GEOLOGY AND HYDROGEOLOGY OF PART OF MAKURDI SHEET 251 SW, NORTH CENTRAL NIGERIA

BY

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ABSTRACT

An integrated geological, geophysical and hydrogeological studies were carried out to investigate the groundwater potential and quality in part of Makurdi, North Central Nigeria. The study area is entirely sedimentary and is dominantly fine to coarse grained sandstone with varying amounts of silt and clay. The schlumberger array was used for the geophysical investigation with a maximum AB/2 of 100m. A total of 20 Vertical Electrical Sounding (VES) stations were established. The model curve types from the electrical resistivity plot include Q, A and H curves. Three to four major lithologic units comprising the top soil (laterite, clay or loose sand) and the subsequent layers comprising of either sandstone, clayey sandstone, clay or sandy clay. The best of these units as regards to groundwater potential is the uniform sandstone unit. Isoresistivity maps at depths of 20, 30 and 50m respectively were generated and revealed that a dominant part of the study area has a very good groundwater potential at shallow depths of about 20 – 30m; while at a depth of 50m, only the North-Eastern and South-Eastern parts of the study area have a good groundwater potential. Hydrogeological data were obtained from one hundred and ten (110) hand dug wells in the study area and thirty five (35) water samples comprising ten (10) boreholes, twenty four (24) wells and four (4) river samples were collected for physic-chemical and bacteriological analysis. The depth of wells in the study area ranges from 0.71 – 8.4m with water elevation ranging from 0.3 – 8.3m and water column ranging from 0.3 – 5.5m. Most of the hand dug wells are shallow and seasonal; the boreholes however are productive all year round. Eleven (11) out of the thirty-five (35) water samples collected did not meet the Nigerian Standards for Drinking Water Quality (NSDWQ 2007) and hence not considered safe for drinking except after adequate treatment. Hydrochemical plots such as Piper, Durov and Gibbs plots were used for classification of the water type and identification of the hydrochemical processes involved in the groundwater chemistry. From the Piper plot, 57.1% of the water samples belong to the Alkaline water type while 42.9% belong to the Earth Alkaline Water type. The Durov plot indicated that the basic hydrochemical process responsible for the chemistry of the groundwater is simple dissolution or mixing with subordinate hydrochemical process of reverse ion exchange of Na-Cl waters. The Gibb's plot indicated that the major geological process controlling the water quality or chemistry is rock weathering with influence of evaporation. Recommendations given include; hand dug wells should be constructed to a depth of at least 9m, however, in areas where the water table appears to be deeper, boreholes should be sunk and the abandoned water works project for supply of pipe-borne water should be revisited by the government. Areas where water is contaminated should adopt adequate treatment measures before consumption and if treatment tends to be too expensive; then alternative means of supply of potable water (boreholes, water tankers) should be considered.

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ABBREVIATION, GLOSSARIES AND SYMBOLS

GPS:	Global Positioning System
LGA:	Local Government Area
Mg/L:	Milligram per Litre
NGSA:	Nigeria Geological Survey Agency
NIMET:	Nigerian Meteorological Agency
NSDWQ:	Nigerian Standards for Drinking Water Quality
pH:	Potential of Hydrogen
TCC:	Total Coliform Count
TDS:	Total Dissolved Salts
WHO:	World Health Organization
WL:	Water Level
VES:	Vertical Electric Sounding

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Water being an elixir of life is a commodity which controls our every day to day existence. However not all available water can readily be put to use by man as the use of water by man depends a great deal on the quality and quantity of such water. The quality of water is also a function of the source from which such water is gotten. The natural dispensation of water on the earth determines to a large extent the source of water that is of most benefit to man. The ocean/sea accounts for almost about ninety-seven percent (97%) of the global water distribution, glacier accounts for two percent (2%), groundwater accounts for less than one percent (0.67%) while the remaining 0.39% goes to surface water and other sources (Gleick, 1993). From the above information; it draws to limelight the importance of groundwater as a means of supply of freshwater owing to its relatively high abundance, less proneness to contamination and natural filtration associated with its process of storage.

How fast groundwater flows is a factor dependent on; the size of pore spaces in the soil or rock, the interconnectivity of the pore spaces and often times on the topography. Groundwater may be brought to the surface naturally through a spring or can be discharged into lakes and streams. Nevertheless, groundwater can also be harnessed artificially by drilling of wells into the aquifer. The volume of groundwater in an aquifer, its extent, depth and thickness of water bearing sediments can be estimated by measuring water levels in local wells; through geophysical surveys and by examining the geologic records from already drilled wells.

Groundwater is a cryptical nature's treasure. Its exploitation has continued to remain a crucial issue due to its mostly unalloyed nature and relative abundance. Though there are other sources of water which includes streams, rivers, ponds, just to mention a few; none is as hygienic as groundwater. This is due to the excellent natural microbiological quality and generally adequate chemical quality groundwater possess for most uses (Macdonald *et al*., 2002). Therefore, to untangle the mystery of groundwater, a detailed geophysical and hydro-geological understanding of the aquifer types and their spatial location are paramount in order to characterize the hydrogeological zones in an area.

Makurdi is basically a sedimentary environment (Geological Survey of Nigeria, 1994) and groundwater in the sedimentary environment is usually contained in the porous and permeable formation (Offodile, 2002). Consequently, such geologic setting requires a critical understanding of the hydrogeology and integration of geophysical data types to effectively characterize the hydro-geologic zones and to enhance successful identification of well locations (Omosuyi, Adegoke and Adelusi 2008).

Although electrical resistivity method has been used immensely for hydro-geologic investigations Ajayi and Hassan (1990); Olaleye (2005) and Alile *et al.* (2008), the use of other supplementary approach such as well data acquisition and other groundwater inventories were also used to complement and further aid the hydrogeological characterization of the study area.

In this study, geophysical and hydrogeological mapping of some selected areas in Makurdi L.G.A of Benue State was carried out using Electrical Resistivity prospecting technique along with hydrogeological and hydrochemical analysis of groundwater inventories. This was done with a view to investigating the groundwater potential, groundwater quality and most importantly recommend the most prolific aquifer type(s) capable of providing adequate and good quality water for the people of the area.

1.2 Statement of the Research Problem

Makurdi (the study area) basically depends on groundwater as the major source of water for the populace. With the exception of the few living around the province of the River Benue, all other areas depend on groundwater for its sustenance. The government is making effort to supply pipe borne water by constructing a new waterworks which however is yet to be completed and as such, a dominant fraction of the populace depend on groundwater which is not readily available both in quantity and quality.

Groundwater in the study area is harnessed through hand-dug wells and boreholes with a dominance of hand dug wells as this is cheaper to construct. However, this have not been able to solve the water supply problem as most of the wells dry up during the dry season (seasonal wells). This seasonal nature of the wells may be due to the fact that the wells are not dug to reach the water table or depletion of the water table as a result of excessive dependency (overuse) on the groundwater. This is however subject to verification from this research work. Furthermore, groundwater is vulnerable to pollution from domestic, municipal, industrial and agricultural activities; the groundwater in the study area is not an exclusion from these tendencies of pollution. Therefore, this study is carried out with a view of investigating the potential as well as quality of the groundwater of the study area. This would aid in tendering solution to the water scarcity/shortage in the study area and also reveal the safety health-wise and otherwise associated with the usage of groundwater in the study area.

Tentatively, this study would attempt to answer the following research questions:

i. What constitutes the geology of the study area (Makurdi)?

ii. What is the groundwater potential of the study area?

iii. What are the factors that determine the groundwater potential and what techniques can be used to determine them?

iv. Can electrical resistivity geophysical method and hydrogeological inventory technique prove useful in the determination of the factors affecting groundwater potential of the study area?

v. What is the quality of the groundwater in the study area?

vi. If water is polluted, what is the possible cause and what is the possible remediation?

vii. What is the feasible solution to the provision of portable water in the study area?

1.3 Justification for the Research

The provision of clean water and sanitation is goal number six (6) amongst the strategic goals of the Sustainable Development Goals (SDGs) set by the United Nations General Assembly in 2015. The importance of potable water to the overall wellbeing of man need not be overemphasized as economic improvement and productivity can only be achieved when man is healthy. Groundwater is a resource that can become contaminated from anthropogenic sources including during its development as a result of which its quality cannot be undermined. The availability of water is one factor but its safety for a particular usage is another important factor which cannot be ignored. This research therefore is focused on generation of reliable data on the groundwater potential and groundwater quality of the study area.

1.4 The Study Area

1.4.1 Location, Extent and Accessibility

Benue State is a state within the middle belt region of Nigeria and covers a total landmass of about 34,059km^2 and is located between latitudes 06^{0}25'00''N and 08^{0}08'00''N and longitudes 7^{0}47'00''E and 10^{0}00'00''E. It is named after the Benue river and was formed from the former Benue-Plateau state and some part of Kwara State in 1976. However in 1991, some parts of the then Benue state were carved out to become part of the new Kogi state. Benue state shares boundaries with six other states namely; Nassarawa State to the north, by Taraba State to the East, by Cross River and Ebonyi States to the south, Enugu State to the south-west and by Kogi State to the west (Figure 1.1). The state is populated by several ethnic groups: Idoma, Tiv, Igede, Etulo, Abakpa, Jukun, Hausa, Nyifon and Akweyan with the Tiv as the dominant ethnic group. The Tiv occupy fourteen of the twenty three local government areas while the remaining nine is occupied by dominantly the Idoma and Igede. Most of the people are farmers while the inhabitants of the river areas engage in fishing as their primary or secondary occupation. It has a population of about 4,235,641 in 2006 census. Benue State is a dominantly sedimentary environment with sediments which have undergone varying degrees of metamorphism and are underlain at variable depth by Basement Complex rocks. The sediments are dominantly sandstone but with sparse distribution of shale, siltstone, limestone and quartzite.

However the study area in particular is in the North-western flank of Makurdi Local Government Area which happens to be the capital of the state and is a monolithologic environment of indurated sandstone. Makurdi has a population density of over 380 person per km^2 (Nigeria Data Portal, 2006). The study area lies between latitudes $07^0$42'25"N and $07^0$45'00"N and longitudes $8^0$30'00"E and $08^0$32'30"E covering a landmass of about $16.25km^2$. The topography of the study area is generally low-lying (70-250m) with dominance of undulating plains and occasional elevations of between 400m to 600m above sea level (Offodile, 2002). The study area is accessible by major roads, railways and footpaths.

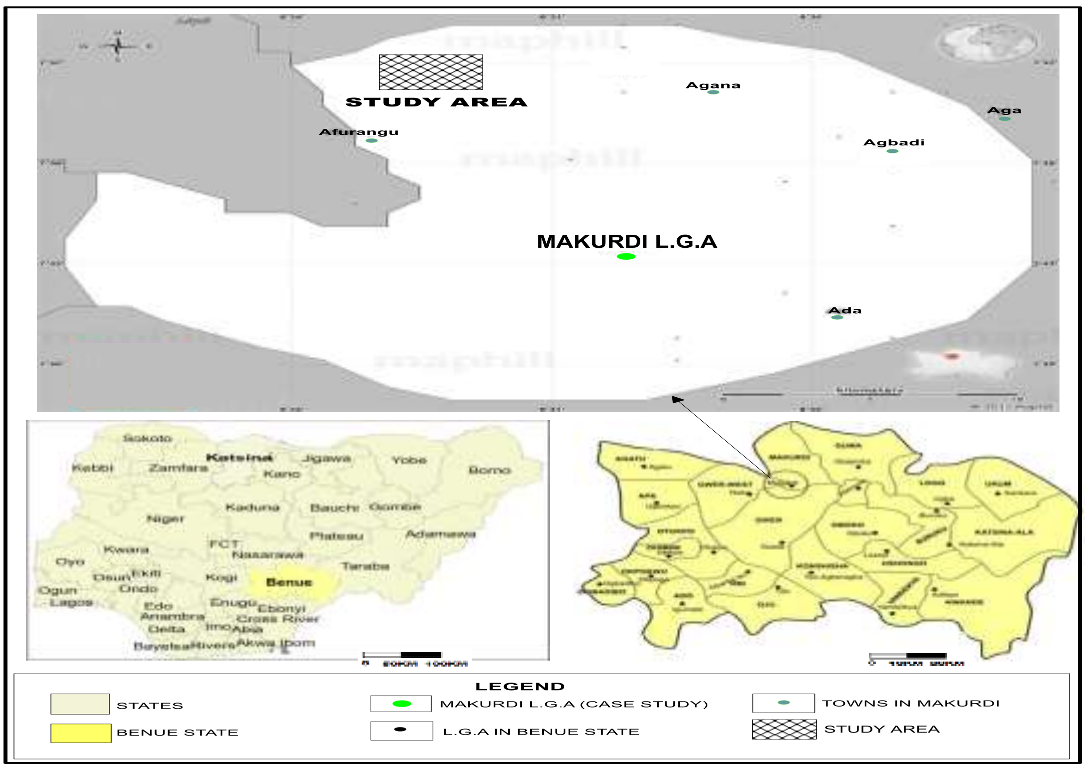


Figure 1.1: Location of study area

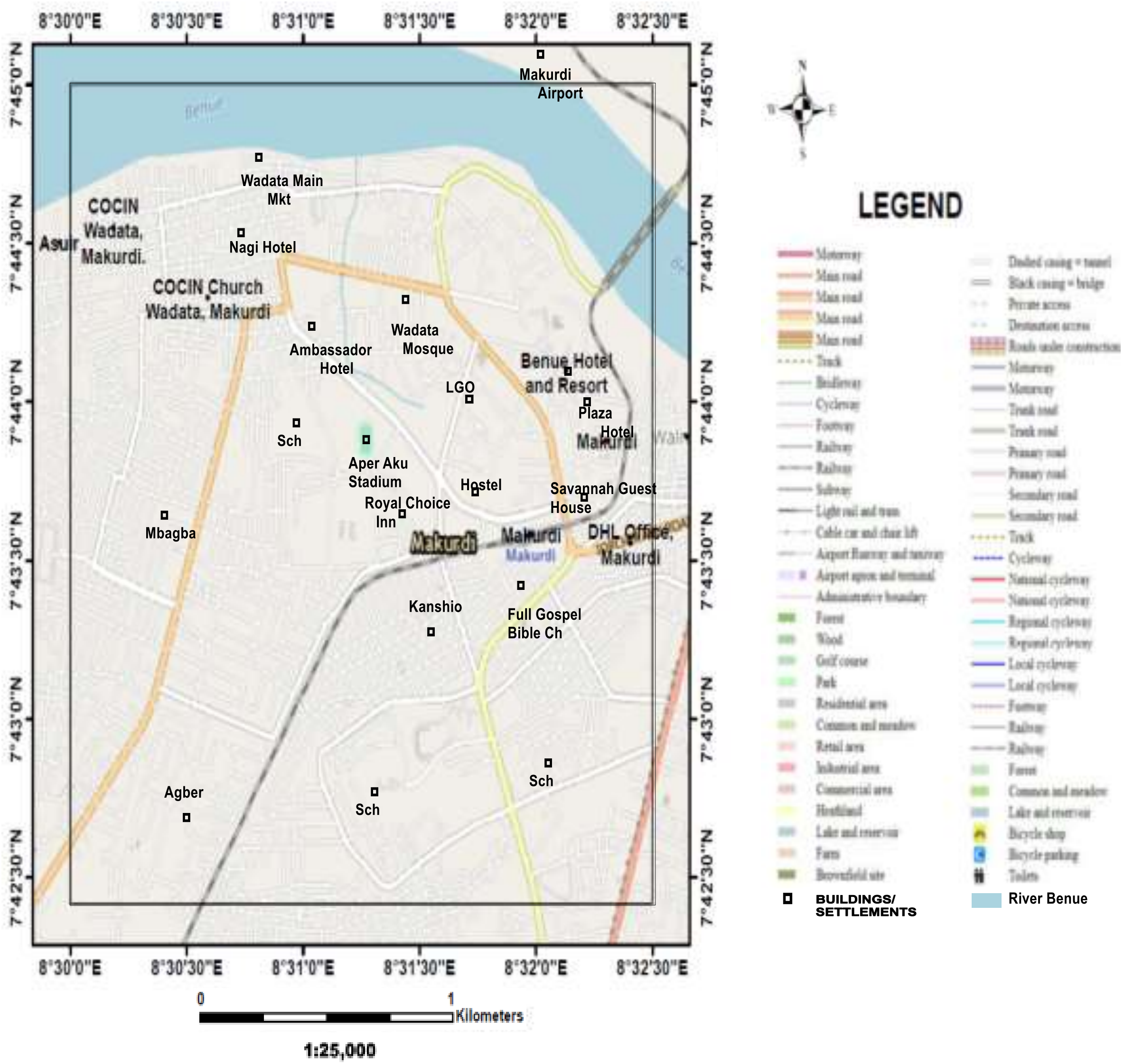


Figure 1.2: Study area

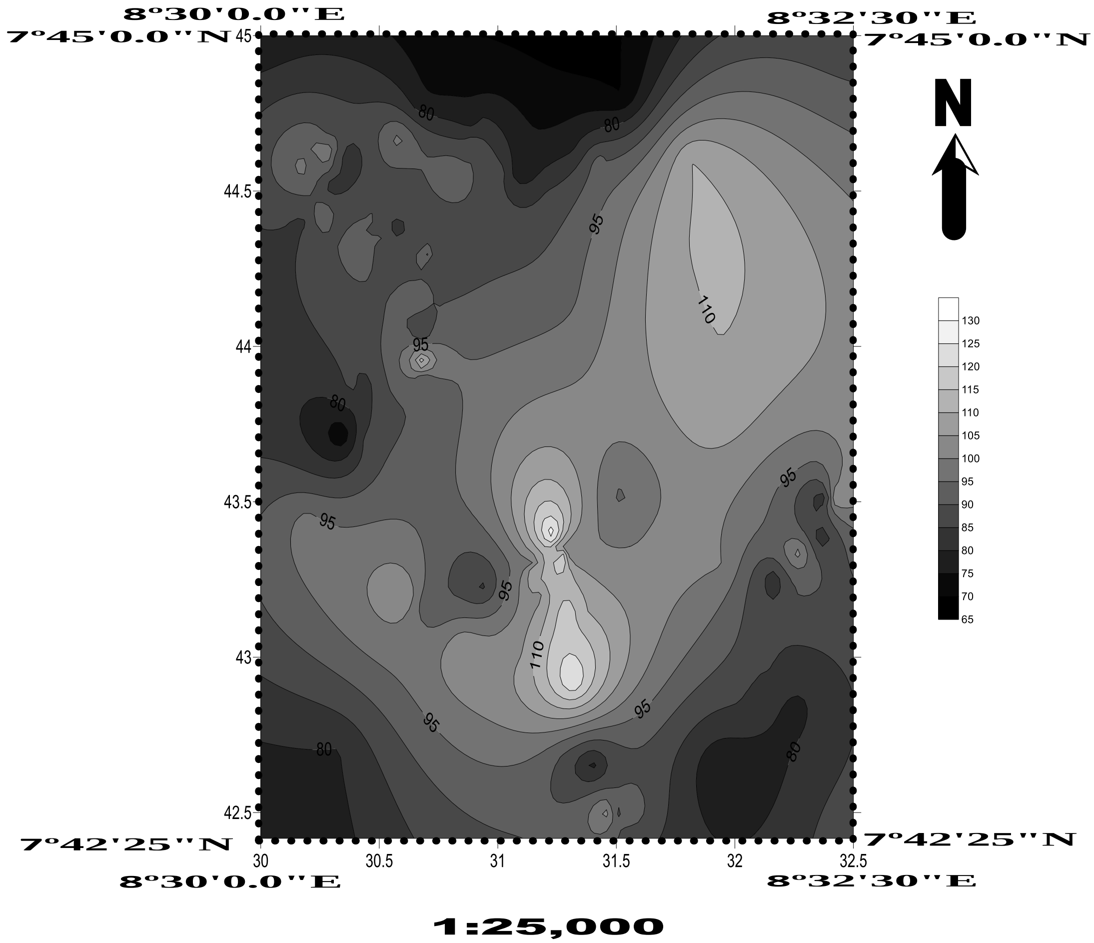


Figure 1.3: Topographical map of the study area

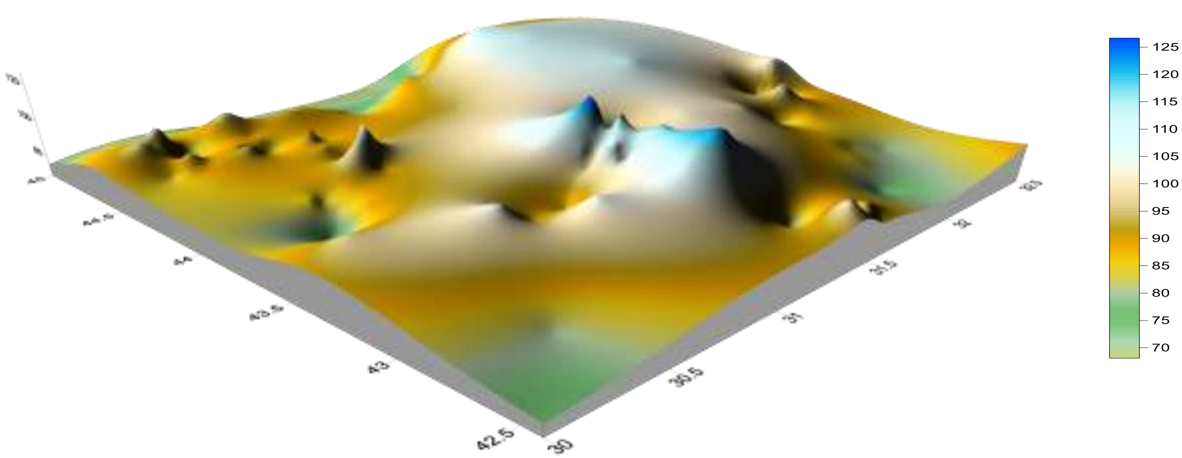


Figure 1.4: 3D Surface relief of the study area

1.4.2 Climate

Benue state has a Tropical subhumid climate with two distinct seasons; the wet and dry season. The wet season usually commences from March/April and terminates by end of October lasting for about seven to eight months. The dry season commences from November to March/April lasting for about four to five months. Rainfall is governed by the relative movement of inter tropical convergence zone (ITCZ). It has an annual total rainfall range of 1200mm – 1500mm. Temperatures are generally very high during the day, particularly in March and April. The annual maximum temperature ranges from 33ºC to 33.96ºC while the annual minimum ranges from 21.58ºC to 23.15ºC (Nigerian Meteorological Agency Tactical Air Command Headquarters Makurdi).

