''	5.60	0.00	11.00	0	12.84	7.24
1	''	6.71	1.11	11.01	1	11.63	6.03
2	''	7.84	2.24	11.02	2	10.92	5.32
3	1.05	8.92	3.32	11.03	3	9.71	4.11
5	1.00	10.46	4.85	11.04	4	8.64	3.04
10	1.00	12.66	7.06	11.05	5	7.73	2.13
15	1.00	12.84	7.24	11.06	6	6.80	1.20
20	1.00	12.84	7.24	11.07	7	5.60	0.00
25	1.00	12.84	7.24				
30	1.00	12.84	7.24				
40	1.00	12.84	7.24				

IELD: 1.00L/S = 60L/Min =3600L/H

EMARK: Productive Borehole

ESTED BY: Engr. Hussaini Abdullahi

NSPECTED BY: Nasiru Abubakar

ign A.Abdullahi Date: 08/02/2016

4

ASHEMA VES 1

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	148.6	149.4	-0.522		
2	2.00	0.400	195.4	189.8	2.86		
3	3.00	0.600	203.8	214.2	-5.10		
4	5.00	1.00	224.6	213.3	5.00		
5	10.00	2.00	134.1	144.4	-7.69		
6	15.00	3.00	120.2	108.1	10.09		
7	20.00	4.00	92.03	97.85	-6.32		
8	30.00	6.00	103.1	103.6	-0.460		
9	45.00	9.00	132.7	131.5	0.863		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	133.0	0.719	-0.719	0.00541	95.73
2	91.10	0.0879	-0.807	9.650E-04	8.00
3	384.7	1.90	-2.70	0.00494	731.4
4	78.24	25.05	-27.76	0.320	1960.4
5	1578.4		-27.76		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

H

ASHEMA VES 5

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	78.26	73.08	2.89		
2	2.00	0.400	85.07	86.79	-2.02		
3	3.00	0.600	92.92	104.8	-12.86		
4	5.00	1.00	147.5	128.8	12.67		
5	10.00	2.00	116.5	120.3	-3.22		
6	15.00	3.00	96.17	91.75	4.58		
7	20.00	4.00	72.26	76.49	-5.86		
8	30.00	6.00	78.52	79.90	-1.76		
9	45.00	9.00	115.7	111.5	3.59		

NO DATA ARE MASKED

Layered Model

Li	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	70.03	1.40	-1.40	0.0200	98.10
2	57.41	0.133	-1.53	0.00232	7.64
3	626.0	1.33	-2.86	0.00213	835.1
4	13.58	4.97	-7.83	0.365	67.50
5	3209.6		-7.83		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

H

YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Maihali Nigeria Limited.

LOCATION: Ashema LGA: Kubau

STATE: Kaduna State SCHEME: Handpump Borehole

BOREHOLE DEPTH: 46m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 5.80m PUMP SETTING: 45m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
07.00	0	"	5.80	0.00	09.30	0	40.91	35.11
	1	"	8.92	3.12	09.31	1	38.73	32.93
	2	"	11.71	5.91	09.32	2	36.51	30.71
	3	0.76	14.80	9.00	09.33	3	34.62	28.82
	5	0.66	17.77	1.97	09.34	4	32.44	26.64
	10	0.52	22.84	17.04	09.35	5	3050	24.70
	15	0.40	27.60	21.80	09.36	6	28.67	22.87
	20	0.37	31.92	26.12	09.37	7	26.42	20.62
	25	0.37	37.60	31.80	09.38	8	24.57	18.77
	30	0.37	40.91	35.11	09.39	9	22.60	16.80
07.40	40	0.37	40.91	35.11	09.40	10	20.51	14.71

YIELD: 0.37L/S = 22.20L/Min = 1332L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Nasiru Abubakar

Sign/Date: Abdullahi 17/01/2016

H

YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Maihali Nigeria Limited.