Table 1.1: Average rainfall, temperature and relative humidity from 1996 to 2010 (Nigerian Meteorological Agency).

Year	Rainfall (mm)	T-Max (°C)	T-Min (°C)	Rel. Hum (%)
Year 1996	94.1	34.7	19	51.7
Year 1997	109	35.8	21.8	80.2
Year 1998	129.7	36.3	24.3	81.8
Year 1999	131.2	35	24.5	82.6
Year 2000	103.8	32.5	22.5	67.2
Year 2001	90.2	30.5	22.3	79.2
Year 2002	107.3	30.0	22.3	76.8
Year 2003	63.5	29.7	22.3	44
Year 2004	85.5	30.0	21.6	58.5
Year 2005	72.6	31.9	21.6	57
Year 2006	116.3	34.0	21.0	80.2
Year 2007	111.5	34.6	17.5	79.2
Year 2008	87.5	30.2	23.2	57
Year 2009	124	36.1	21.2	80.5
Year 2010	91.8	36.8	22.4	68.7

T-Max = Maximum Temperature, T-Min = Minimum Temperature, Rel. Hum.= Relative Humidity.

Table 1.2: Monthly Rainfall, temperature and relative humidity (Nigerian Meteorological Agency, 2010).

Month	Rainfall (mm)	Temperature (°C)	Relative Humidity (%)
January	0.0	27.6	87.1
February	0.0	32.1	68.8
March	3.0	32.0	68.9
April	180.1	29.7	85.6
May	190.3	27.85	86.9
June	239.6	26.9	87.5
July	86.1	26.5	87.8
August	275.3	26.6	87.8
September	140.5	27.0	87.5
October	280.1	26.7	87.7
November	1.2	27.1	87.4
December	0.0	25.6	88.4

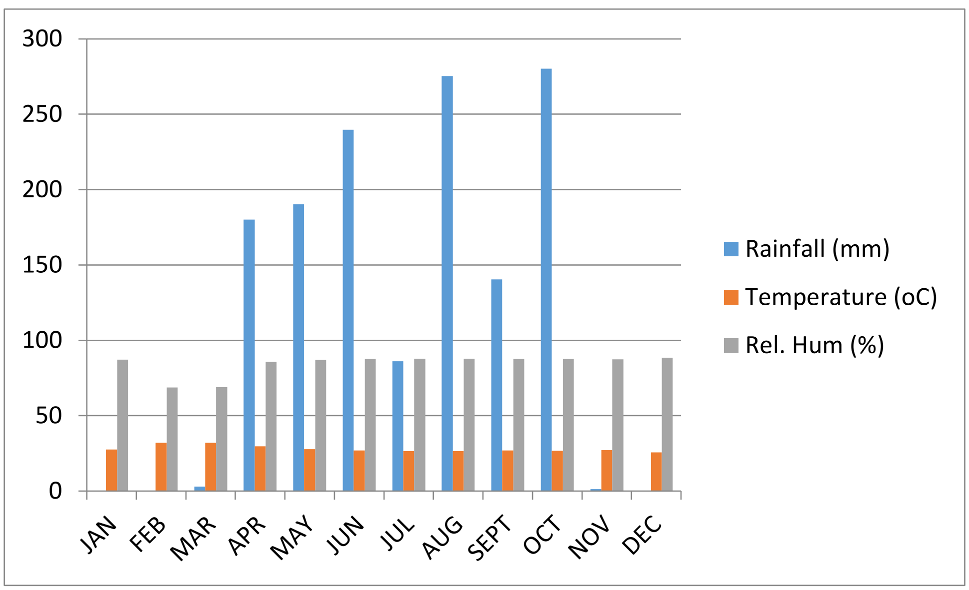


Figure 1.5: Chart of Monthly Rainfall, Temperature and Relative Humidity for the year 2010.

1.4.3 Vegetation

The vegetation is characterized by the Guinea savannah in the eastern and northern parts with mixed grasses and trees that are generally of average height. It is however characterized on the western and southern fringes by Tropical rain forests comprising of tall trees, oil palm trees and tall grasses.

1.4.4 Drainage

Benue state has a dendritic drainage pattern with River Benue as the dominant geographical feature and the major river into which other river tributaries discharge into. Katsina Ala river is the largest tributary, while other smaller river tributaries include the following Mkomon, Amile, Duru, Kpa, Mu, Okpokwu, Loko, Konshisha, Aya, Apa, Be, Ombi and Ogede. The flood plains are characterized by fine sands, silt and clay.

1.5 Aim and Objectives

The aim of this research work is to investigate the geological setting, the groundwater potential and quality of part of Makurdi area.

The objectives are:

i. To reveal the subsurface stratification.

ii. To generate a geological map of the study area.

iii. To produce hydrogeological maps of the study area.

iv. To determine the groundwater quality of the study area.

1.6 Scope of the Research

This research work would involve detailed geological, geophysical and hydrogeological mapping of the study area. Groundwater quality of the study area would also be assessed. The limitations of this work includes; urbanization which limited the depth of investigation during geophysical data acquisition due to limited space and ethnic, political and religious barrier during well data acquisition especially due to the high state of insecurity in the country. Secondly, the research work was carried out during the dry season, therefore data for rainy season were not obtained which would have aided seasonal comparison and proper understanding of the groundwater potential of the study area.

1.7 Organization of Study

This study would be laid out in 5 chapters. Chapter 1 presents background information on the study which includes statement of the problem, aim and objectives, justification and study area (climate, relief, drainage and vegetation). Chapter 2 discusses the literature review and the geology of the area. Chapter 3 presents the methods and processes employed in conducting the research. Chapter 4 is the presentation, analysis and discussion of results and the last chapter (chapter 5) is the conclusion and recommendations.

CHAPTER TWO

2.0 REVIEW OF RELATED LITERATURE

2.1. Review of the Geology of Nigeria.

The Nigerian geology is divisible into three

1. The Precambrian Basement Complex
2. The Younger Granite Ring Complex
3. The Cretaceous Sedimentary Basins

The Basement Complex outcrops in over about 50% of the total surface area of the country while the cretaceous and younger sedimentary rocks overlie the crystalline rocks in the remaining surface area of the country. The Basement Complex is exposed in four regions of the country; in North-western, North-central, South-western and Eastern regions (Ajibade *et al.*, 1988). The Eastern region of the Basement Complex is divided into three segments, by the sedimentary rocks of the Benue trough. A number of younger granite complexes of the Mesozoic age intrude the Basement Complex of the North central region while the sedimentary rocks occur in sedimentary basins.

2.1.1 Basement Complex

The Nigerian basement is divided into three broad lithological groups viz:

a. The magmatic – gneiss – quartzite complex: This group is the most widespread and occupies about 30% of the total surface area in Nigeria (Rahaman, 1988). It is a heterogenous rock group and comprises largely of migmatitic and granitic gneisses; basic schist and gneisses; and relicts metasedimentary calcareous, quartzitic and granulitic rocks of various origins and a series of metamorphosed basic and ultrabasic rock represented by amphibolites and talc schist. In Nigeria, it has been demonstrated particularly in Minna area that there are two types of Migmatites; those that were formed by high grade metamorphism and anatexis and those that were formed by magmatic injection (Rahaman and Ocan, 1987). Definite metasedimentary rocks are represented by quartzites marble and mica schist (Wilson, 1972; Russ, 1957; Jones & Hockey, 1964). The metasedimentary rocks have been referred to as the older metasediments by Oyawoye (1964), and Mc Curry (1967). The rocks have been metamorphosed in the middle to upper amphibolites facies; Russ (1957). The ages of this group of rocks vary from Archean to Pan – African (Grant, 1970, 1971; Ogezi, 1988).

In comparison to its abundance this is probably the least studied of the major rock groups. There are perhaps several reasons for this anomaly. Firstly, strong deformation and migmatitic processs have intended to drag different rock units of possibly different ages and origins into parallelism such that rock contacts are often mutually conformable. A simple banded structure is thus commonly observed in outcrops and because of this, this rock group is quickly walked over by most field geologists. Careful studies of this rock group in areas of less intense deformation often reveal a long and complex history of evolution. Attempts to unravel this history are based on ability to recognize episodes of dyke or vein formation.

Rahaman and Ocan (1978) recognized at least a series of events in the migmatite-gneiss-quartzite complex which includes:

- Emplacement of dolerite dykes (youngest)
- Undeformed to slightly deformed pegmatite, quartz veins and dykes,

- Emplacement of basic dykes and mangerite schist.
- Emplacement of microgranodioritic and dioritic dykes
- Emplacement of granitic gneiss and pegmatite
- Emplacement of microgranodioritic dykes
- Emplacement of mafic to ultramafic rocks
- Emplacement of aplitic sheets
- Formation of early gneiss
- Igneous and/sedimentary activity (oldest)

Most authors on the Nigerian Basement Complex subscribe to the view that the rocks of the migmatite-gneiss-quartzite complex comprise largely a sedimentary series with associated minor igneous rocks which has been variably altered, by metamorphic, migmatitic and ganitic processes (McCurry, 1976)

b. The schist belts: This group consists of metasedimentary and metavolcanic rocks which occupy N-S trending belts in the western half of Nigeria. The schist belts are best displaced in North – Western Nigeria where each formation occupies a discrete belt separated from the others by the migmatite – gneiss complex (Ajibade, 1988). They are in places demonstrated younger than the migmatite – gneiss complex, but they are intruded by the older granites. They range in age from proterozoic to earliest phanerozoic (Egbuniwe, 1982). Ten schist belts have been described in the North Western Nigeria and they include the Anka, Maru, Kushaka, Zuru, Wonaka, Malun-Fashi, Birnin – Gwari, Ushama, Kazaure and Toto belts (Ajibade *et al.*, 1987). In the South – Western region four schist belts have been described. They include Ife – Ilesha, Egbe – Isanlu, Kabba – Lokoja, Igarra, Iseyin Oyan schist belts (Turner, 1983; Ajibade *et al.*, 1987). Relatively smaller schist bodies have also been described from the Mambilla plateau (Carter, 1963) and the Oban Massif (Ekwueme, 1985)

c. Syntectonic to late tectonic older granite suite: This intruded both the migmatite gneiss complex and rocks of the schist belts. The older granite suites includes: Porphyritic biotite granite and granodiorites, diorites, gabbros, charnockites and syenites (Russ 1957, Mc Curry *et al.*, 1976 and Fitchers *et al.*, 1985). The most abundant are the granodiorite; Pan African (600 ±150 ma) ages.

2.1.2 Younger-Granite Ring Complexes

The ring complexes are of Jurassic age and intruded the late Precambrian to lower Paleozoic to lower Paleozoic basement rocks of Northern Nigeria in a N-S zone, the complexes probably represent the root zones of the ancient volcanoes of the type character by calderas collapses (Kogbe, 1989). The dominant granites of the complexes range from aluminous to peralkaline in composition and they are associated with smaller amounts of syenites, gabbros and anorthosites. The younger granites of Nigeria in particular are famous for their tin (cassiterite) mineralization, which is mainly associated with the biotite granites. These rocks also contain significant quantities of the niobium – rich mineral columbite are in alluvial concentration. The peralkaline granites also contain accessory uranium bearing minerals which probably provided the primary source for the sedimentary uranium deposit of Niger (Wright, 1985).

2.1.3 Sedimentary Basins

The sedimentary basins of Nigeria consist of cretaceous to recent marine, transitional and continental deposits formed during several episodes of sedimentation, tectonism, trangression and regression. It constitutes about 50% of the rock types of Nigeria. There are six main sedimentary basins in Nigeria:

1. Benue trough
2. Bida basin
3. Niger delta
4. Dahomey basin
5. Sokoto (Illumeden) basin
6. Bornu (chad) basin.

Benue Trough: This is an intracratonic riftline sedimentary basin formed as a result of external forces and was formed within the continents cretaceous ages stretching in NE-SW direction and also resting unconformably upon the pre-cambrian basement.

Borno-Chad Basin: This is a sedimentary basin located in the North-Eastern end of the country and whose formation is related to the continental drift between the African and South American plates in which the two plates were moving in opposite direction.

Sokoto Basin: This basin is located in the North-Western end of the country and in the South-Western part of the Illeumeden basin and extends to Mali and the northern part of Benin republic. It was believed to have been created by epeirogenic movement within the cratonic crust from paleozoic to upper cretaceous time.

Dahomey Basin: This is located in both Republic of Benin and Southern Nigeria. It is separated from the Niger Delta by the Benin hingeline and Okitipupa ridge. Its formation is also related to the separation of the African and South American plate.

Bida Basin: This basin shares the same origin with the Benue Trough, that is, an intracratonic basin formed as a result of rifting. It is located in the Western part of Nigeria running through Niger State as well as Kogi State. It is divided into two parts namely: the Northern and Southern Bida basin.

Niger Delta: This is a marginal sag basin located in the southern part of Nigeria and is well known for its oil potential. Its formation is also related to the separation of African and South American plate. It’s made up of three prominent formations; the Benin, Agbada and Akata Formations.

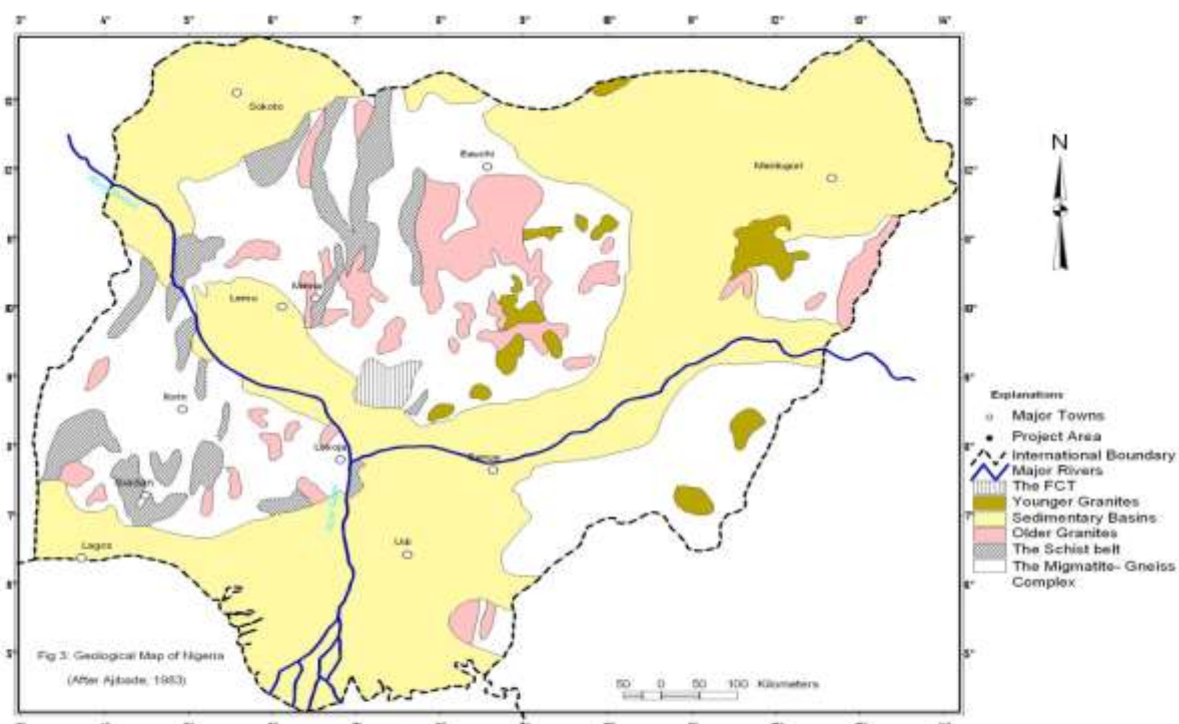


Figure 2.1: Geological map of Nigeria (Geological Survey of Nigeria, 1994).

2.2 Geology of Benue State.

Benue State falls within the Middle Benue Trough which is about 800km long and 80 – 150km wide. This Trough trends NE-SW structurally and is considered to have originated as an aulacogen (Hoque and Nwajide, 1984). The models as well as geology of the Trough as regards its origin have been proposed and described by various authors. From the different proposed models, the triple junction rift model (RRR) explicates that the trough originated as the failed third arm of a rift during the separation of South American plate from African plate during the cretaceous period. The two arms of the RRR rift system are thought to have formed the Atlantic ocean, and the third, the failed arm, is represented by the Benue Trough (Reyment, 1965; Grant, 1965; Burke, 1970; and Wright, 1981). However, Benkhelil (1982) and others ascribe the origin of the Trough to the onshore extension of equatorial oceanic fracture zones along the NW and SE margins of the trough. Benue Trough is divided into Upper, Middle and Lower sections each with varying stratigraphic successions. In the Middle Benue Trough, there is a crystalline basement which outcrops in some places and are characterized by many major and minor intrusive (Cratchley and Jones, 1965; McCurry, 1976). Benue State is underlain by both sedimentary and igneous rocks with a dominance of the sedimentary (Nwafor *et al.*, 1997). The Igneous rocks constitutes about 25% of the geology and are found in eastern parts of the state. The igneous rocks include basement intrusive and extrusives among which are gabbro, dolerites, basalts, diorite and rhyolites. They are Pre-Cambrian to Jurassic in age. The other 75% which is sedimentary constitutes the cretaceous sediments of various formations. These formations include the sediments of the Asu River Group and the Eze-Aku Formation. Recent alluvial deposits which include gravels, sand, silt and clay are found along the valleys and other low-lying areas. The area of study is however dominated by indurated Makurdi sandstone and with dispersed exposure of laterites. The topography of Benue State is generally low-lying (100-250m) with dominance of undulating plains and occasional elevations of between 1,500m to 3,000m above sea level (Offodile, 2002).

2.3 Groundwater Occurrence, Distribution and The Hydrologic Cycle

Water is in continuous circulation between the land, ocean and the atmosphere. However, we have water that participates in the hydrologic cycle (rainwater, river and lake water and groundwater) and that which does not participate in the hydrologic cycle (connate water).

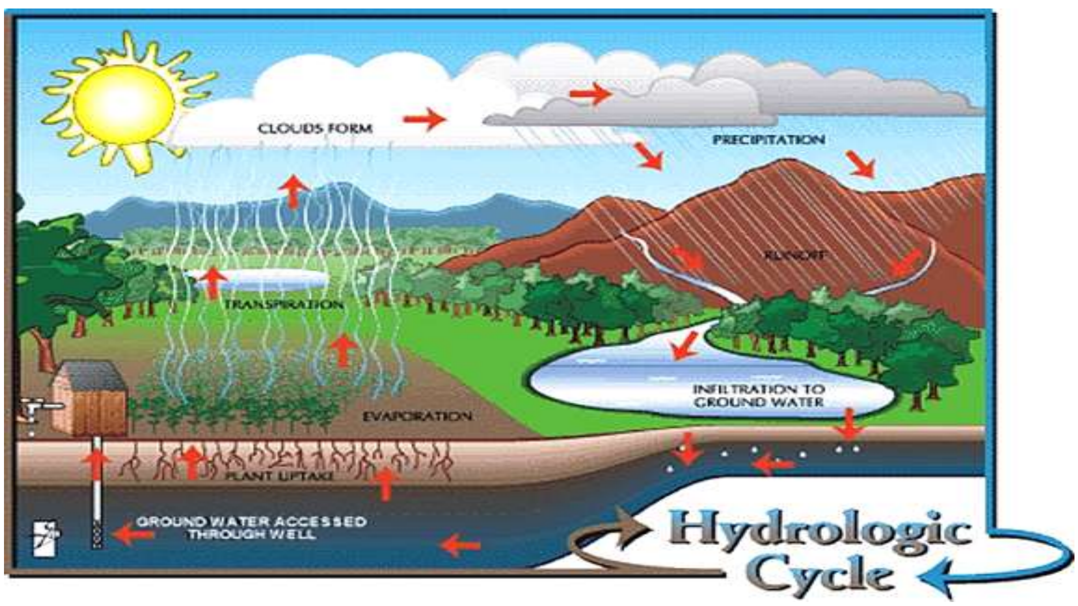


Figure 2.2: Hydrologic cycle (Gleick, 1993)

From the total amount of water that evaporates from the land and ocean; about twenty percent (20%) falls back as precipitation onto the land while the remaining eighty percent (80%) falls back as precipitation over the ocean. About sixty eight percent (68%) of water that goes into the hydrologic cycle over the land based portion leaves as evapotranspiration back to the atmosphere; about thirty one percent (31%) leaves as surface water discharge while the remaining one percent (1%) as groundwater discharge back to the ocean (Wei, 1986).

Water travels through different routes within the hydrologic system. Some initially flows overland into channels and eventually into streams before ultimately discharging out to the ocean. Some infiltrate into the ground and travel as groundwater and discharge either directly into the ocean or back to the land surface into streams and lakes. This therefore implies that water travels through both surface and subsurface routes. Groundwater flow is therefore one of the ways through which meteoric water moves through the cycle.

2.4 Groundwater Flow System

Groundwater flow results from differences in energy of the water (groundwater) from one point to another. Groundwater flows from a point of higher energy to a point of lower energy. The energy of the water at a particular point is a function of the potential energy, elastic energy and kinetic energy at that particular point. However, the kinetic energy can be ignored in most cases due to the typically very low groundwater flow velocity; making its effect quite negligible compared to the elastic and potential energy.

2.4.1 Darcy's Law

Darcy's law empirically describes groundwater flow quantitatively using experiments conducted by Henry Darcy in 1856 of water flowing through filter sands (Figure 2.3). Darcy observed from his experiment that for a given sand, the flow increased directly proportional to the difference in hydraulic head and inversely proportional to the length of flow.

Darcy's law can be expressed one dimensionally as:

$q = Q/A = -K\ dh/dl$

where Q = flow rate [L^3/T]

A = Cross sectional area through which water flow occurs [L^2]

q = Specific discharge or flow rate Q through cross sectional area A [L/T]

K = proportionality constant [L/T]

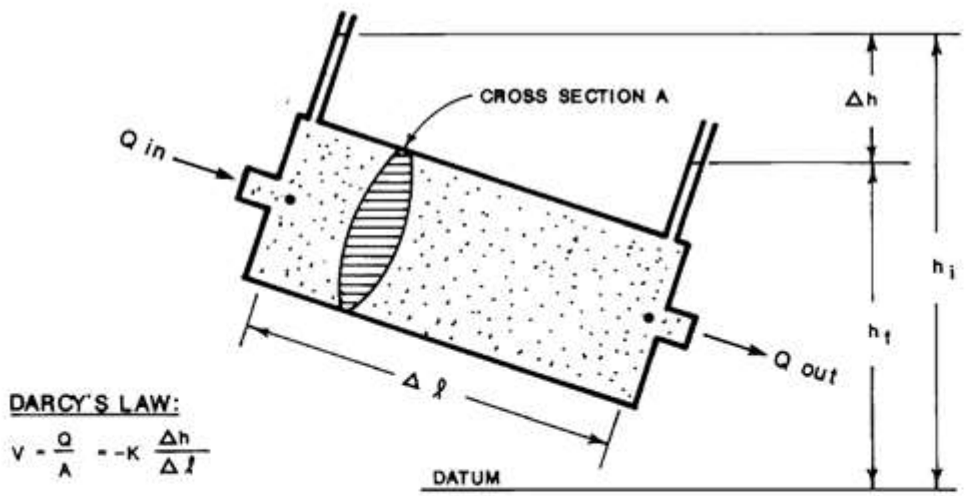


Figure 2.3: Darcy's experiment (Darcy, 1856)

From the figure above, the term $\Delta h/\Delta l$ is the hydraulic gradient and is the driving force for ground water flow. The negative sign, by convention, in Darcy's law signifies flow from a higher to a lower head. Any change in hydraulic gradient would result to a corresponding directly proportional change in the specific discharge. The proportionality constant (K) called the hydraulic conductivity is a combined property of viscosity and density of the fluid and the permeability of the porous medium. Therefore hydraulic conductivity is simply a measure of the ability of the fluid to flow through a porous medium.

Darcy's law is valid only for laminar flow at very low velocities and applies in most situations of groundwater flow through porous media. The law however ceases to hold when turbulent flow occurs. All quantitative groundwater analyses are established using Darcy's law as a basis. Equations for pumping test analysis, groundwater infiltration and contaminant transport all invoke Darcy's law.

2.5 Aquifer

Underground substrata have the capability of bearing water provided they are porous and permeable or unconsolidated (such as gravel, silt or sand) or they are discontinuous (faulted and fractured). Such water beneath the subsurface are held by geological units called aquifer and can be accessed using a hand dug well or borehole. Aquifers vary in depth; there are aquifers close to the surface and those at deep depth from the surface. Those closer to the surface are not only more likely to be used for water supply and irrigation but are also easily topped up by local rainfall. In general, the more productive aquifers occur in sedimentary geologic formations.

2.5.1 Aquifer Anatomy

An aquifer could be classified based on the morphology of its overlying layers/strata. The porosity, permeability and transmissivity of the overlying strata bounding an aquifer determines the condition of groundwater within that aquifer and hence its type. The characteristics of aquifers vary with the geology and structure of the substrate and topography in which they occur. Based on the aforementioned characteristics/properties of an aquifer; it can be classified basically into three (3) as follows:

a. Confined aquifer

b. Unconfined aquifer

c. Perched aquifer

Confined aquifer: This is an aquifer that is overlain by a relatively impermeable layer of a rock or substrate such as an aquiclude or aquitard. The water here is under high pressure if the confined aquifer follows a downward grade from its recharge zone. This can result to the generation of artesian wells where groundwater flow out freely from wells without the need of a pump and rise to a higher elevation than the static water table.

Unconfined aquifer: This is also sometimes referred to as water table or phreatic aquifer owing to the fact that their upper boundary is the water table or phreatic surface. Simply put; unconfined aquifers are aquifers without a confining layer (an aquiclude or aquitard) between it and the surface. They are in most cases the shallowest form of aquifer at a given location.

Perched aquifer: As the name implies, it refers to groundwater accumulating above a low permeability unit or strata, such as clay layer. It's used to refer to a small local area of groundwater that occurs at an elevation higher than a regionally extensive aquifer. The only major difference between perched and unconfined aquifer is in its size; perched aquifer is smaller.

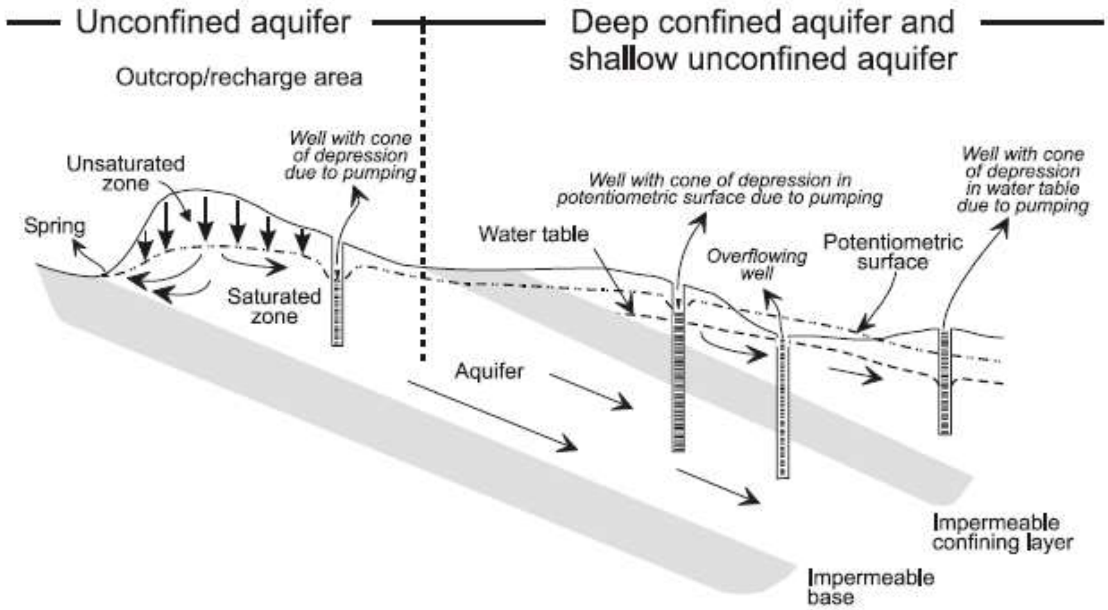


Figure 2.4: Schematic cross-section illustrating confined and unconfined aquifers (RSK Geophysics, 1999)

2.5.2 Importance of Aquifers

Aquifers play an important role in our day to day lives owing to the following under-listed facts (USGS, 2017);

a. We can only use about one percent (1%) of earth's surface water

b. About ninety-nine percent (99%) of all usable water is actually groundwater.

c. Aquifers provide ninety-nine (99%) of all groundwater

d. About fifty percent (50%) of all potable water comes from aquifers.

2.6 Geological Field Mapping

This entails all processes taken in the identifying of all the geological aspects in a selected area of interest with an aim of preparing a detailed geological report and a map to summarize all the investigations. The required information to be obtained during geological mapping includes but not limited to the following.

i. Various rock types of the region (Geology)

ii. Structural disposition of the region.

iii. Various geological formations

iv. Geochronology/Age relationships.

v. Fossil content of the region (where applicable)

vi. Distribution of mineral ore deposits and so on.

2.6.1 Essence of Geological Mapping

There are three basic reasons why geological field mapping is carried out and they are:

a. For exploitation of natural resources.

b. For academic purposes.

c. As a requirement of the government.

2.6.2 Phases of Geological Field Mapping

A good geological field mapping is executed in three phases for an effective result/report. Enlisted below are the three phases involved

a. The planning phase

b. The data collection phase

c. The reporting phase

Planning phase

This phase is also referred to as the desk study phase and is mostly carried out in the office although a short reconnaissance field trip may be included. This phase allows one to work out a workable field programme. This field programme is a step-by-step guide that outlines time to be spent in the field and the objectives of each day and thus ensuring successful and satisfactory results.

Data collection phase

This phase is carried out in the field for the sole purpose of collecting data. This data acquired could be in the form of measurements, photographs, notes as well as physical samples. One must ensure that he/she is equipped with all the necessary tools for acquisition of all these forms of data where necessary. One must also be very observant, physically psyched and mentally prepared to make note of not only geological features but of the entire surrounding.

It should also be noted by the geologist that a mapping project must be qualitative as well as quantitative. Therefore, accuracy whilst taking readings should be emphasized and all possible data should be collected as no amount of information is too much (Bolton, 1989).

Reporting

This is the most challenging phase of all the three phases as misinterpretation or wrong analysis of data can lead to an inaccurate report and inconsequence misinformation. In this phase, all possible available data collected is taken back to the office or laboratory for interpretation; sorting and analysis. It's a norm that "a report is as good as its data" and thus the need to collect good accurate data cannot be overemphasized.

2.6.3 Parameter to Consider in Geological Mapping

2.6.3.1 Geology

To map out the rock types; it's important to carefully lay out a plan for the entire location so that traverses can be made without leaving out some areas. Integrate study of topographical maps and aerial photographs can aid one to avoid areas that are impractical to traverse on foot or impossible to climb due to their steepy nature.

One must ensure that fresh samples without any alteration are collected. The size of the sample is a function of its intended use; which could be petrographic, X-ray analysis, whole rock analysis or just for reference. Samples collected for whole rock analysis should be broken using another rock from the same formation to ensure that it is not contaminated by metals from the geological hammer.

During the geological description of the rock; ambiguity should be avoided such that other observers given the same sample would describe it the same way (Wyllie, 1999). Moreso, every fine detail must be included whether it is deemed relevant or not geologically.

2.6.3.2 Strike and Dip

This is a technique of relating the orientation of a plane in three dimensional spaces. This technique is usually applied to the orientation of tilted layers of rock and thus one can easily see the deformation or disorientation a formation has undergone. This is done with the aid of a compass clinometer and is done severally to aid precision.

2.6.3.3 Geological Landforms

Features such as mountains/hills, calderas, crayons, craters e.t.c. and their dimensions should be obtained by actual measurement and adequately documented and accurately positioned on the maps.

2.6.3.4 Geological Structures

Structures like faults and fractures always indicate movement within the earth's crust and should be mapped meticulously as they could be easily confused with simple erosional surfaces. Other structures such as exfoliation, mineral veins (sills and dykes). This structure gives an insight to the geological processes that controlled the emplacement as well as the deformation of the rock or formation as the case may be. Therefore, it is imperative to be accurate in measuring all formations and structures with well calibrated equipment so that if extrapolations are to be made for modelling or exploitation purposes; the error margin would be very slim.

2.6.4 Compilation of a Geological Map

The accuracy and quality of the geological map produced from the geological field mapping depends a whole lot on the proper use of a GPS (Global Positioning System) and also proper interpretation using appropriate Geographic Information System (GIS) software. However, it is important for a geologist to draw a simple sketch map during fieldwork for comparison purposes. Since a map is basically a visual summary of an entire report and the two should complement each other; it should be compiled using standard symbols and colours that can easily be understood by other geologists and other related fields.

2.6.5 Geological Mapping Techniques

This depends on the aim of the investigation and the amount of time available for the field work. However, three things are mandatory in the output of whichever technique is to be adopted. The map so generated from any technique adopted must be:

a. Legible

b. Distinguish between observed facts and inferences drawn from the facts.

c. Readable by another geologist.

On a general basis, any technique adopted should involve the following steps

a. When one arrives at a rock outcrop; one should first find his position on the map. This could either be done using simple identifiable features on the base map or by resection of distant features using the compass to ray-in your position on the map.

b. The position should be marked on the map.

c. The lithology, general and special features of the rock (mineral composition, grain size, structures, degree of weathering and colour) should be noted.

d. If the rock is of sedimentary origin; the following should be noted:

   i. The diagnostic sedimentary structures should be examined

   ii. The geometry should be determined which would enable the reconstruction of the directions of transport of the sediment depositing current. The geometrical features includes cross bedding, ripple marks, bottom structures in turbidites; to mention a few.

iii. Primary sedimentation features should be examined to determine the younging direction of the beds (normal or overturned strata)

iv. Fossil content which gives an indication of rock age (zone fossils) or indicate the conditions of deposition (paleoecology).

v. Tectonically produced structures (cleavage, folds, joints, lineations e.t.c) and deformation markers should be searched for and examined to establish the principal strain directions and values.

e. Fresh samples are to be taken for further studies and analysis in the laboratory.

f. Photographs should be taken of important features and these photographs should be taken as close to the outcrop as possible. A scale should be included in the photograph and the subject feature should be focused in the field of view of the camera while taking the photograph.

g. Documentation and sketches of features should be done neatly, accurately and in detail in the field note book.

2.7 Hydrogeological Mapping

This constitutes all programmes and techniques that are suitable to collect, document, retrieve, plot, interpret and represent hydrogeological information in graphical form. Hence, hydrogeological maps when designed with the standard legend provide a common graphical language to both map makers and map users alleviating mutual understanding between them. It also serves as a very powerful tool for conveying information, particularly for planning and management as well as for education and public information with regards to groundwater.

Two distinct broad groups of hydrogeological maps can be distinguished, which correspond with the two main roles of the maps and their uses:

- General hydrogeological maps and groundwater systems maps associated with reconnaissance or scientific levels. They are suitable tools to introduce the importance of water (including groundwater) resources in the political and social development process;
- Parameter maps and special purpose maps which are used as a basis of economic development for planning, engineering and management. They differ greatly in content and representation according to whether they are designed for specialists or non-specialists in hydrogeology.

Both groups are closely interrelated and complementary. For instance, a general hydrogeological map cannot be compiled without information on the hydraulic parameters of rock bodies. Furthermore, specific hydrogeological knowledge will not be considered in development projects if politicians, planners and scientists are not aware of the crucial importance of groundwater, both in qualitative and quantitative terms, for development.

2.7.1 Basic Requirements for Hydrogeological Maps

Hydrogeological maps depict information on groundwater and the relevant rock bodies in relation to the earth's surface; that is topography. Therefore, some basic requirements must be satisfied, otherwise the map would be incomplete and useless.

First and foremost, the map must answer, as precisely as possible, the following basic questions:

a. What are the conditions in a certain place or area?

b. Where can I find what I am interested in?

And, at a more detailed level,

c. What quantitative and qualitative information is there, and where do I find it?

From these basic questions, it is clear that there are three fundamental requirements for the preparation of a hydrogeological map,

i. An adequate topographic base map

ii. A reliable hydrogeological and associated data

iii. A suitable representational scheme and map legend.

The topographic map is a basic element for any hydrogeological mapping programme. Its importance is twofold, first as a guide for orientation on the surface and secondly as a source of useful hydrological information, for example river network, watersheds and surface properties. The topographic base map must be up-to-date and contain all information essential to foster the understanding of the hydrogeological situation of the area mapped. An obsolete base map devalues a new hydrogeological map considerably, as it may lead the map user to the conclusion that merely careless and superficial work has been produced by the map maker. If a good topographic base does not exist or the map is outdated, input from the hydrogeologist himself or other helpful persons from cartographic and remote sensing units can help to update the topographic base map.

2.7.2 Hydrogeological Data Acquisition

Despite a wealth of hydrogeological data obtainable from various commonly scattered sources in most countries, it is rarely considered sufficient to prepare a reliable hydrogeological map. Reasons for this insufficiency are incomplete data sets, lack of data in particular areas, contradictory data in places and data measured by different incompatible methods. It is therefore, necessary to foresee additional data collection as an essential step in hydrogeological map preparation. However, any field work for producing new hydrogeological data should be carefully planned and priorities set for data collection before going to the field. A thorough pre-treatment and reinterpretation of the data available in archives, data banks and on maps is generally the best way to render the additional data collection most efficient.

The purpose and proposed content of the hydrogeological map exert, of course, influence on the decision as to which data should be considered important. Anyway, one should aim at complete and homogeneous data sets rather than focusing on just single parameters and variables.

2.7.3 Hydrogeological Field Inventory

Regardless of the scope of the maps, a minimum amount of data comprising a basic set is indispensable for the preparation of all types of maps. There are hydrogeological key points such as springs and wells which have to be surveyed in any case. Their exact location is of prime importance, to allow their correct siting on the hydrogeological map.

Certain hydrogeological data are to be considered essential since without them even basic hydrogeological maps (showing groundwater contours, salinity and depth-to-groundwater) could not be prepared properly. Such data includes:

- Observation point number or well number necessary for an orderly identification, storage, retrieval and plotting of the data. This identification number must be systematic and unambiguous.
- Location of wells and other inventories by coordinates using a Global Positioning System (GPS) necessary for exact plotting and orientation of points for repeated observation.
- Map sheet referenced to the regular coverage of topographic base maps at rather large scale (1:10 000 to 1:50 000), necessary to facilitate the numbering of observation points.
- Altitude of land surface should also be taken for computing the elevation of the groundwater table. The reliability must be qualified by mentioning the method of determination.
- Discharge of springs or base-flow of streams, necessary to estimate the natural discharge conditions of groundwater flow regimes.
- Depth to groundwater (sometimes called "static water level") necessary for computing the water table elevation in order to obtain indications of processes acting from land surface and vegetation on the groundwater (for example evapotranspiration),
- Elevation of groundwater table, essential for the construction of groundwater table maps, which enable the hydrogeologist to recognize the direction of groundwater flow, its gradient, and, together with topographical data, (surface water) recharge

and discharge areas. A groundwater table map is one basic requirement, together with values for transmissivity, to assess the quantity of groundwater flow. Note that in areas of perennial river runoff the river bed is the intersection of the groundwater table and the land surface.