LOCATION: Ashema LGA: Kubau

STATE: Kaduna SCHEME: Handpump Borehole

BOREHOLE DEPTH: 46m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 5.80m PUMP SETTING: 45m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
07.50	50	0.37	40.91	35.11	09.41	11	18.71	12.91
	60	0.37	40.91	35.11	09.42	12	16.84	11.04
	90	0.37	40.91	35.11	09.43	13	14.53	8.73
	120	0.37	40.91	35.11	09.44	14	12.64	6.84
09.30	150	0.37	40.91	35.11	09.45	15	10.55	4.75
					09.46	16	8.62	2.82
					09.47	17	6.71	0.90
					09.48	18	5.80	0.00

YIELD: 0.37L/S = 22.20L/Min = 1332L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Nasiru Abubakar

Sign/Date: 17/01/2016

KAWANKWARMI VES 1

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	28.82	29.36	-1.89		
2	2.00	0.400	41.08	38.65	5.90		
3	3.00	0.600	48.52	49.89	-2.83		
4	5.00	1.00	64.75	65.97	-1.89		
5	10.00	2.00	72.19	72.05	0.190		
6	15.00	3.00	60.98	62.10	-1.83		
7	20.00	4.00	57.18	54.47	4.73		
8	30.00	6.00	51.37	54.32	-5.75		
9	45.00	9.00	72.98	70.83	2.94		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	27.05	1.25	-1.25	0.0464	33.95
2	169.4	0.621	-1.87	0.00367	105.3
3	468.2	0.962	-2.83	0.00206	450.7
4	10.08	5.15	-7.99	0.511	51.98
5	522.1		-7.99		

ALL PARAMETERS ARE FREE

KAWANKWARMI VES 4

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	12.41	12.44	-0.297		
2	2.00	0.400	18.70	18.58	0.590		
3	3.00	0.600	26.91	25.84	3.94		
4	5.00	1.00	37.18	38.22	-2.81		
5	10.00	2.00	52.12	56.40	-8.22		
6	15.00	3.00	71.51	65.42	8.51		
7	20.00	4.00	71.66	72.27	-0.863		
8	30.00	6.00	86.22	87.87	-1.92		
9	45.00	9.00	116.4	116.0	0.346		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	169.0	1.08	-1.08	0.00643	183.6
2	468.4	0.646	-1.73	0.00138	302.6
3	16.42	0.981	-2.71	0.0597	16.12
4	519.0		-2.71		

ALL PARAMETERS ARE FREE

1

YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Kano Hydro Drilling Company.

LOCATION: Kwankwarmi LGA: Kubau

STATE: Kaduna SCHEME: Handpump Borehole

BOREHOLE DEPTH: 37.80m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 5.80m PUMP SETTING: 37m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
02.40	40	0.30	37.00	31.20	04.11	11	15.33	9.53
	45	—	—	—	04.12	12	13.40	7.60
	50	0.30	37.00	31.20	04.13	13	11.53	5.73
	55	—	—	—	04.14	14	10.49	4.69
03.50	60	0.30	37.00	31.20	04.15	15	9.51	3.71
	65	—	—	—	04.16	16	8.36	2.56
	70	0.30	37.00	31.20	04.17	17	7.48	1.68
	75	—	—	—	04.18	18	6.55	0.75
	80	0.30	37.00	31.20	04.19	19	5.80	0.00
	90	—	—	—				
04.00	120	0.30	37.00	31.20				

YIELD: 0.30L/S = 18L/Min = 1080L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Adamu Emishe

Sign/Date: 21/01/2016

3

RAFIN BUSA VES 1

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	106.4	108.6	-2.07		
2	2.00	0.400	171.6	167.4	2.42		
3	3.00	0.600	196.6	193.3	1.68		
4	5.00	1.00	195.0	200.2	-2.67		
5	10.00	2.00	177.1	175.6	0.813		
6	15.00	3.00	167.8	168.5	-0.374		
7	20.00	4.00	177.8	174.4	1.93		
8	30.00	6.00	198.0	203.7	-2.88		
9	45.00	9.00	265.7	261.7	1.52		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	47.31	0.359	-0.359	0.00759	16.99
2	814.6	0.510	-0.869	6.268E-04	416.0
3	146.1	18.60	-19.47	0.127	2718.4
4	507.8		-19.47		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