- Type of well giving a first indication of the number of aquifers.
- Total depth of well indicating the relative position of an aquifer, and, in connection with depth to groundwater, the level head characteristic (for example whether confined).
- Salinity (deduced from field measurements of electrical conductivity) is a basic datum which indicates groundwater suitability.
- Date informing about the time of observations of either own field investigations or previous observers (this date does not necessarily correspond with the date of filling in the survey form).
- Source of data roughly describing the reliability of the data.

Both natural and anthropogenic features have to be portrayed together on a hydrogeological map to indicate the state of exploitation of groundwater resources and possible changes of the natural regime. This may produce lowering or rising water tables, migration of groundwater divides, changes in head distribution and the flow field, disappearance of artesian conditions and considerable changes of groundwater quality parameters; not to mention resulting changes at surface, such as land subsidence, drainage regime, or drying up of springs, lakes and rivers.

Hydrogeological maps of the same area showing a set of highly time dependent parameters (such as spring discharge, groundwater table or chemical ion contents) at different dates may look very different. Therefore hydrogeological maps should always make reference to a date or time period, and they have to be updated and re-issued from time to time.

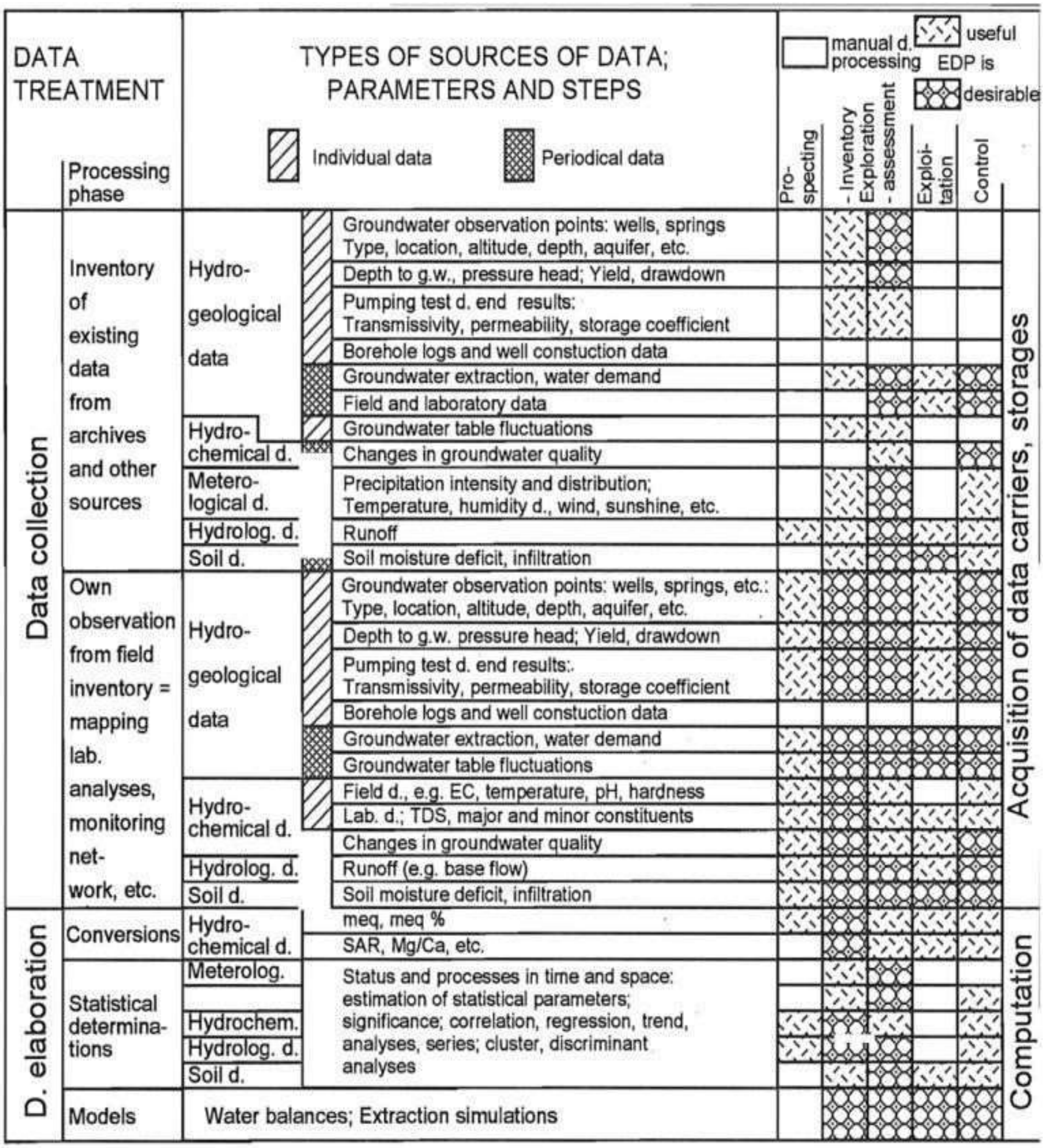


Figure 2.5: Scheme for the collection of hydrogeological data (RSK Geophysics, 1999).

2.7.4 Cartographic Representation of Hydrogeological Data and Scale

The generator of a hydrogeological map must be familiar with at least some important cartographic principles. This will avoid painful misunderstandings between the hydrogeologist and the cartographic draughtsman and ensure that the map be readable and follow cartographic standards.

The general sequence of cartographic preparation of a hydrogeological map is outlined in Figure 2.5. The map generator should contact the cartographic drawing unit in the initial phase of preparation, to seek advice and assistance both for the topographic base map as well as for the drafting of the thematic sheets. For more comprehensive, systematic mapping programmes involving many map authors. Managers should provide in addition to a general legend and a model map, instructions for the preparation of map manuscripts by authors. This will guarantee that map drafts meet an agreed standard and that the cartographic processing may be optimized, shortened and possibly automated.

All points on the map must be recognizable through their coordinates (latitude related to the equator and meridian related to the Greenwich meridian) and their altitude (related to datum sea level). Various projections and grids have been developed, each having particular advantages and disadvantages, but all aiming at fulfilling and optimizing the theoretical requirements that distances and surfaces should be exact in relative size and azimuths, and angles correct.

Decisions on the system of representation; mainly the legend to be applied and on the scale projection and suitable topographic base map must be made in the preparatory phase of a hydrogeological map project.

2.7.5 Degree of Interpretation

The data and information presented on hydrogeological maps may correspond with different degrees of treatment and interpretation. In general, the following five levels are distinguished:

(a) Basic data; that is results of direct observations or measurements that should be as objective as possible and depend only on the site and date.

(b) Primary derived data based on simple treatment and interpretation such as isolines derived from point data on water level or chemical parameters.

(c) Secondary data derived from (b) or more complex treatment and investigation methods such as statistics, computing, well tests, geophysics, including results of modelling, estimates of spatial variables deduced from numerical simulation methods, for example recharge, transmissivity and fluxes.

(d) Results of tertiary interpretation and classification, for example transformation of lithology into hydrogeological units, classification of productivities of aquifers, accessibility, exploitation cost, suitability of groundwater for special uses, etc.

Information always requires the availability of reliable data, a particular demand and skilful personnel to tailor the information both in content and in graphical expression for the user. Planners and executives are generally not interested in scientific hydrogeological details, nor do they know the hydrogeologist's terminology. Therefore, scientific data must be translated into a language, both graphical and verbal to enable the non-hydrogeologist to grasp the information he needs. Therefore, computer based interactive interpretation, transformation and visualization methods are very powerful tools to meet the demand of special users or user groups.

2.7.6 Types and Classification of Hydrogeological Maps

Hydrogeological maps and other graphic representations reflect the state of the art in hydrogeological knowledge and reflect the specific requirements of their users. A wealth of such material exists worldwide, which corresponds to the evolution in water science at various stages throughout the world. The level of data and information available on a map and the possible use of the map enables a number of types of hydrogeological maps to be distinguished (Struckmeier, 1989).

The types of hydrogeological maps in a broad sense are

(a) General comprehensive hydrogeological and groundwater resource potential maps

(b) Parameter maps (this type includes parameters and variables, as well as other basic data portrayed on single value maps)

(c) Groundwater systems maps

(d) Special aspect or purpose groundwater maps, including derived maps, such as vulnerability, suitability and protection maps.

However, the most common types of hydrogeological maps in a more simplified classification are:

i. Water level contour map
ii. Water level change map
iii. Depth to water map
iv. Water level profile map
v. Well hydrographs.

The growing widely-varying range of computer-derived graphical representations is an additional type which is developing rapidly in certain countries with access to good data bases and advanced geo-information system (GIS) technology.

2.8 Geophysical Investigation

Geophysical investigation techniques provide a toolbox of rapid, discrete and cost effective methods for the location and identification of subsurface features. Geophysical surveying may be used to pinpoint locations within a site in order to target with conventional intrusive investigation and it could also be used to eliminate the need for the disruption caused by boreholes, trial pits, cores or breakouts.

However, in every investigation, the appropriate geophysical technique must be used in the correct survey manner in order to maximise the ability of the survey to yield clear results. Furthermore, surveys should be designed and undertaken by qualified and experienced geophysical professionals who would make use of available instrumentation and software to provide the best possible interpretation in a timely and efficient manner. Well planned survey design tailored to the target and to the environment, can maximise the collection of unnecessary data, and can also prevent inconclusive or misleading interpretations.

There are various kinds of geophysical investigation depending on the properties of the subsurface material of interest. It is most preferable to use more than one geophysical method for investigation in order to improve the accuracy and efficiency of the obtained results.

For the purpose of this research work however, the electrical resistivity method would be discussed as this is the survey method employed for this research work.

2.8.1 Electrical Resistivity Survey Method

The basic theory of this method is based on fact that the electrical properties of the subsurface vary with the ground material, presence and saturation level of fluids and the presence of buried objects. This technique attempts to describe the distribution of these properties as a function of depth and horizontal distance.

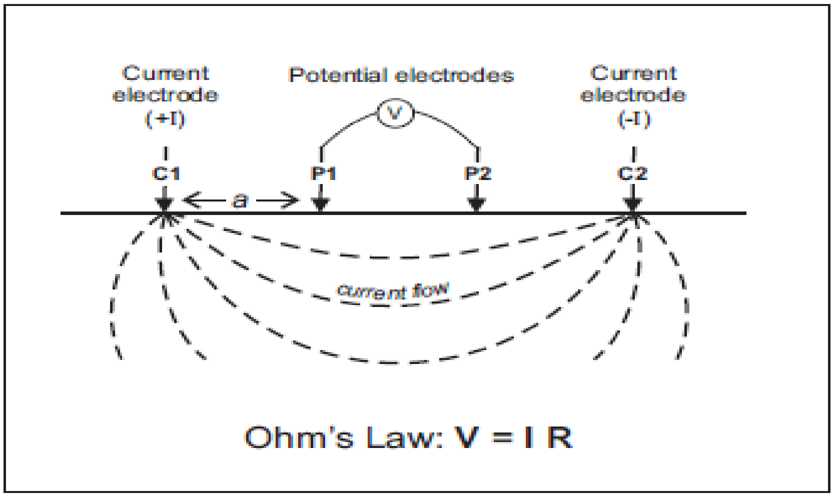


Figure 2.6: Generalized form of electrode arrangement in resistivity measurement (RSK Geophysics, 1999).

In this technique, the measurements of ground resistance are made by introducing an electric current into the subsurface via two current electrodes planted into the ground. The current passing through the ground sets up a distribution of electrical potential in the subsurface. The difference in electrical potential between two additional electrodes known as the potential electrodes is then measured as a voltage. This voltage is then converted into a resistance reading for the ground between the two potential electrodes using Ohm's law. The resistance is then multiplied by a geometric factor to obtain the resistivity. The resistivity plot is then obtained by either plotting manually or using appropriate software.

Subsequently, the interpretation of the plot is also done manually through curve matching or other manual interpretation technique through the use of appropriate software.

Application of electrical resistivity techniques includes but not limited to the following:

i. Stratigraphic mapping.
ii. Determination of depth to bedrock
iii. Locating fissures, faults and mineshafts
iv. Assessment of aquifer heterogeneity
v. Locating buried channels and sinkholes/cave systems
vi. Mapping and monitoring leachate plumes.
vii. Landfill investigation.
viii. Landslide assessments
ix. Soil corrosivity assessment

2.9 Groundwater Water Quality Assessment.

The physical, chemical, and biological characteristics of groundwater relates concurrently to the intended use of water as they serve as the basic determinant factor for water usage. Groundwater quality is threatened mainly by human activities, although harmful substances are sometimes introduced by natural processes. Sustainable groundwater management must be based not only on prevention of the overexploitation of groundwater resources but also on prevention of contamination, because unlike treatment at the point of use, prevention protects all of the resource. Usually, economic activities are classified as primary activities, which produce commodities (mining, agriculture); secondary or industrial activities (energy production, manufacturing and building); and services (including transport). Also inclusive are activities of private households. All of these activities create ‘waste products’, which may threaten the environment including groundwater.

The main contaminants of groundwater include chemicals such as heavy metals, organic solvents, mineral oils, pesticides and fertilizers, and microbiological contaminants such as faecal bacteria and viruses.

2.9.1 Water Quality Standard

This is a regulatory/educational tool that serves as a basis for assessing water quality which in turn sets a trigger for initiating necessary actions for improved water quality as well as determines the end point for terminating such actions. Standards are fixed by law and adopted in countries to their national priorities taking in account their economic, technical, social, cultural and political situation. Therefore not all countries adopt World Health Organization (WHO) guidelines or standard.

Standards are to be established, requested and enforced by competent national authorities by adopting a risk benefit approach. At anytime, the standards can be changed or modified whenever new scientific evidence becomes available.

Criteria for formulation of standard includes but not limited to the following:

i. Toxicological or epidemiological findings
ii. Economic interest
iii. Socio-cultural characteristics

iv. Average daily intake

v. Hygienic practices

vi. Public awareness and sensitivity

vii. Technological development

viii. Political situation.

Below are tables showing the WHO standard (2006) and the Nigerian Standard Drinking Water Quality (NSDWQ, 2007). References were made to them during the course of interpretation of results.

Table 2.1: World Health Organization standard for drinking water (WHO, 2006)

CHEMICALS OF HEALTH SIGNIFICANCE	
Parameters	**Guideline Value/Level**
Inorganic	
Antimony	0.005 mg/l
Arsenic	0.01 mg/l
Barium	0.7 mg/l
Boron	0.3 mg/l
Cadmium	0.003 mg/l
Chromium	0.05 mg/l
Copper	2 mg/l
Cyanide	0.07 mg/l
Fluoride	1.5 mg/l
Lead	0.01 mg/l
Manganese	0.5 mg/l
Mercury	0.001 mg/l
Molybdenum	0.07 mg/l
Nickel	0.02 mg/l
Nitrate	50 mg/l
Nitrite	3 mg/l

Selenium	0.01 mg/l
Aluminium	0.2 mg/l
Ammonia	1.5 mg/l
Chloride	250 mg/l
Copper	1 mg/l
Hardness	-
Hydrogen Sulfide	0.05 mg/l
Iron	0.3 mg/l
Manganese	0.1 mg/l
Dissolved Oxygen	-
Parameters	**Guideline Value/Level**
pH	-
Sodium	200 mg/l
Sulfate	250 mg/l
TDS	1000 mg/l
Zinc	3 mg/l
Organic Parameters	
Toluene	24 – 170
Xylenes	20 – 1800
Ethyl benzene	2.4 – 200
Styrene	4 – 2600
Monochlorobenzene	10 – 120
1,2-dichlorobenzene	1 – 10
1,4-dichlorobenzene	0.3 – 30
Trichlorobenzenes	5 – 50
Synthetic detergents	-
Disinfectants & Disinfectants By-products	
Chlorine chlorophenols	600 – 1000
2-chlorophenol	0.1 – 10
2,4-dichlorophenol	0.3 – 40
2,4,6-trichlorophenol	2 – 300

Table 2.2: World Health Organization standard for physical parameters of drinking water (WHO, 2006)

PHYSICAL PARAMETERS	
Parameters	**Guideline value/level**
Color	15 TCU
Taste and Odor	-
Temperature	-
Turbidity	5 NTU

Table 2.3: Nigerian Standard Drinking Water Quality (Nigerian Industrial Standard, 2007)

Parameter	Unit	Maximum Permitted	Health impact
		Inorganic Constituents	
Aluminium	mg/L	0.2	Potential Neuro-degenerative disorders
Arsenic	mg/L	0.01	Cancer
Barium	mg/L	0.7	Hypertension
Cadmium	mg/L	0.003	Toxic to the kidney
Chloride	mg/L	250	None
Chromium	mg/L	0.05	Cancer
Conductivity	mg/L	1000	None
Copper	mg/L	1	Gastrointestinal disorder
Cyanide	mg/L	0.01	Very toxic to the thyroid and the nervous system.
Fluoride	mg/L	1.5	Fluorosis, Skeletal tissue (bones and teeth) morbidity
Hardness (as $CaCO_3$)	mg/L	150	None
Hydrogen sulphide	mg/L	0.05	None
Iron	mg/L	0.3	None

Lead	mg/L	0.01	Cancer, interference with vitamin D metabolism, affect mental development in infants, toxic to the central and peripheral nervous systems.
Magnesium	mg/L	0.2	Consumer acceptability
Manganese	mg/L	0.2	Neurological disorder
Mercury	mg/L	0.001	Affects the kidney and central nervous system
Nickel	mg/L	0.02	Possible carcinogenic
Nitrate	mg/L	50	Cyanosis, and asphyxia (blue-baby syndrome) in infants under 3 months
Nitrite	mg/L	0.2	Cyanosis, and asphyxia (blue-baby syndrome) in infants under 3 months
pH	mg/L	6.5 – 8.5	None
Sodium	mg/L	200	None
Sulphate	mg/L	100	None
Total Dissolved Solids	mg/L	500	None
Zinc	mg/L	3	None
		Organic constituents	
Detergents	mg/L	0.01	Possibly carcinogenic
Mineral oil	mg/L	0.003	Possibly carcinogenic
Pesticides	mg/L	0.01	Possibly carcinogenic
Phenols	mg/L	0.001	Possibly carcinogenic
Poly Aromatic Hydrocarbons	mg/L	0.007	Possibly carcinogenic
Parameter	**Unit**	**Maximum Permitted**	**Health impact**
Total Organic Carbon or Oxidisability	mg/L	5	Cancer
		Disinfectants and their by-products	
Free residual chlorine	mg/L	0.2 – 0.25	None
Trihalomethanes Total	mg/L	0.001	Cancer
2,4,6-Trichlorophenol	mg/L	0.02	Cancer
		Physical/Organoleptic Parameters	
Colour	TCU	15	None
Odour and Taste	-	Unobjectionable	None
Temperature	0^0Celsius	Ambient	None
Turbidity	NTU	5	None

2.10 Previous Work

MacDonald and Davies (1996) under the British Geological Survey carried out a project titled the hydrogeology of Oju area, Benue state, eastern Nigeria. This project was funded by the United Kingdom (UK) Department for International Development (DFID) for the benefit of developing countries. They collected geological, geophysical and hydrochemical data from Oju at several interval of time and the result obtained was collated with existing information on the environment as well as with literature review of similar environments. From these they arrive at the following conclusions

i. There is little potential for groundwater in the river gravels.

ii. The geology of Oju comprises low permeability cretaceous sediments.

iii. In the south of Oju, the sediments have been hardened by regional metamorphism and therefore groundwater is most likely to occur within fracture zones. If this is the case, properly sited and constructed boreholes would be best option.

iv. A good aquifer runs across the centre of Oju. This good aquifer is the Makurdi sandstone which comprises feldspathic sands which should provide sustainable groundwater supplies.

v. There are small igneous intrusions throughout the area; adjacent to these, are shales that have been baked and are often hard and fractured. Therefore, wells or boreholes sited next to intrusions may have a high potential for groundwater.