3

RAFIN BUSA VES 2

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	123.4	124.0	-0.499		
2	2.00	0.400	184.4	181.2	1.74		
3	3.00	0.600	200.2	201.8	-0.790		
4	5.00	1.00	199.3	202.9	-1.82		
5	10.00	2.00	189.0	183.3	3.03		
6	15.00	3.00	178.0	179.9	-1.05		
7	20.00	4.00	189.0	185.8	1.73		
8	30.00	6.00	201.0	212.2	-5.55		
9	45.00	9.00	279.0	270.1	3.18		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	53.56	0.335	-0.335	0.00627	17.98
2	706.2	0.454	-0.789	6.430E-04	320.7
3	164.9	22.88	-23.67	0.138	3775.3
4	1367.3		-23.67		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

3

YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Kano Hydro Drilling Company

LOCATION: Gidan Jifa rafin Busa LGA: Kubau

STATE: Kaduna State SCHEME: Handpump Borehole

BOREHOLE DEPTH: 45m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 7.20m PUMP SETTING: 18m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
05.00	0	"	7.20	0.00	07.30	0	15.72	8.52
	1	"	8.51	1.31	07.31	1	14.94	7.74
	2	"	9.68	2.48	07.32	2	13.86	6.66
	3	0.83	10.42	3.22	07.33	3	12.70	5.50
	5	0.71	12.53	5.33	07.34	4	11.59	4.39
	10	0.54	15.58	8.38	07.35	5	10.64	3.44
	15	0.48	15.72	8.52	07.36	6	9.92	2.72
	20	0.40	15.72	8.52	07.37	7	8.86	1.66
	25	0.40	15.72	8.52	07.38	8	7.74	0.54
	30	0.40	15.72	8.52	07.39	9	7.20	0.00
05.40	40	0.40	15.72	8.52				

YIELD: 0.40L/S = 24L/Min = 1440L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Adamu Emishe

Sign/Date: Abdullahi 21/01/2016

YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Kano Hydro Drilling Company.

LOCATION: Gidan Jifa Rafin Busa LGA: Kubau

STATE: Kaduna SCHEME: Handpump Borehole

BOREHOLE DEPTH: 45m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 7.20m PUMP SETTING: 18m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
05.30	50	0.40	15.72	8.52				
	60	0.40	15.72	8.52				
	90	0.40	15.72	8.52				
	120	0.40	15.72	8.52				
07.30	150	0.40	15.72	8.52				

YIELD: 0.40L/S = 24L/Min = 1440L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Adamu Emishe

Sign/Date: Abdullahi 21/01/2016

4

UNG. YELWA DAUMALIKI VES 1

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	35.79	36.10	-0.880		
2	2.00	0.400	40.93	39.48	3.53		
3	3.00	0.600	40.49	42.56	-5.12		
4	5.00	1.00	46.76	45.25	3.22		
5	10.00	2.00	54.39	55.12	-1.35		
6	15.00	3.00	72.41	75.72	-4.57		
7	20.00	4.00	95.19	99.65	-4.69		
8	30.00	6.00	151.3	148.6	1.80		
9	45.00	9.00	239.9	221.6	7.65		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	35.14	1.26	-1.26	0.0359	44.38
2	67.76	1.32	-2.58	0.0195	89.60
3	24.66	3.15	-5.73	0.127	77.74
4	149.9	2.37	-8.11	0.0158	356.2
5	11814.0		-8.11		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