Ofoma, *et al.*, (2005) carried out physico-chemical analysis on the groundwater in parts of Port Harcourt city, Eastern Niger Delta, Nigeria. They collected water samples from different parts of Port Harcourt city and analysed the samples using conventional field and laboratory techniques. The result obtained was compared with the World Health Organization (WHO) 1993 standards for drinking water. All the parameters analyzed fall within the WHO standard except for the pH which was far below the required standard and this they attributed to the breakdown of organic matter derived from vegetation cover and humus buried in sediments. They therefore recommend that the groundwater be treated for pH before consumption.

Ariyo *et al.*, (2005) carried out a geochemical investigation on the aquifers in the Basement Complex-sediment transition zone around Ishara, southwestern Nigeria. They carried out physic-chemical analysis of nineteen water samples collected from available wells and surface water in the study area. The results from their findings are:

i. Higher values of total dissolved solids and electrical conductivity in Basement Complex samples than those from the sedimentary terrain.
ii. There was no difference in the statistical analysis of the geochemical and physical parameters of surface water samples from each terrain which was attributed to little time of interaction with the lithology through which they flow.
iii. With the exception of silica and nitrate; all other parameters are higher in concentration/values in water from Basement Complex than those from sedimentary terrain due to the mineral composition of the aquifer materials.
iv. On a general note; there is a strong relationship between the aquifer materials in the study area and water from the findings.

Abdullahi *et al.*, (2005) carried out a research on Aquifer depletion and groundwater situation in Damaturu, northeastern Nigeria. They based their studies on the data obtained from secondary source with regards to depth, age and yield of productive boreholes and wells. They considered a total of twenty seven boreholes and seven dug wells in the metropolis. Their findings are:

i. The yield of wells are between 0.002 – 0.09L/s
ii. Boreholes drilled before 1990 are about 60 – 135m in depth and have a total discharge of 27.3L/s.
iii. Boreholes drilled from 1992 – 2001 are up to 199m in depth and yield varied from 2.0 – 8.0L/s. This therefore indicates that as the years goes by, there is continuous depletion in the groundwater contained in the aquifer and hence the deeper the boreholes.

Idris-Nda (2005) carried out a study on the groundwater potential of part of Kushaka schist belt of north-central Nigeria. He carried out the study using geological, hydrogeological and surface geophysical (electromagnetic and electrical resistivity) methods. His findings from the studies are:

i. The principal rock type of the Kushaka Formation is quartz-biotite-muscovite schist and it is highly weathered with depths of weathering ranging between 10 and 30 meters
ii. The groundwater lies mainly within the weathered part with yields ranging between 0.8 and 1.4L/s.
iii. The hydraulic conductivity of the weathered schist was found to be 6 x 10^{-2}m/d with a transmissivity of 1.2m^2/d. The plots/curves from the resistivity sounding were mostly the H and A type three layer models generally interpreted as top soil,

weathered schist and the bedrock with the depth to fresh basement ranging between 15 and 30m.

Arabi *et al.,* (2010) carried out a study on qualitative evaluation of groundwater from parts of upper Benue river basin. They collected water samples from the study area and analyzed for major and minor elements using Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) and Atomic Absorption Spectrometer. The result reveal that groundwater from the study area were of medium salinity indicating that the water could be used for irrigation except for crops that are sensitive to salinity where differential effects may be expected. Therefore, groundwater from the study area is good basically for domestic use.

Aweto (2012) carried out a DC-electrical resistivity investigation of Oke-lla area with a view to delineating fractured zones within the crystalline basement rocks. The results of his investigation revealed three distinct geoelectric layers: top soil, weathered layer and fractured/fresh crystalline basement rocks with the fractured zone as the productive water bearing zone occurring at an average depth of 37.5m.

Ocheri (2010) carried out a research in which he examined the iron level in groundwater from boreholes and their spatial distribution across rural communities of Benue state. He collected water samples from 26 boreholes and analyzed for iron concentration. The result of analysis showed that 35% of the boreholes have high iron concentration above WHO guide limit for drinking water. He said the high iron concentration can be traced to the geology, dissolution of iron minerals from rock and soil, precipitation/run off and infiltration activities, use of galvanized materials in hand pump construction and agricultural land use activities. He recommended that the water can be treated through filtering and or reverse osmosis to reduce the risk of health over time.

Ocheri *et al.*, (2011) carried out a study on the temporal variability of heavy metals concentration in rural groundwater of Benue state. They collected water samples from boreholes in the rural communities of study area in both the wet and dry seasons. The results of the analysis showed higher concentration of the heavy metals in the wet season with the exception of Zn which had higher concentration in the dry season. From the result, they concluded that as climate becomes wetter or drier due to phenomenal changes, concentration of heavy metals are likely to respond appropriately.

Okafor and Mamah (2012) carried out an investigation on the groundwater potential in Katsina-Ala, Benue state using an integration of geophysical techniques. They used VLF-EM and Electrical Resistivity sounding methods to carry out the investigation. Their findings are: the weathered and or the fractured basement are the aquifer types delineated across the area and the thickness of the weathered aquifer unit varies from 5.3m to 32.8m in the area. They also zoned the area on the basis of geo-electric parameters into high, intermediate and low groundwater potential zones.

Chukwudi (2012) carried out hydrogeophysical studies for the delineation of potential groundwater zones in Enugu state, Nigeria. He carried out the research work using well records and electrical resistivity geophysical technique. From his study, he delineated the study area into five groundwater potential zones for future development and choosing of drilling sites.

Ibrahim *et al.*, (2012) carried out a study to investigate the groundwater potential of Orisumibare village in Illorin south area of Kwara state, Nigeria. They employed the electrical resistivity method in the research. Their findings are; the study area is characterized by five classes of geoelectric layers (highly resistive topsoil, lateritic clay layer, highly weathered basement, partially weathered/fractured basement and the fresh basement) and Vertical Electrical Sounding points 1, 2, 3, 4, and 5 are viable points for good aquifers in the form of weathered and fractured basement. They therefore concluded that borehole drilling in the study area is achievable but to a depth of 45 meters.

Ocheri and Egahi (2013) carried out principal component analysis of rural groundwater of Benue state, Nigeria. Water samples from 26 rural community boreholes were collected during the wet season and carried out physic-chemical analysis on them. The result obtained was subject to correlation and principal component analysis (PCA). The result of the PCA showed that the groundwater quality in the study area is influenced by geology of the environment, mineralization in soil and rocks, effect of agricultural land use, effects of materials used in borehole construction and influence of seasons.

Ochuko (2014) carried out a hydrogeophysical and hydrogeological investigations of groundwater resources in Delta central, Nigeria. He employed the electrical reistivity survey method , down the hole logging and pumping test to carry out the study. His findings are: the presence of four geoelectric layers in the study area (comprising loamysandy top soil, clay, fine sand and coarse sand) and the presence of a confined aquifer at a ranging depth of 20.2 and 25.4m.

Nwankwoala (2015) presented a paper on hydrogeology and groundwater resources of Nigeria. In his presentation he pointed out the following facts; the extent of amount of groundwater storage in Nigeria is not yet known, but available records indicate that major aquifers are located in the sedimentary deposit basins which cover about 50% of the nation's land area while the remaining 50% is underlain by crystalline rocks of the Basement Complex. He also highlighted the fact that groundwater basins are difficult to govern and manage, partly because of poor information and also due to poor visibility of the resource and hence the need for proper understanding of the resource and information in support of water resource planning is central and vital for sustainability.

Kehinde-Philips *et al.*, (2015) carried out a research on the "health effects of arsenic and cadmium concentrations in the well and surface water within Ayo-Iwoye area, southwestern Nigeria. They collected thirty water samples comprising of nineteen from hand dug wells, six from streams and five from rivers and analyzed them for their physico-chemical analysis. They also carried out analysis for the concentration of arsenic and cadmium in human blood of the residents in the study area. Their findings are; all parameters fall within recommended values of WHO for drinking water with the exception of As and Cd which have concentrations above the recommended WHO drinking water values. However the concentration of As and Cd in human blood of the residents is still within the average normal range.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

The study methodology that was adopted involved three basic phases; the preliminary studies phase, the field-work phase and the data analysis and interpretation phase. This involved geological mapping, well data gathering and geophysical investigation.

3.2 Materials

The following materials were used for the research work.

- Global Positioning System (GPS)
- A terrameter with a complete set of electrodes and cable reels
- Existing topographic and geologic map of the area
- Hammer and sampling bags
- Tape, ruler, padlock, pencil, pen and calculator
- Data recording book/graph book
- Water samples

3.3 Preliminary Studies

All work related to the study were reviewed in this phase. Existing maps of the area as well as other literatures related to the study area were duly studied and the necessary materials for fieldwork were made available in due preparation for the fieldwork proper. Necessary permits were sought and reconnaissance survey was done for familiarity with the area of study and also to compare with the level of information at hand acquired from the desk study.

3.4 Fieldwork

3.4.1 Geological Mapping of the Area

This was carried out in other to identify the various geological formations within the study area. A plan was carefully laid out dividing the entire study area into grids in other to make it easy for traverses to be done without leaving out some areas. The traverse was done with the aid of a compass clinometer and other anthropogenic features on the base map (A topographic map of Makurdi sheet 251 SW on a scale of 1:25,000).

At each location where an exposure or outcrop was found; the first thing done was to locate the position on the map. An intricate study was then carried out on the exposure. The lithology, general and special features of the rock such as mineral composition, texture, structures, degree of weathering, colour and bioturbation amongst others were examined and noted adequately. Pictures of important features were taken and sketches were also drawn where necessary.

3.4.2 Well Data Acquisition

Well data was collected from a total of 110 wells. An attempt was made for the data to be collected in an evenly distributed manner all over the entire study area. However, urbanization was an obstacle to achieve this target. Information collected from each well includes: location of the well, the geographical co-ordinates of the well, the elevation of the well above sea level, the type of well (lined or unlined), well depth, well diameter, depth to water and water column.

Plate IIIa: Taking well parameters in the field.

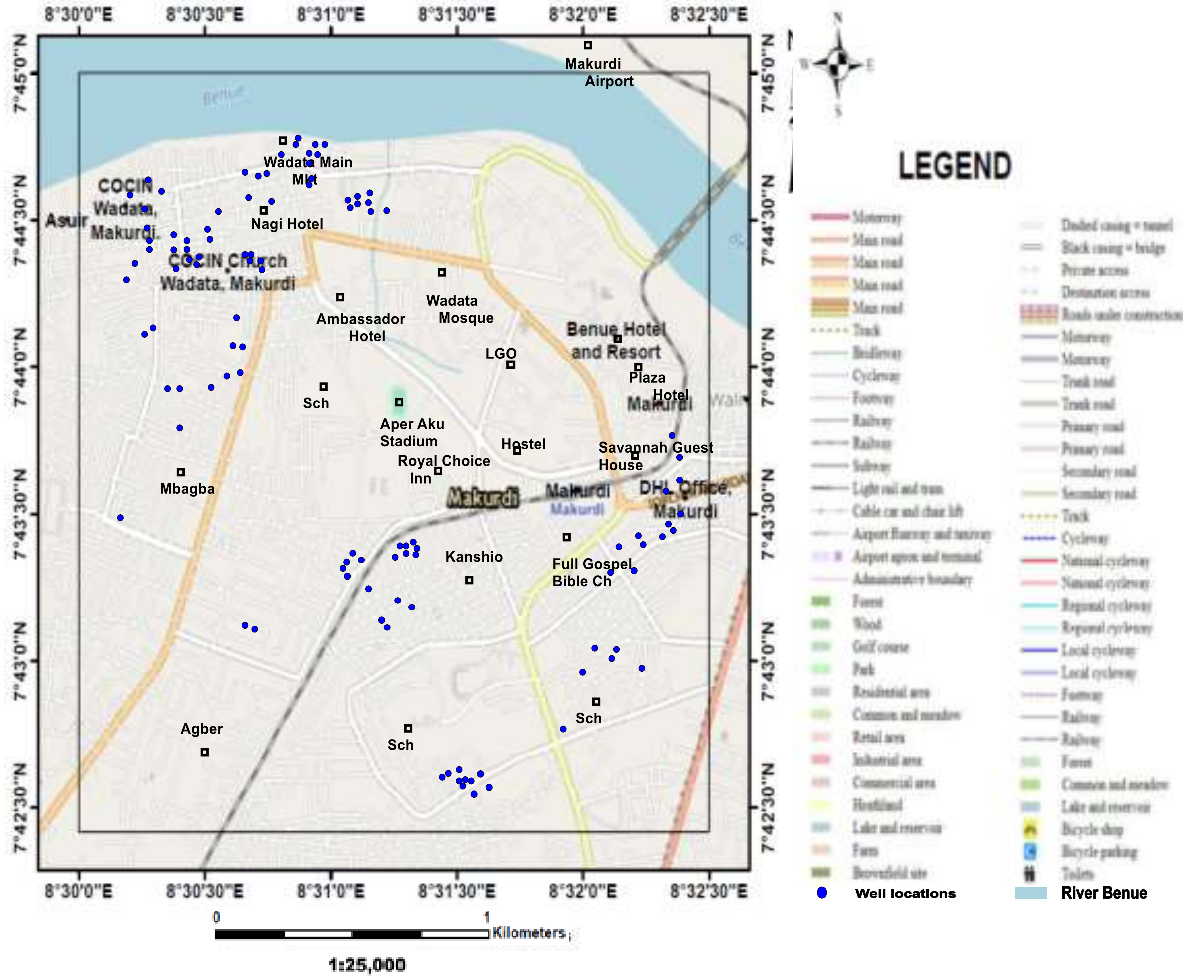


Figure 3.1: Locations of well data acquisition

3.4.3 Geophysical Data Acquisition

The geophysical investigation method adopted for the research was the electrical resistivity method. The Schlumberger array was adopted. This array was chosen because it reveals the variation of resistivity with depth, reflecting more or less horizontal stratification of earth materials which is the basic information that is sought for. Twenty (20) vertical electrical soundings were done to an AB/2 depth of 100m and the VES points were spread out uniformly across the study area to investigate the subsurface stratification.

Plate IIIb: Acquisition of electrical resistivity data on field using a rectified terrameter.

In the process, four electrodes were driven into the ground; two current electrodes (A and B) and two potential electrodes (M and N). An artificially induced current is introduced into the ground through the current electrodes A and B and the resulting potential difference was measured at the surface from the voltmeter connected to the two potential electrodes M and N. From the observed current (I) and voltage (V) readings, the resistance was calculated using Ohm's law (V=IR) which was then multiplied by the geometric factor to obtain the apparent resistivity. As the process proceeds, the current electrodes are spread out concurrently to increase the depth of investigation with the potential electrode distance kept constant. However, at certain current electrode spacing, the potential electrode distance was also changed. A plot of apparent resistivity against electrode spacing was then plotted and interpreted to indicate vertical variations in resistivity with depth which in turns depicts the various subsurface stratification or layering.

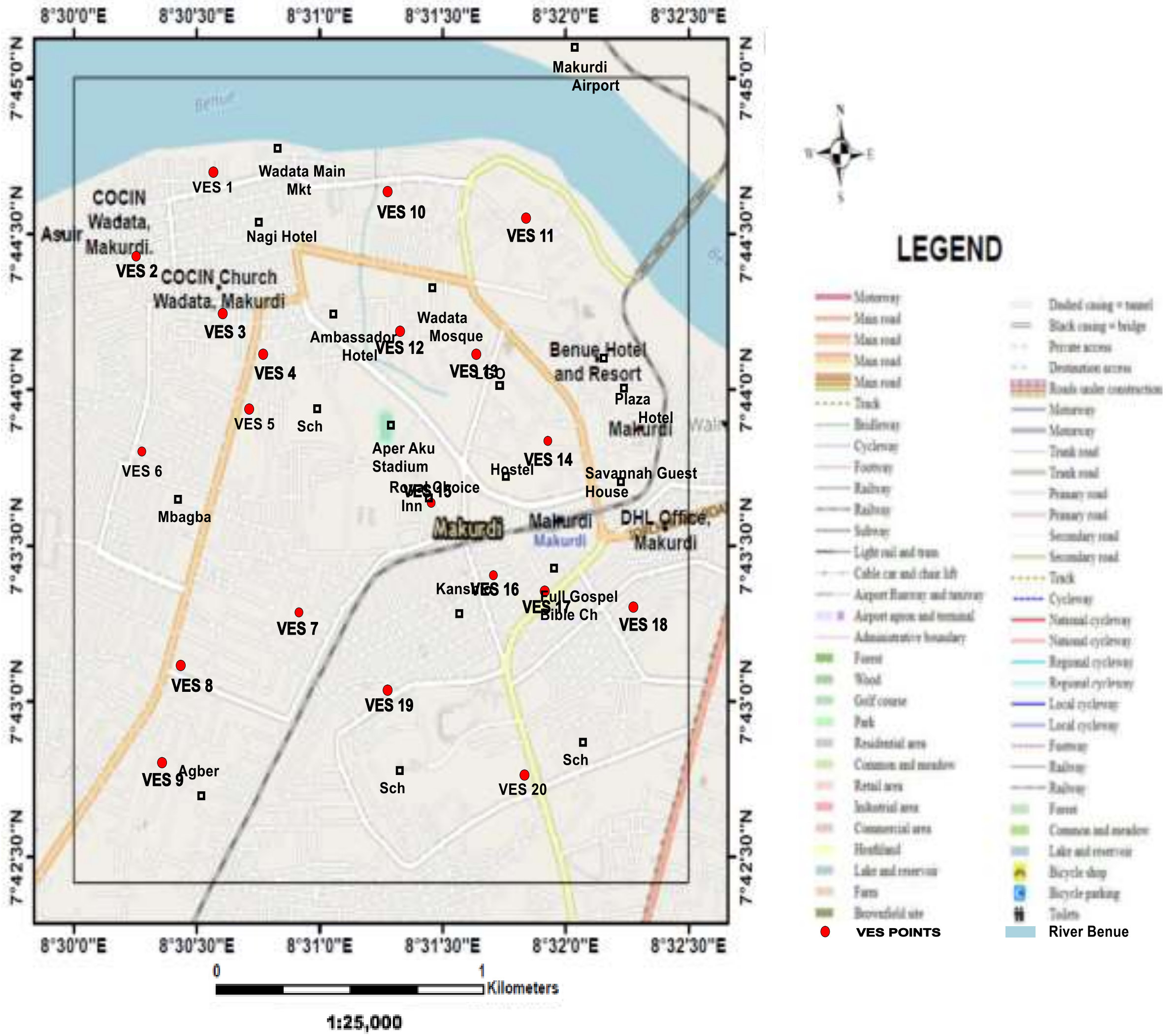


Figure 3.2: Location of VES points

3.5 Groundwater Sampling

Groundwater samples were collected in clean screw-cap, high-density polyethylene bottles. When filling sampling bottles, the bottle was first rinsed two to three times with the water sample. Preservation prior to analysis was done by adding a few drops of concentrated nitric acid after the sample has been collected.

While at a sampling location, the well-head chemistry was measured, with the aim of collecting data representative of the hydrochemical conditions in the aquifer. Therefore Parameters such as temperature, pH and redox potential (E*h*) were taken on field as this parameters would all change once the groundwater sample is exposed to ambient conditions at the ground surface, during storage and laboratory analysis. On-site measurement of electrical conductivity (EC) and alkalinity was also conducted.

Thirty-five representative samples were collected; four samples from river Benue, ten from boreholes and twenty five from hand dug wells. The samples were analyzed for their physico-chemical concentrations using both field and laboratory techniques in line with the standard methods prescribed for water examination and reported based on the WHO drinking water guidelines. The geographical coordinates of where the samples were obtained were also recorded to enable their adequate location on the map (Figure 3.3).

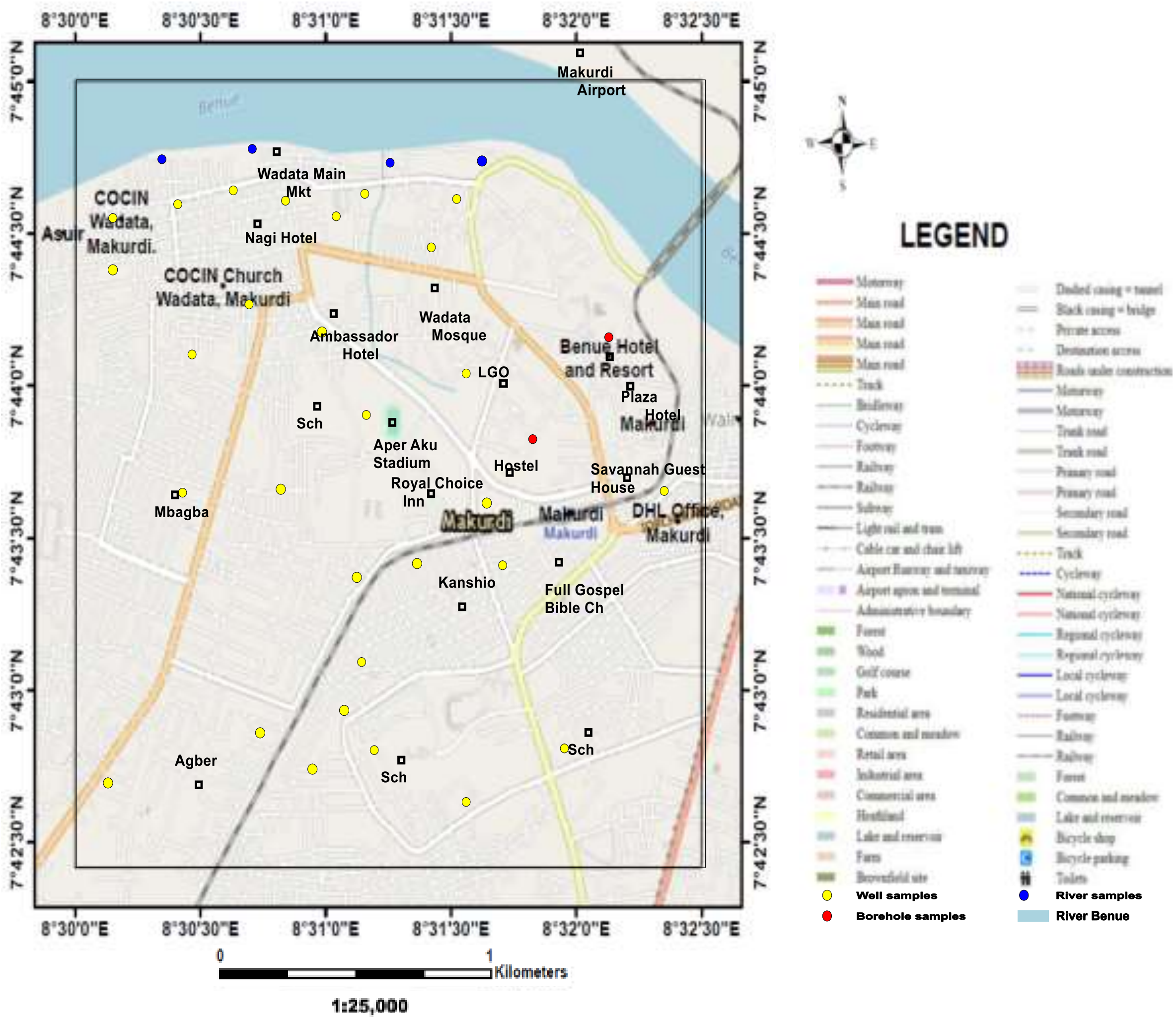


Figure 3.3: Water sampling locations.

3.6 Reporting

Several software packages were used for analysis, interpretation and presentation of results. Below are the software packages that were used and the respective purpose for which they were used for.

i. Microsoft Excel

ii. Paint

iii. WinResist

iv. Surfer 10

v. Rockworks15

Microsoft excel

All graphs and charts were plotted using Microsoft Excel 2007 for direct visual assessment and comparism.

Paint

This was used for editing pictures

WinResist

This was used for analyzing the electrical resistivity data into graph plots. This graph is then interpreted and aid in the subdivision of the subsurface into layers.

Surfer 10

This was used in digitization of maps, generation of a topographic map using the elevation readings and also for generation of 3-D surface relief maps. It was also used for several other forms of editing of images.

Rockworks15

This software was used for plotting the hydrochemical plots.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

In this chapter, effort was made to present the results obtained from the field in a simplified and easily apprehensible manner.

4.1 GEOLOGY

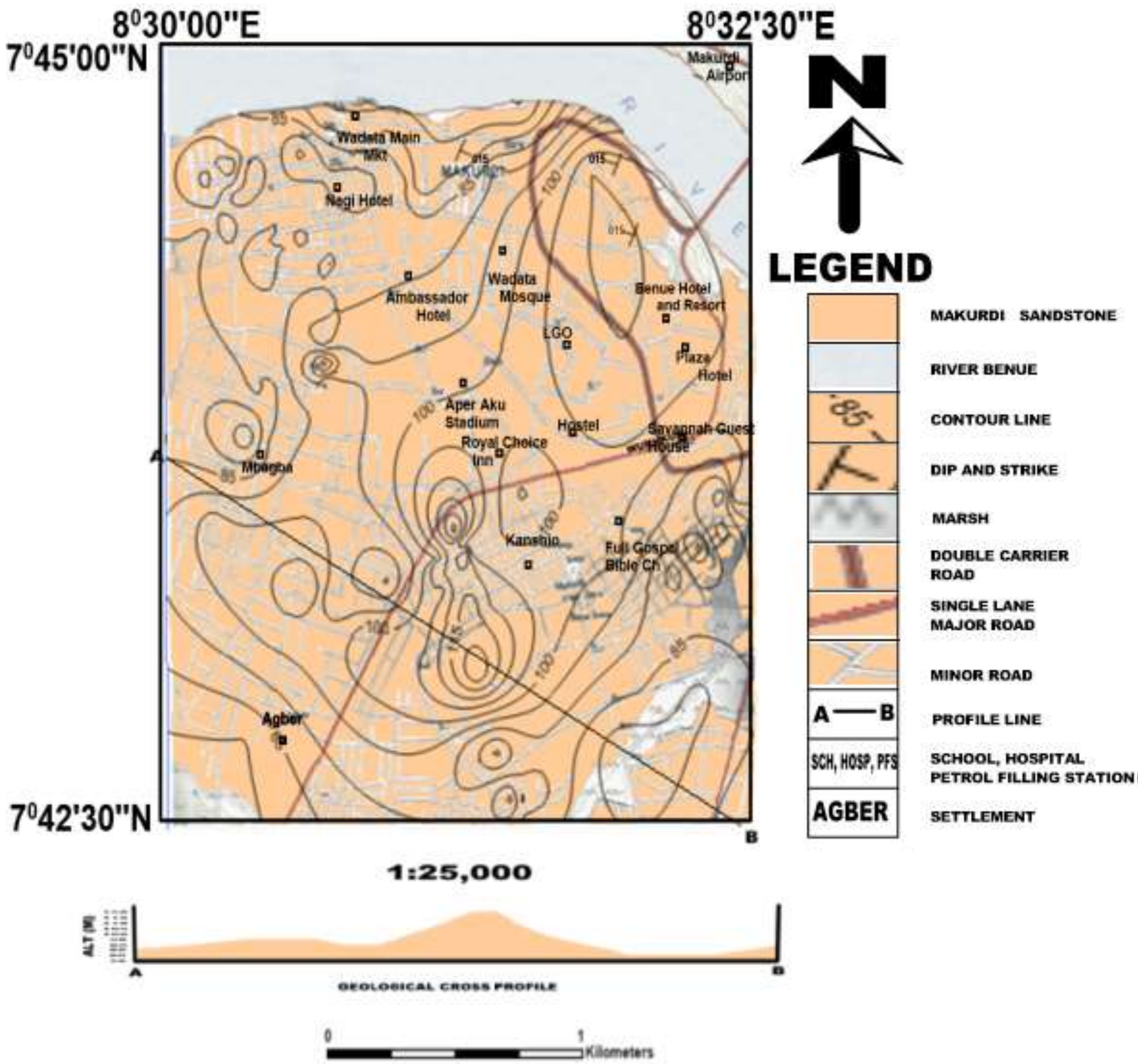


Figure 4.1: Geological map and cross profile of the study area

4.1.1 Structural Characterization of the Study Area

Below are the pictures of the various structures as seen in different locations in the study area.

Plate IVa: Mottling of colours as seen in some exposures

Plate IVb: Iron concretions as seen in some exposures

Plate IVc: lineations as seen in some exposures

Plate IVd: Dipping beds

Plate IVe: Thin laminations

Plate IVf: Bioturbation

Plate IVg: Fractured blocks as a result of physical weathering

Plate IVh: Graded bedding as seen in the base of one of the outcrop

Plate IVi: Ripple marks as seen in some exposures (paleocurrent indicator)

Plate IVj: Eroded surface (gully erosion)

4.2 Hydrogeology

4.2.1 Field Data

About a hundred and ten well data were collected from wells dissipated all across the study area. Below are statistical charts and maps derived from the analysis of the hydrologic data collected on field. A table containing all the information collected on the field can be found in the appendix (Appendix A).

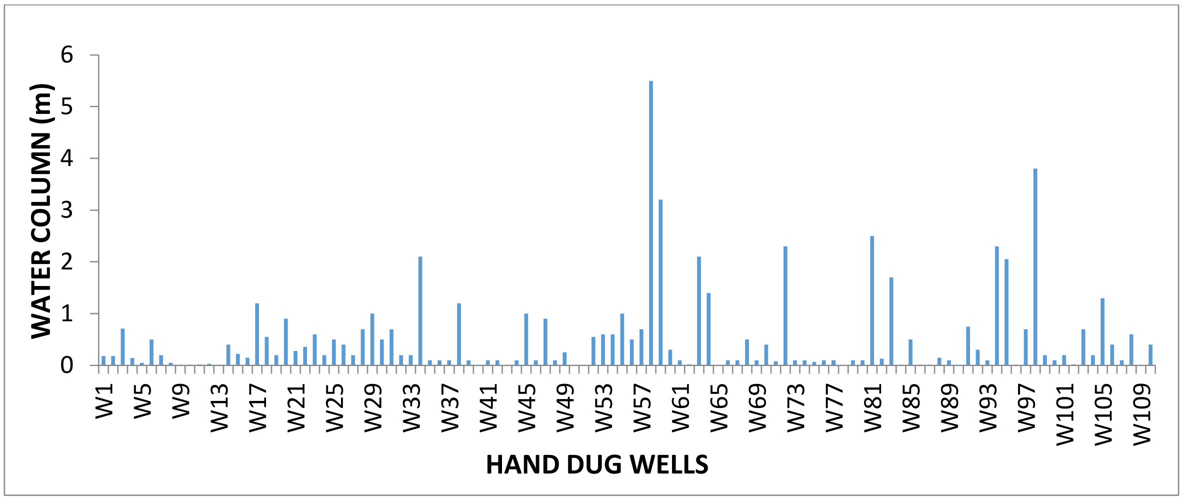


Figure 4.2: Water column plot of the study area

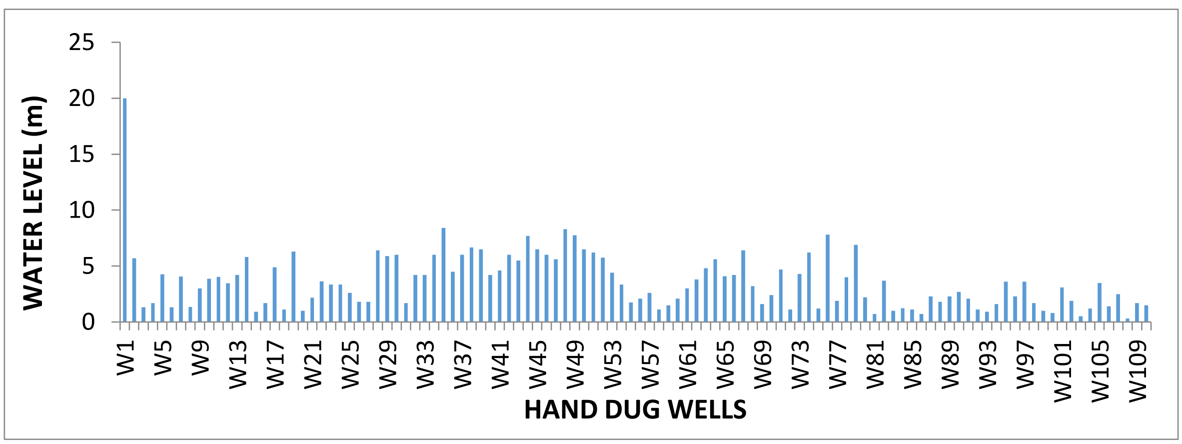


Figure 4.3: Water level plot of the study area

4.2.1.1 Depth to Water Condition of the Study Area

Static water contour plot of the area shows the various water level distribution of the well in the area. This map provides information on the position (depth) of the groundwater (static water level) in relation to the ground level. The map provides a means by which one could easily tell the depth to which one could harness groundwater at any location within the study area.

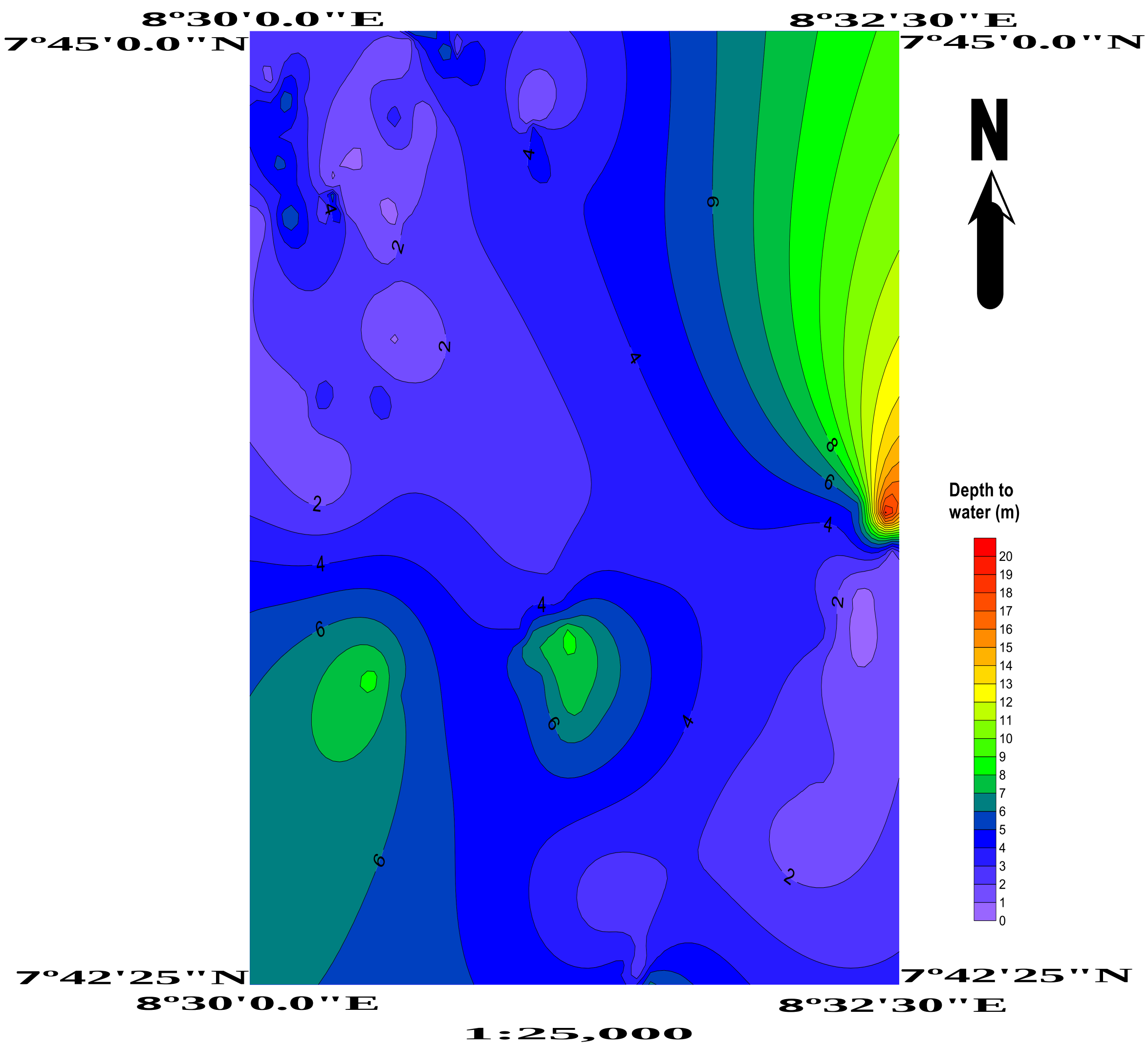


Figure 4.4: Depth to water map of the study area

4.2.1.2 **Water Table Elevation of the Study Area**

Water table elevation is derived by subtracting the static water level from the altitude of the ground level above sea level. The value so derived is then plotted to produce the water table elevation map of the study area. This map would aid in showing the elevation of the groundwater level of the study area. It's a supplement map to the depth to water map as each of them provides information as regards the proximity of the groundwater to the ground level. However, this map categorically shows us the altitude of the static water level in the study area above the sea level.

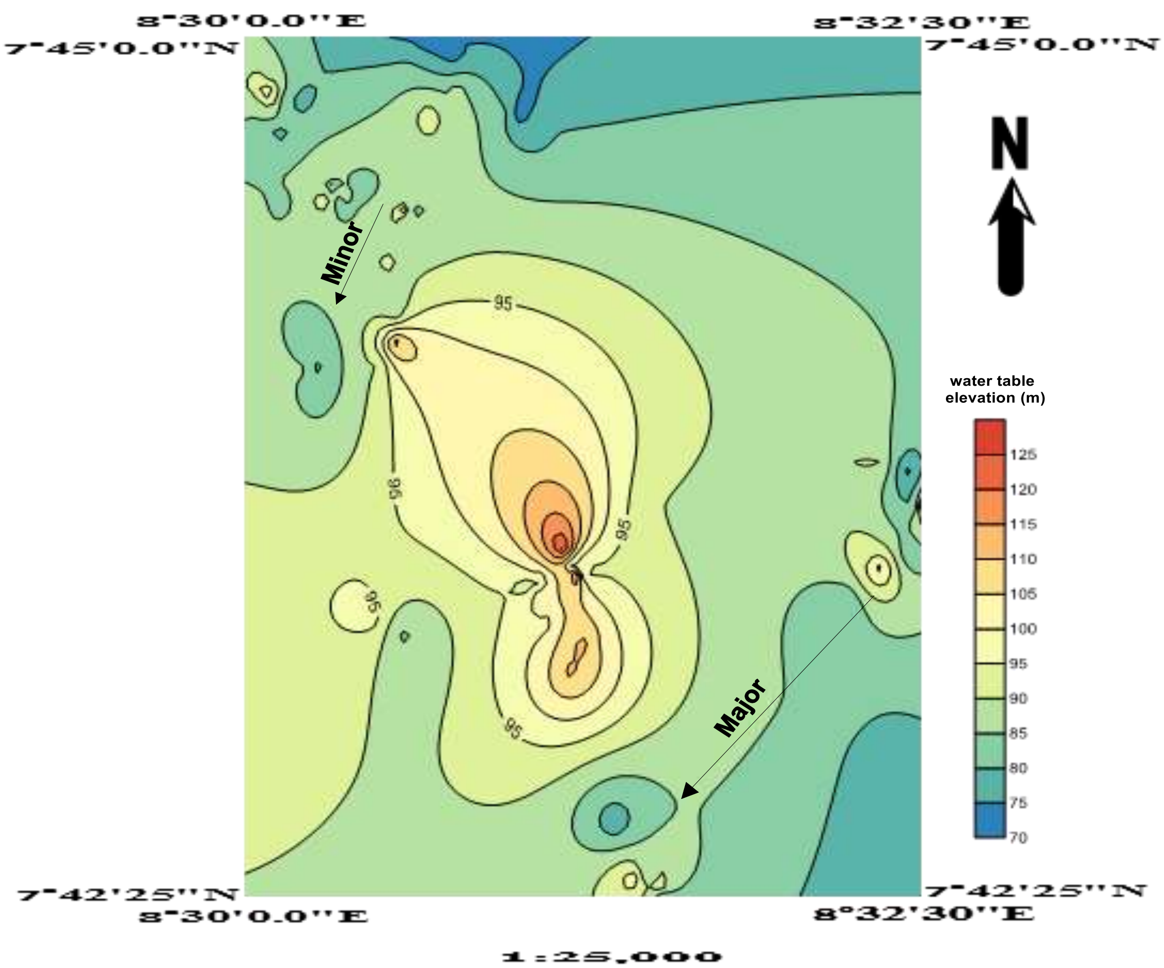


Figure 4.5: Water level elevation of the study area showing the groundwater flow direction

4.2.2 Geophysics

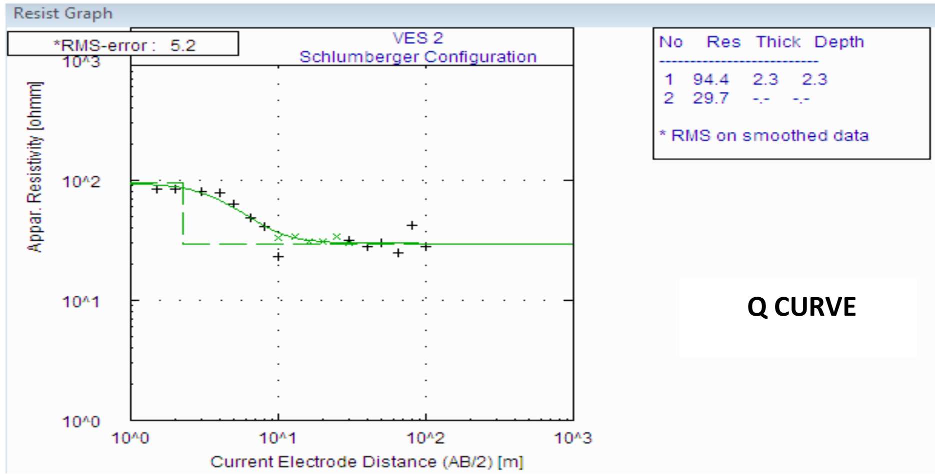
4.2.2.1 Field Data Obtained from Geophysical Investigation

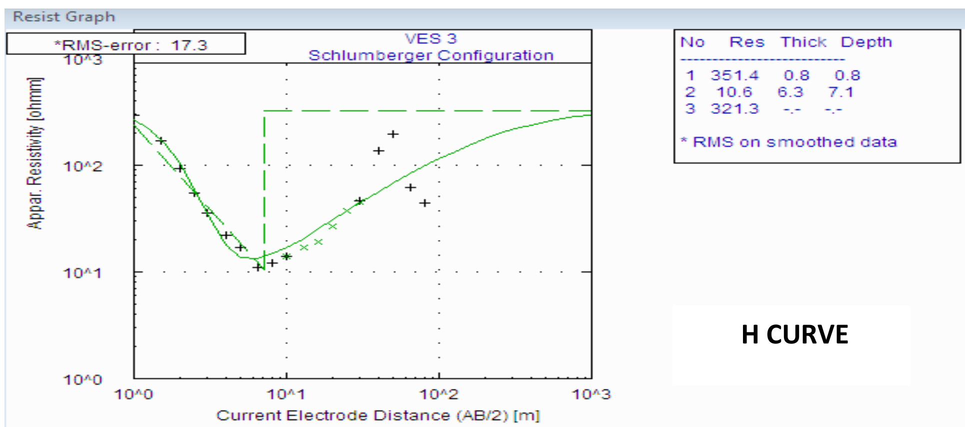
Field data as well as interpreted results from the geophysical investigation carried out are hereby presented below.