4

UNG. YEL-DAUMALIKI VES 2

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	59.55	59.18	0.621		
2	2.00	0.400	55.80	57.09	-2.32		
3	3.00	0.600	57.05	55.36	2.95		
4	5.00	1.00	53.25	54.37	-2.10		
5	10.00	2.00	62.30	61.33	1.55		
6	15.00	3.00	76.48	76.72	-0.322		
7	20.00	4.00	95.04	96.64	-1.68		
8	30.00	6.00	139.1	140.8	-1.22		
9	45.00	9.00	213.0	207.9	2.39		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	59.88	1.03	-1.03	0.0172	61.86
2	52.12	1.10	-2.13	0.0211	57.39
3	50.39	3.83	-5.96	0.0760	193.1
4	54.74	5.05	-11.02	0.0923	276.7
5	4498.0		-11.02		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

8

WUDU SABON GARI VES 1

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	1210.9	1207.9	0.243		
2	2.00	0.400	994.5	1018.7	-2.43		
3	3.00	0.600	763.5	738.1	3.32		
4	5.00	1.00	335.0	340.9	-1.75		
5	10.00	2.00	138.7	137.2	1.08		
6	15.00	3.00	121.8	124.9	-2.51		
7	20.00	4.00	134.2	130.0	3.14		
8	30.00	6.00	154.7	159.6	-3.14		
9	45.00	9.00	221.3	217.7	1.59		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	1241.0	0.974	-0.974	7.856E-04	1210.0
2	1616.6	0.537	-1.51	3.326E-04	869.1
3	124.1	6.64	-8.15	0.0535	825.1
4	81.62	9.75	-17.91	0.119	796.5
5	1151.3		-17.91		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

WUDU SABON GARI VES 2

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	904.0	891.3	1.40		
2	2.00	0.400	879.6	872.9	0.754		
3	3.00	0.600	719.8	792.8	-10.13		
4	5.00	1.00	586.3	526.3	10.23		
5	10.00	2.00	146.4	155.7	-6.37		
6	15.00	3.00	120.7	114.6	5.00		
7	20.00	4.00	129.5	128.7	0.642		
8	30.00	6.00	157.0	162.5	-3.50		
9	45.00	9.00	203.3	199.4	1.90		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	889.9	1.35	-1.35	0.00152	1205.4
2	1421.2	0.970	-2.32	6.825E-04	1378.7
3	35.84	2.39	-4.71	0.0668	85.84
4	92.96	3.74	-8.46	0.0403	348.3
5	317.5		-8.46		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Kano Hydro Drilling Company

LOCATION: Sabon Gari Wudu LGA: Kubau

STATE: Kaduna State SCHEME: Handpump Borehole

BOREHOLE DEPTH: 46.80m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 6.20m PUMP SETTING: 27m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (HRS)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
08.00	0	"	6.20	0.00		0	19.88	13.68
	1	"	8.66	2.46		1	17.62	11.42
	2	"	9.46	3.26		2	15.89	9.69
	3	0.90	11.54	5.34		3	13.62	7.42
	5	0.86	13.81	7.61		4	11.51	5.31
	10	0.83	15.92	9.72		5	10.42	4.22
	15	0.74	17.80	11.60		6	9.71	3.51
	20	0.50	19.42	13.22		7	8.50	2.32
	25	0.50	19.88	13.68		8	7.48	1.28
	30	0.50	19.88	13.68		9	6.55	0.35
08.40	40	0.50	19.88	13.68		10	6.20	0.00

YIELD: 0.50L/S = 30L/Min = 1800L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Adamu Emishe

Sign Date: 22/01/2016

YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Kano Hydro Drilling Company.

LOCATION:Sabon Gari Wudu LGA: Kubau

STATE: Kaduna SCHEME: Handpump Borehole

BOREHOLE DEPTH: 46.80m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 6.20m PUMP SETTING: 27m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
08.50	50	0.50	19.88	13.68				
	60	0.50	19.88	13.68				
	90	0.50	19.88	13.68				
	120	0.50	19.88	13.68				
10.30	150	0.50	19.88	13.68				

YIELD: 0.50L/S = 30L/Min = 1800L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Adamu Emishe

Sign/Date: 22/01/2016

UNG.WUR-KARGI VES 1

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	80.45	80.99	-0.675		
2	2.00	0.400	103.9	102.0	1.79		
3	3.00	0.600	110.8	110.3	0.502		
4	5.00	1.00	111.1	115.0	-3.49		
5	10.00	2.00	114.9	111.4	3.03		
6	15.00	3.00	106.0	105.5	0.420		
7	20.00	4.00	100.1	103.1	-2.97		
8	30.00	6.00	110.2	107.9	2.02		
9	45.00	9.00	121.1	121.8	-0.564		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	49.29	0.317	-0.317	0.00644	15.65
2	127.8	1.00	-1.32	0.00788	128.8
3	119.8	6.31	-7.63	0.0526	756.8
4	61.25	6.72	-14.35	0.109	411.7
5	173.8		-14.35		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

UNG.WUR-KARGI VES 2

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	26.21	26.16	0.155		
2	2.00	0.400	37.55	38.28	-1.95		
3	3.00	0.600	48.75	46.85	3.87		
4	5.00	1.00	55.96	57.92	-3.50		
5	10.00	2.00	76.41	75.20	1.57		
6	15.00	3.00	88.25	87.11	1.28		
7	20.00	4.00	94.44	95.71	-1.34		
8	30.00	6.00	105.6	106.9	-1.16		
9	45.00	9.00	117.1	115.9	0.973		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	19.44	0.616	-0.616	0.0317	11.99
2	78.96	0.901	-1.51	0.0114	71.16
3	64.72	2.36	-3.88	0.0365	153.3
4	112.7	5.61	-9.50	0.0498	633.2
5	130.3		-9.50		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

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YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Kano Hydro Drilling Company

LOCATION: Unguwar Worobaso Kargi LGA: Kubau

STATE: Kaduna State SCHEME: Handpump Borehole

BOREHOLE DEPTH: 47m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 5.50m PUMP SETTING: 30m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
		"	5.50	0.00		0	13.69	8.19
12.00	0	"	6.84	1.34		1	12.74	7.24
	1	"	7.71	2.21		2	11.82	6.32
	2	1.00	8.66	3.16		3	10.67	5.17
	3	0.97	10.42	4.92		4	9.54	4.04
	5	0.94	13.69	8.19		5	8.49	2.99
	10	0.90	13.69	8.19		6	7.68	2.18
	15	0.90	13.69	8.19		7	6.71	1.21
	20	0.90	13.69	8.19		8	5.50	0.00
	25	0.90	13.69	8.19				
	30	0.90	13.69	8.19				
12.30	40							

YIELD: 0.90L/S = 54L/Min = 3240L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Adamu Emishe

Sign/Date: 22/01/2016

YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Kano Hydro Drilling Company.

LOCATION: Unguwar Wurobaso LGA: Kubau

STATE: Kaduna SCHEME: Handpump Borehole

BOREHOLE DEPTH: 47m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 5.50m PUMP SETTING: 30m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
02.50	50	0.90	13.69	8.19				
	60	0.90	13.69	8.19				
	90	0.90	13.69	8.19				
	120	0.90	13.69	8.19				
03.30	150	0.90	13.69	8.19				

YIELD: 0.90L/S = 54L/Min = 3240L/H

REMARK: Productive Borehole

TESTED BY: Engr Hussain Abdullahi

INSPECTED BY: Adamu Emishe

Sign Date: 22/01/2016

10

UNG. YELWA DAUMALIKI VES 1

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	35.79	36.10	-0.880		
2	2.00	0.400	40.93	39.48	3.53		
3	3.00	0.600	40.49	42.56	-5.12		
4	5.00	1.00	46.76	45.25	3.22		
5	10.00	2.00	54.39	55.12	-1.35		
6	15.00	3.00	72.41	75.72	-4.57		
7	20.00	4.00	95.19	99.65	-4.69		
8	30.00	6.00	151.3	148.6	1.80		
9	45.00	9.00	239.9	221.6	7.65		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	35.14	1.26	-1.26	0.0359	44.38
2	67.76	1.32	-2.58	0.0195	89.60
3	24.66	3.15	-5.73	0.127	77.74
4	149.9	2.37	-8.11	0.0158	356.2
5	11814.0		-8.11		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