Table 4.1: Quantitative data acquired from Geophysical Survey of the study area

AB/2	MN/2	K	V 1	V 2	V 3	V 4	V 5	V 6	V 7	V 8	V 9	V 10	V 11	V 12	V 13	V 14	V 15	V 16	V 17	V 18	V 19	V20
1	0.2	7.54	265	92	295	79	143	30	95	38	476	152	118	95	122	366	463	46	382	291	408	64
1.5	0.2	17.4	225	85	170	31	127	31	102	34	526	143	100	114	66	265	470	36	357	224	311	72
2	0.2	31	169	85	94	23	184	30	88	28	561	90	87	117	68	213	485	28	322	160	218	77
2.5	0.2	49	140	81	55	16	79	35	82	23	611	95	66	113	71	306	504	26	287	141	194	76
3	0.2	70	120	78	36	15	69	37	78	18	585	87	61	93	75	232	493	26	236	130	169	69
4	0.2	125	121	63	22	10	52	37	80	21	449	75	61	74	86	234	405	22	184	136	111	60
5	0.2	196	159	49	17	10	56	38	84	16	451	64	45	57	91	210	390	18	145	135	78	54
6.5	0.2	332	229	50	11	8	54	34	80	14	193	60	46	39	93	197	315	22	110	159	51	42
8	0.2	502	450	41	12	8	53	25	81	17	145	57	42	34	79	175	211	19	94	147	45	42
10	0.2	785	126	23	14	10	52	21	60	20	109	47	35	30	74	147	167	19	57	131	32	33
8	1.5	65	427	36	40	9	68	35	87	21	189	66	44	26	80	138	219	21	79	147	56	36
10	1.5	102	255	33	14	9	63	28	72	25	140	62	37	26	75	129	166	20	53	176	46	26
13	1.5	175	200	34	17	40	63	25	56	29	122	98	36	26	65	91	143	21	40	130	37	28
16	1.5	266	57	31	19	11	64	27	48	33	58	122	34	20	57	73	87	24	43	131	36	22
20	1.5	417	45	31	27	13	57	31	65	40	49	150	41	16	54	63	128	18	50	109	38	38
25	1.5	652	43	34	33	15	65	42	62	52	52	112	36	23	59	67	150	18	58	103	42	28
30	1.5	940	50	30	45	18	66	59	59	46	67	113	50	16	64	67	126	15	53	89	38	43
25	5	188.5	28	54	37	13	62	54	55	49	57	48	40	29	62	88	121	20	48	126	39	32
30	5	274.8	29	32	46	10	65	82	53	55	27	45	46	43	59	78	104	19	43	115	39	35
40	5	494.6	27	28	36	17	68	61	33	60	28	51	54	32	55	90	125	18	48	100	31	42
50	5	777.15	35	30	46	16	69	57	22	62	19	53	48	36	44	112	342	22	52	97	39	49
65	5	1318.8	29	25	42	22	73	39	70	58	21	75	40	58	48	108	280	21	62	90	42	55
80	5	2001.75	21	42	44	38	74	74	52	55	32	80	37	64	48	113	265	28	65	86	46	71
100	5	3132.15	22	28	38	45	83	98	55	51	47	88	32	78	46	117	248	39	74	79	48	82

4.2.2.2 Type Model Curves Obtained from VES Points within the Study Area





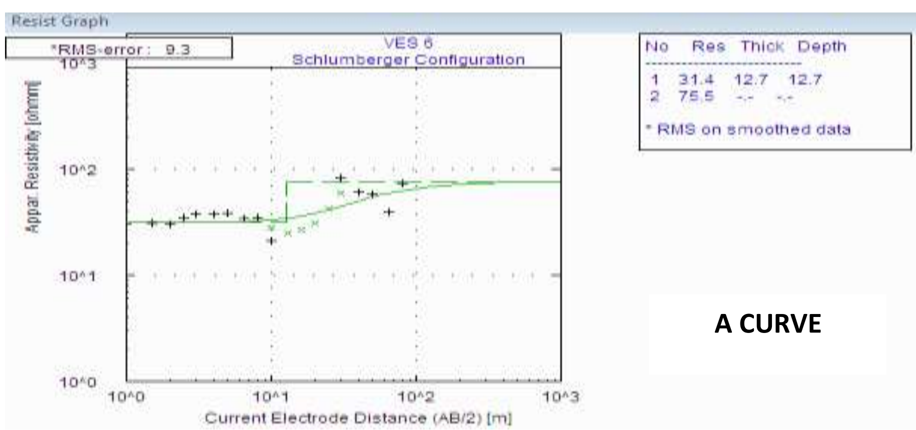


Figure 4.6: Type Q,H and A model curves respectively as obtained from VES points 2,3 and 6.

4.2.2.3 Isoresistivity Maps

Below are the various isoresistivity maps produced at depth 20, 30 and 50m respectively (Figure 4.7 – 4.9). Interpretation was done using the resistivity range of values for various sediments within the Makurdi environment developed by Dominic in 2012 (Table 4.2). Unlike the basement environment where we are interested in fractures or saturated thick overburden, in the sedimentary environment, we are interested in the most porous and permeable formation which in this case is the sandstone formation. Where the sandstone is found to be indurated, we look out for fractures. Therefore we would concentrate on areas with apparent resistivity readings that correlate with the range of apparent resistivity values for sandstone (Table 4.3).

Table 4.2: Range of apparent resistivity values for different sediments within the Makurdi environment (Dominic, 2016)

APPARENT RESISTIVITY VALUE (ΩM)	ANTICIPATED FORMATION
<20	Shale
21-49	Sandy shale
50-120	Sandy formation
121-300	Sandy clay formation
301-600	Clayey formation
>600	Fresh Basement or lateritic formation

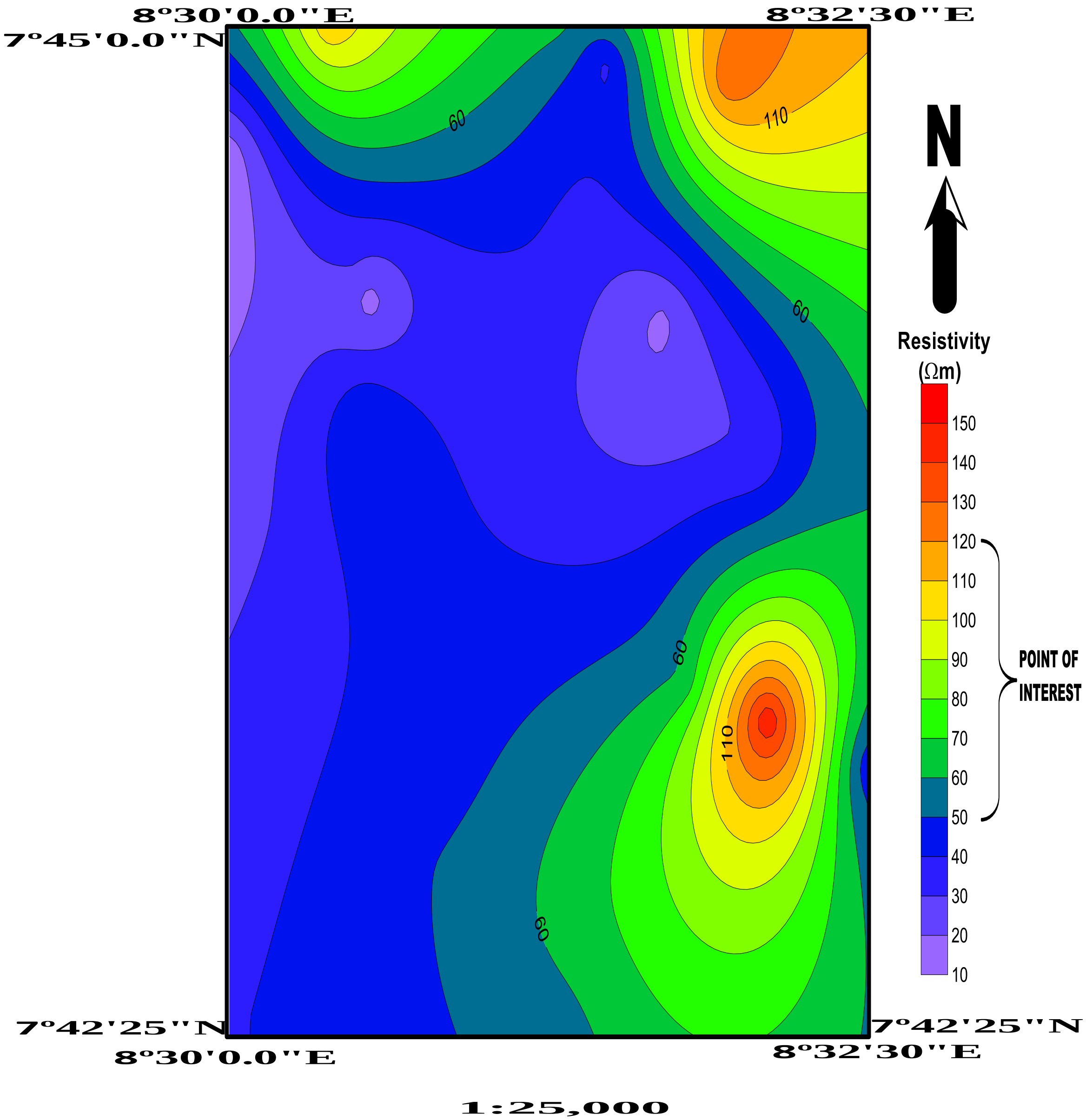


Figure 4.7: Isoresistivity contour at a depth of 20m

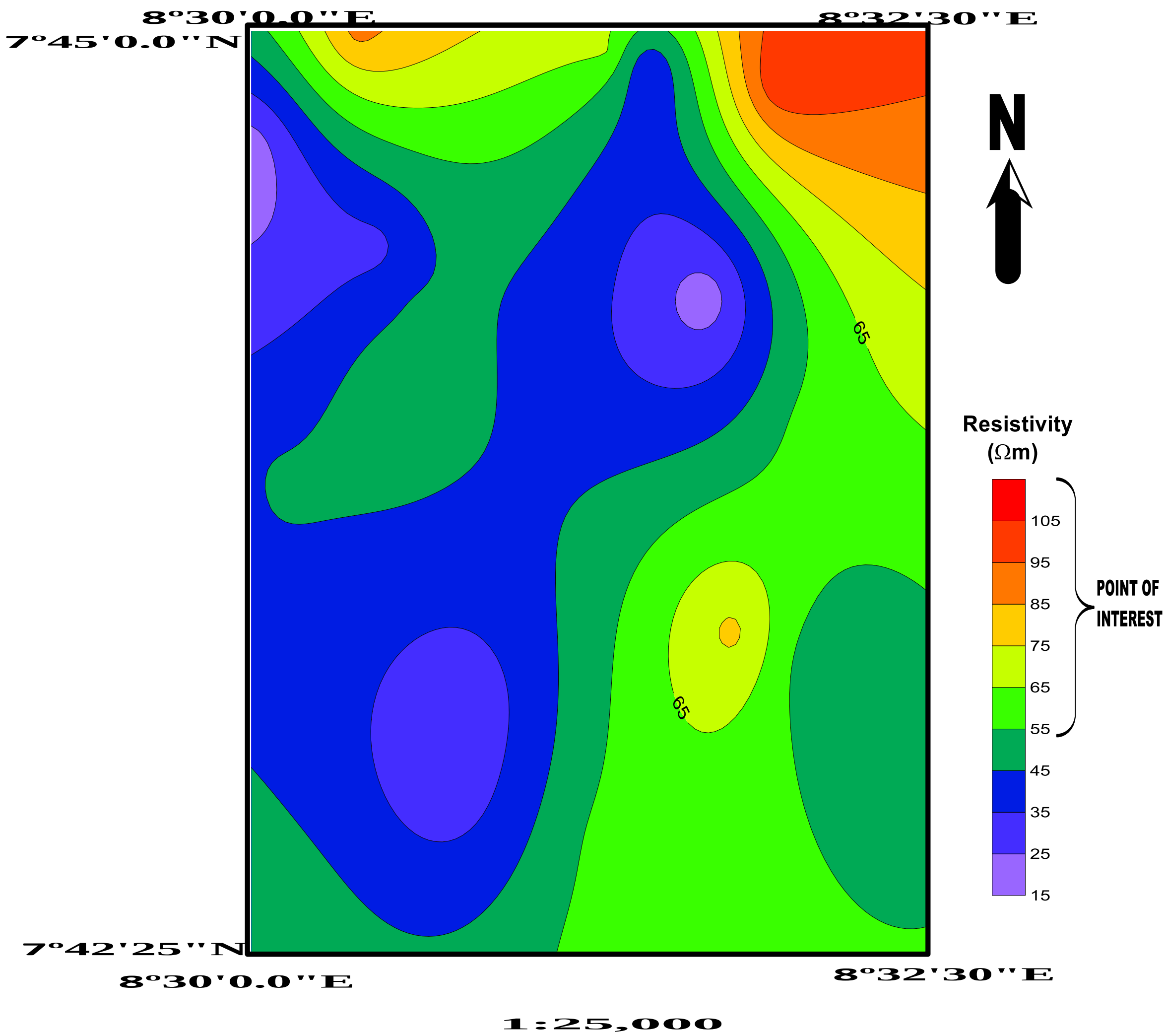


Figure 4.8: Isoresistivity contour at a depth of 30m

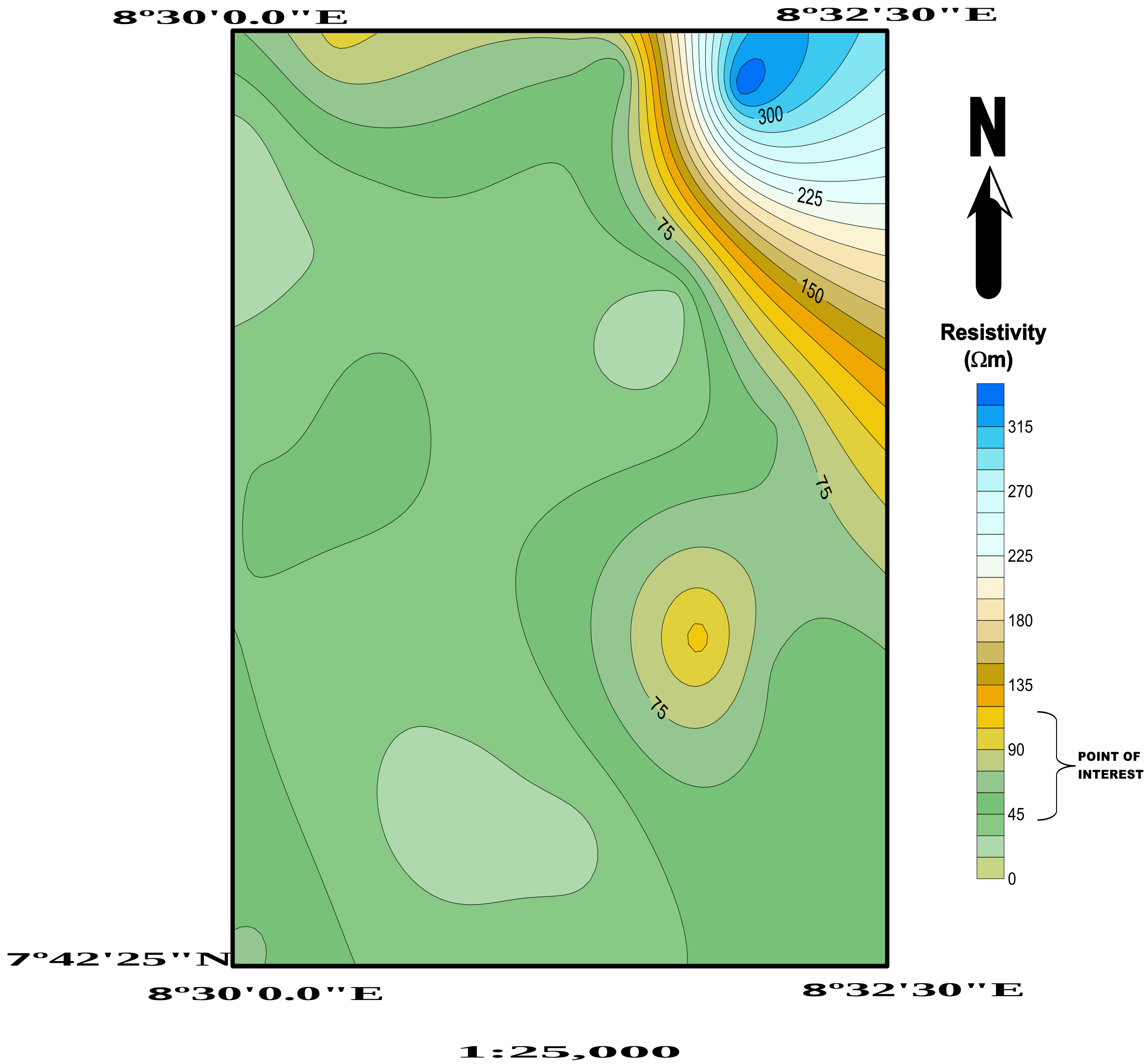


Figure 4.9: Isoresistivity contour at a depth of 50

4.2.2.4 Qualitative Interpretation of Geophysical Investigation

Table 4.3a Summary of qualitative interpretation of VES 1 to 10

	RESISTIVITY ℓ (Ωm) / THICKNESS T (m) / DEPTH d (m)									
	POINTS OF GEOPHYSICAL INVESTIGATION									
LAYER	VES 1	VES 2	VES 3	VES 4	VES 5	VES 6	VES 7	VES 8	VES 9	VES 10
Layer1 ℓ1/T1/d1	174/1.8/1.8	94.4/2.3/2.3	351.4/0.8/0.8	122.9/0.6/0.6	175.9/1.1/1.1	31.4/12.7/12.7	88.6/5/5	42.6/1.1/1.1	594.4/2.8/2.8	241.7/0.5/0.5
Layer 2 ℓ2/T2/d2	317.4/3.3/5.1	29.7/∞	10.6/6.3/7.1	9.8/9.5/10.1	27.7/1.7/2.8	75.5/∞	43.2/∞	10.0/3.1/4.1	304/12.3/15.1	80.6/25.4/25.9
Layer 3 ℓ3/T3/d3	24.2/∞		321.3/∞	31.2/2.8/12.9	70.8/∞			81.1/∞	15.9/∞	49.5/∞
Layer4 ℓ4/T4/d4				29.9/∞						
CURVE TYPE →	Q	Q	H	H	H	A	Q	H	Q	Q