UNG. YEL-DAUMALIKI VES 2

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	59.55	59.18	0.621		
2	2.00	0.400	55.80	57.09	-2.32		
3	3.00	0.600	57.05	55.36	2.95		
4	5.00	1.00	53.25	54.37	-2.10		
5	10.00	2.00	62.30	61.33	1.55		
6	15.00	3.00	76.48	76.72	-0.322		
7	20.00	4.00	95.04	96.64	-1.68		
8	30.00	6.00	139.1	140.8	-1.22		
9	45.00	9.00	213.0	207.9	2.39		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	59.88	1.03	-1.03	0.0172	61.66
2	52.12	1.10	-2.13	0.0211	57.39
3	50.39	3.83	-5.96	0.0760	193.1
4	54.74	5.05	-11.02	0.0923	276.7
5	4498.0		-11.02		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

10

YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Kano Hydro Drilling

LOCATION: Sabon Garin Kusuntu LGA: Kubau

STATE: Kaduna State SCHEME: Handpump Borehole

BOREHOLE DEPTH: 45m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 5m PUMP SETTING: 24m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
04.00	0	‘’	05.00	0.00	06.30	0	14.55	9.55
	1	‘’	6.24	1.24	06.31	1	13.50	8.50
	2	‘’	7.30	2.30	06.32	2	12.63	7.63
	3	0.83	8.18	3.18	06.33	3	11.49	6.49
	5	0.70	10.15	5.15	06.34	4	10.38	5.38
	10	0.65	14.22	9.22	06.35	5	9.53	4.53
	15	0.40	14.30	9.30	06.36	6	8.42	3.42
	20	0.40	14.55	9.55	06.37	7	7.46	2.64
	25	0.40	0.64	9.55	06.38	8	6.51	1.51
	30	0.40	0.64	9.55	06.39	9	5.40	0.40
04.40	40	0.40	0.64	9.55	06.40	10	5.00	0.00

YIELD: 0.40L/S = 24L/Min =1440L/H

REMARK: Productive Borehole

TESTED BY: Engr. Hussaini Abdullahi

INSPECTED BY: Adamu Emishe

Sign Abdullah Date: 09/02/2016

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YOKE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

NAME OF CONTRANCTOR: Kano Hydro Drilling

LOCATION: Sabon Garin Kusuntu LGA: Kubau

STATE: Kaduna State SCHEME: Handpump Borehole

BOREHOLE DEPTH: 45m PUMP CAPACITY: 0.75Hp

STATIC WATER LEVEL: 5m PUMP SETTING: 24m

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPIMG BEGIN (Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
04.50	50	0.64	14.55	9.55				
	60	0.64	14.55	9.55				
	90	0.64	14.55	9.55				
	120	0.64	14.55	9.55				
06.30	150	0.64	14.55	9.55				

YIELD: 0.40L/S = 24L/Min =1440L/H

REMARK: Productive Borehole

TESTED BY: Engr. Hussaini Abdullahi

INSPECTED BY: Adamu Emishe

Sign Abdullahi Date: 09/02/2016

UNGUWAN ADEVES 1

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	338.2	329.8	2.47		
2	2.00	0.400	233.3	244.9	-4.97		
3	3.00	0.600	191.0	179.1	6.24		
4	5.00	1.00	123.8	126.5	-2.14		
5	10.00	2.00	89.90	88.91	1.09		
6	15.00	3.00	56.87	57.46	-1.05		
7	20.00	4.00	40.97	39.79	2.87		
8	30.00	6.00	30.89	33.20	-7.49		
9	45.00	9.00	45.87	43.50	5.14		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	359.6	0.988	-0.988	0.00275	355.6
2	134.8	0.859	-1.84	0.00637	115.8
3	71.75	1.05	-2.89	0.0146	75.39
4	189.4	2.91	-5.81	0.0154	552.4
5	9.87	8.88	-14.69	0.899	87.75
6	403.9		-14.69		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

UNGUWAN ADE VES 2

Schlumberger Array

Northing: 0.0 Easting: 0.0 Elevation: 0.0

No.	Spacing (meters) AB/2	MN	Data Resistivity	Layered Model: Synthetic Resistivity	DIFFERENCE	Smooth Model: Synthetic Resistivity	DIFFERENCE
1	1.00	0.200	438.2	448.6	-2.37		
2	2.00	0.400	334.8	317.7	5.10		
3	3.00	0.600	234.8	242.7	-3.37		
4	5.00	1.00	200.8	209.8	-4.47		
5	10.00	2.00	189.8	166.1	12.49		
6	15.00	3.00	98.09	107.3	-9.47		
7	20.00	4.00	68.90	71.40	-3.63		
8	30.00	6.00	56.89	50.52	11.19		
9	45.00	9.00	50.90	54.97	-8.00		

NO DATA ARE MASKED

Layered Model

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
1	502.9	0.932	-0.932	0.00185	468.9
2	136.2	0.657	-1.58	0.00482	89.52
3	119.0	0.561	-2.15	0.00472	66.84
4	342.2	3.39	-5.54	0.00993	1163.1
5	17.18	7.33	-12.88	0.426	126.1
6	95.22		-12.88		

ALL PARAMETERS ARE FREE

Prepared for Unregistered Version

)KE ENGINEERINMG SERVICES NIG. LTD.

WATER SUPPLY SECTION

OF CONTRANCTOR: Maihali Nigeria Limited

TION: Haying Ade LGA: Kubau

: Kaduna State SCHEME: Handpump Borehole

HOLE DEPTH: 47m PUMP CAPACITY: 0.75Hp

C WATER LEVEL: 5.60m PUMP SETTING: 30m

CONSTANT DISCHARGE				RECOVERY PERIOD			
ME NCE JMPIMG EGIN Min)	DISCHARGE RATE L/sec	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)	TIME (Min)	TIME SINCE PUMPING STOPPED (Min)	WATER LEVEL BELOW DATUM (M)	DRAW DOWN (M)
0	''	5.60	0.00	11.00	0	12.84	7.24
1	''	6.71	1.11	11.01	1	11.63	6.03
2	''	7.84	2.24	11.02	2	10.92	5.32
3	1.05	8.92	3.32	11.03	3	9.71	4.11
5	1.00	10.46	4.85	11.04	4	8.64	3.04
10	1.00	12.66	7.06	11.05	5	7.73	2.13
15	1.00	12.84	7.24	11.06	6	6.80	1.20
20	1.00	12.84	7.24	11.07	7	5.60	0.00
25	1.00	12.84	7.24				
30	1.00	12.84	7.24				
40	1.00	12.84	7.24				

IELD: 1.00L/S = 60L/Min =3600L/H

EMARK: Productive Borehole

ESTED BY: Engr. Hussaini Abdullahi

NSPECTED BY: Nasiru Abubakar

ign A.Abdullahi Date: 08/02/2016

APPENDIX 3: RESISTIVITY AND CONDUCTIVITY RANGES FOR WEATHERING GRADES (Source: Hazell *et. al.*, 1992)

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

APPENDIX 4: WHO 2003 and 2011 Standard Permissible Limit for Physical and Chemical Parameters of Water for Drinking and Domestic Use

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

APPENDIX 5: Physical / Organoleptic Parameters (NIS, 2007)

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

APPENDIX 6: RESISTIVITY AND CONDUCTIVITY RANGES FOR WEATHERING GRADES (Source: Hazell *et. al.*, 1992)

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