Table 4.3b Summary of qualitative interpretation of VES 11 to 20

	RESISTIVITY ℓ (Ωm) / THICKNESS T (m) / DEPTH d (m)									
	POINTS OF GEOPHYSICAL INVESTIGATION									
LAYER	VES 11	VES 12	VES 13	VES 14	VES 15	VES 16	VES 17	VES 18	VES 19	VES 20
Layer1 ℓ1/T1/d1	130.3/0.9/0.9	124.9/1.8/1.8	83.2/6.2/6.2	273.6/4.4/4.4	502/3.5/3.5	56/0.7/0.7	365/2/2	554.5/0.4/0.4	363.7/1.4/1.4	74.9/3/3
Layer 2 ℓ2/T2/d2	41.4/∞	27.7/∞	48.5/∞	34.1/9.8/14.2	59.7/11.1/14.7	19.7/∞	47/∞	140.5/8.3/8.7	36.6/∞	17.2/9.1/12.1
Layer 3 ℓ3/T3/d3				209.4/∞	1157/∞			91.2/∞		102.1/∞
CURVE TYPE →	Q	Q	Q	H	H	H	Q	Q	Q	H

4.2.2.5 Geoelectric profiles for interpreted curves

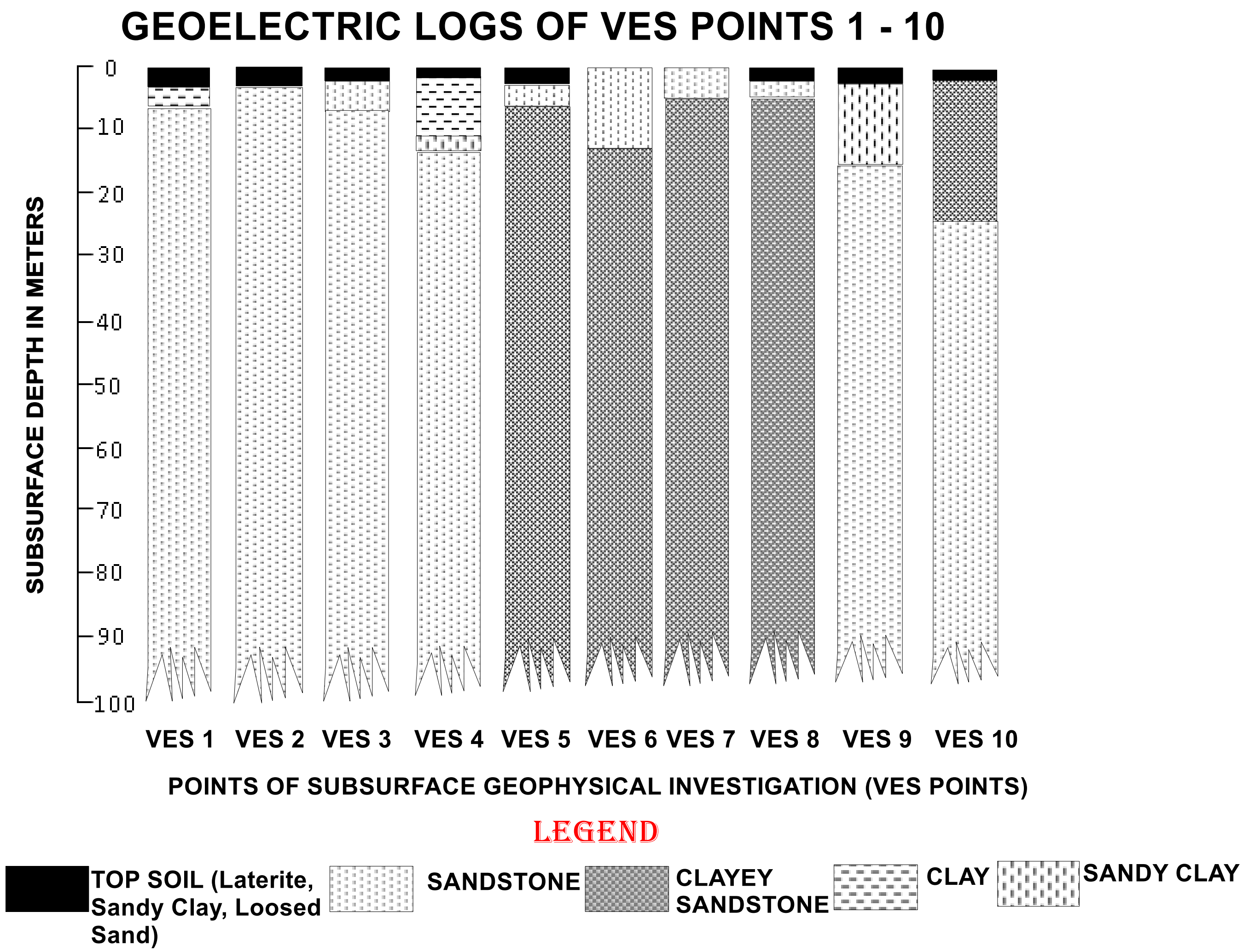


Figure 4.10: Geoelectric profiles for VES locations 1-10

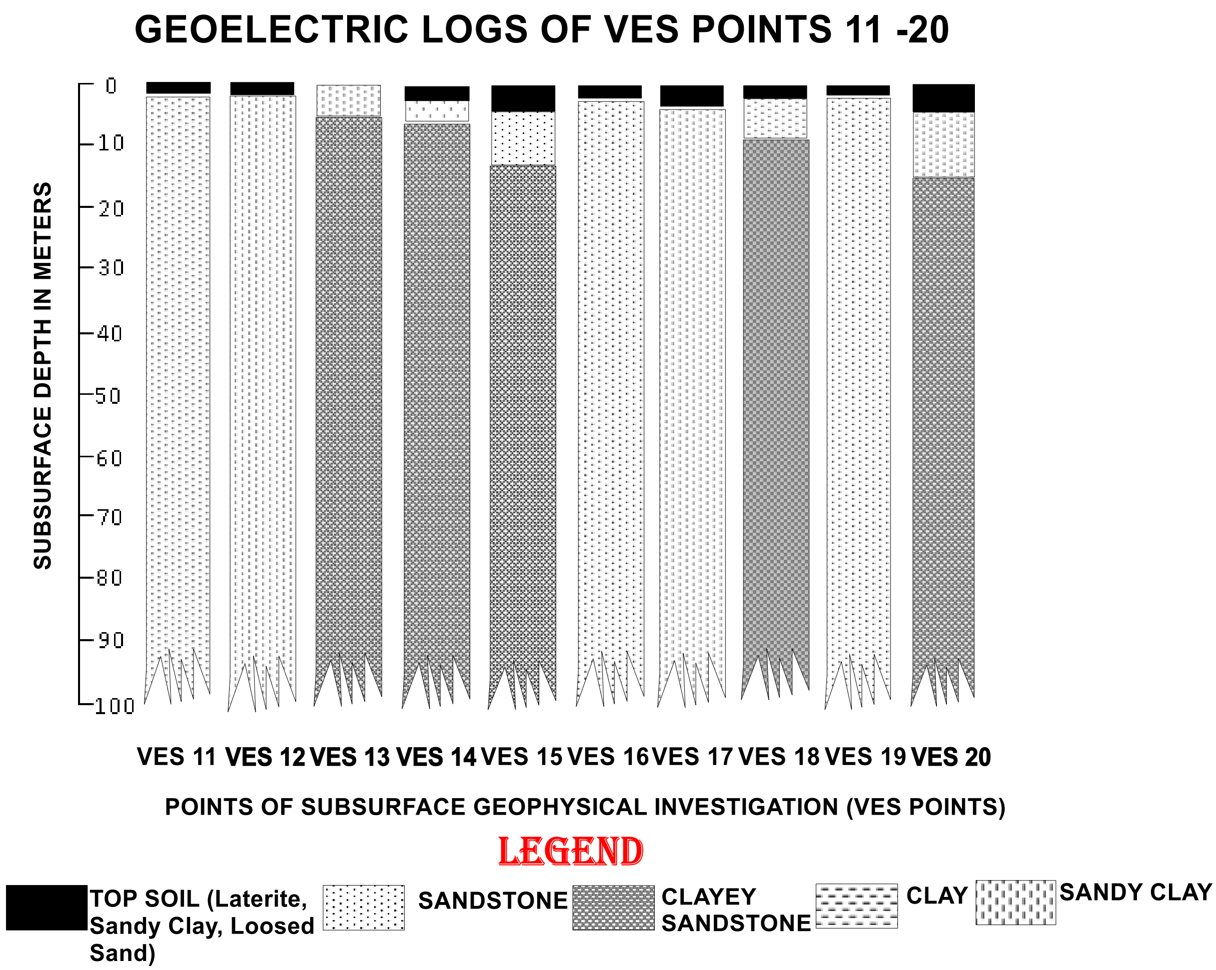


Figure 4.11: Geoelectric profiles for VES locations 11-20

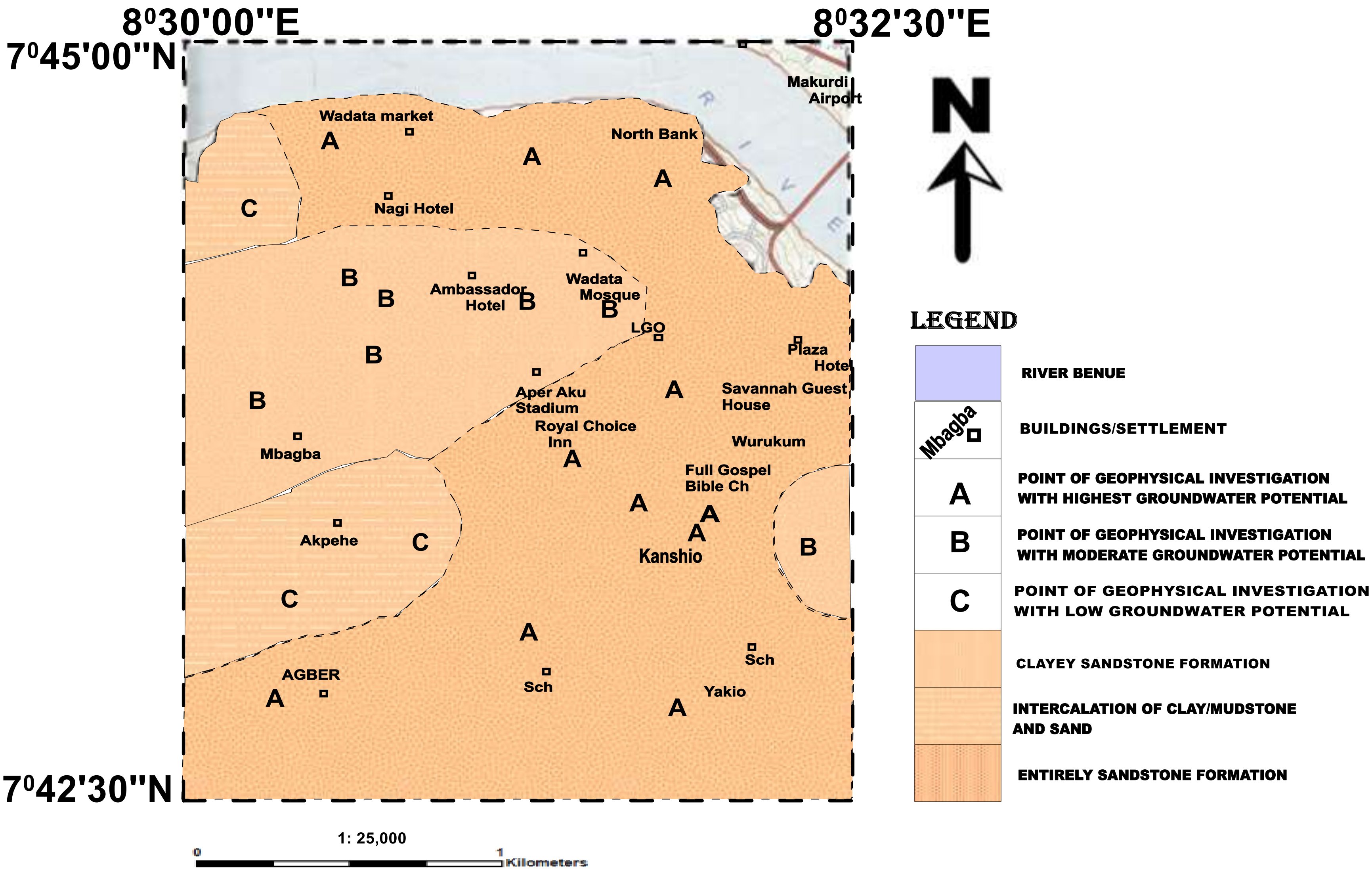


Figure 4.12: Groundwater potential map of the study area

4.2.3 Hydrogeochemistry

Thirty five (35) water samples were collected for hydrogeochemical analysis from different locations within the study area. Twenty one (21) from hand dug wells, ten (10) from boreholes and four (4) from the river. Twenty four (24) parameters comprising both physico-chemical and bacteriological parameters were analyzed for. Refer to appendix C for the result of the hydrochemical analysis carried out. Tables 4.4 and 4.5 showing some statistical details obtained from the results of the analyzed parameters.

Table 4.4: Range of values for analyzed parameters

PARAMETER	RANGE OF VALUES
Physical Parameters	
pH	7.26 – 9.0
Ec	72.5 – 1577µS/cm
TDS	48 – 1190
Chemical Parameters	
Ca	6.41 – 57mg/L
Mg	2.93 – 94 mg/L
Na	5 – 200 mg/L
K	4 – 41 mg/L
Cl	4 -250 mg/L
HCO_3	7 – 112 mg/L
CO_3^{2-}	0 mg/L
SO_4^{2-}	3 – 100 mg/L
F	0 – 2 mg/L
Bacteriological Parameters	
Total coliforms	5 – 190
Faecal coliforms	0 - 57

Table 4.5: Mean value of analyzed parameters in comparison with the NSDWQ (2007) and WHO, 2006

S/no	Parameter	Mean value	NSDWQ (2007)	WHO (2006)
1	TDS (mg/L)	378.39	500	-
2	Conductivity (mS/cm)	539.47	1000	1000
3	Dissolved Oxygen (mg/L)	6.48	-	-
4	Temperature (ºC)	30.64	Ambient	-
5	pH	8.03	6.5-8.5	-
6	Turbidity (NTU)	1.90	5	5
7	Total Hardness (mg/L)	145.31	150	-
8	Total alkalinity	40.83	-	-
9	Iron	0.16	0.3	-
10	Copper	0.41	1	2
11	Sulphate	26.08	100	100
12	Phosphate	2.51	-	
13	Phosphorus	0.89	-	
14	Nitrate	21.7	50	50
15	Bicarbonate	39.31	-	
16	Nitrite	0.24	0.2	3
17	Fluoride	0.16	1.5	1.5
18	Chloride	38.28	250	-
19	Sodium	50.06	200	-
20	Potassium	22.34	-	-
21	Calcium	27.12	-	-
22	Magnesium	21.19	20	-
23	Total coliform	40.36	10	10
24	Faecal coliform	6.29	Nil	Nil

4.2.3.1 Mean values of the analyzed parameters

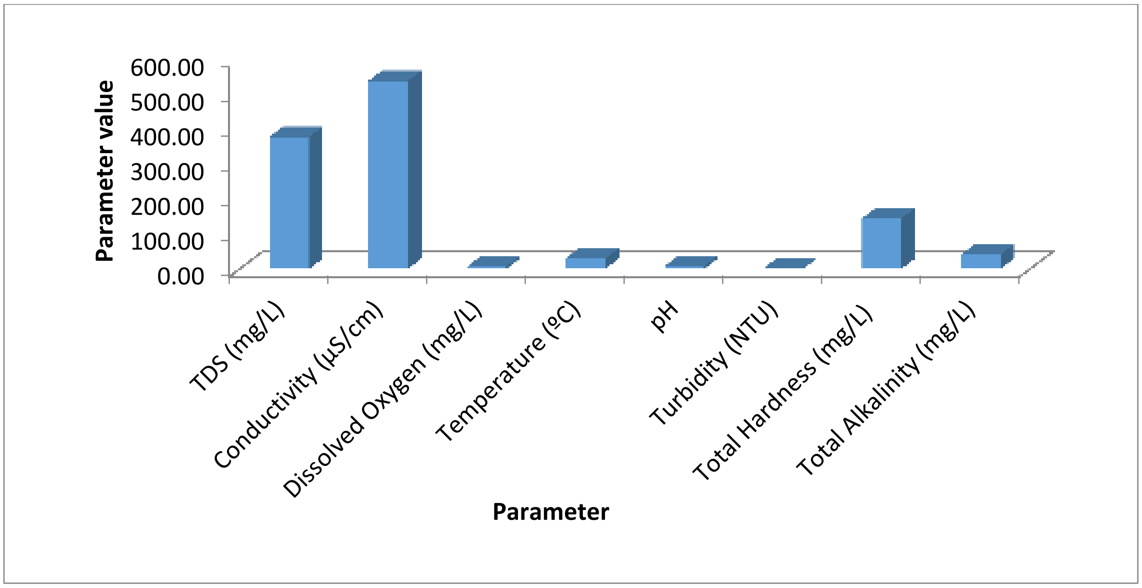


Figure 4.13: mean value of physical parameters

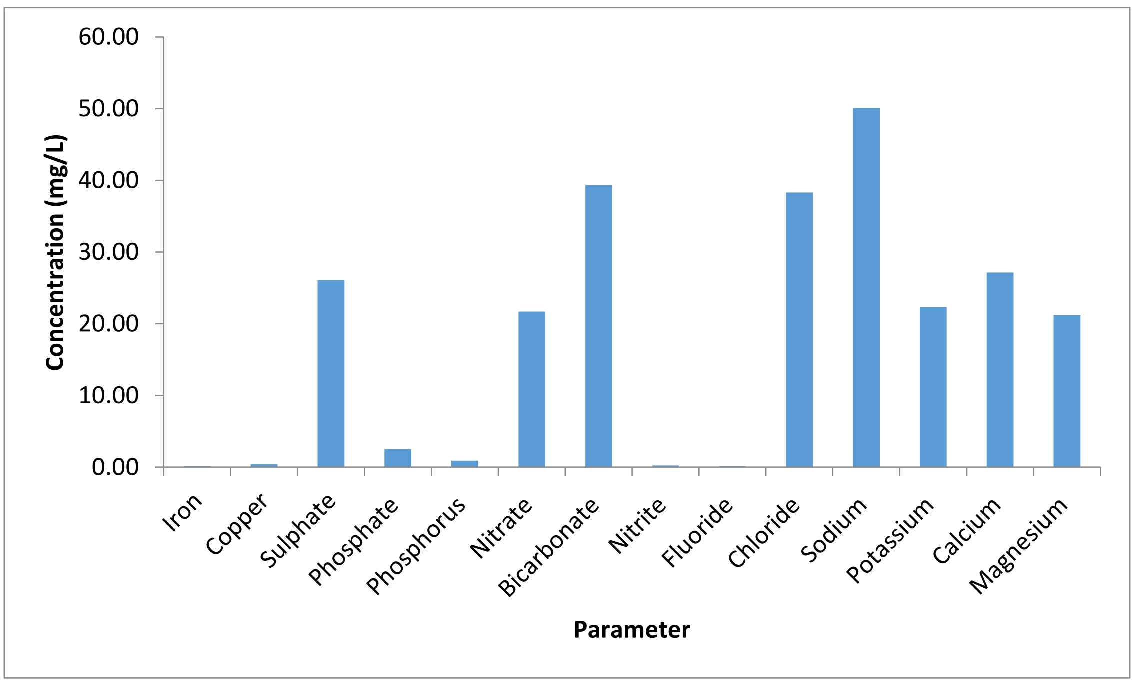


Figure 4.14: mean value of chemical parameters

4.2.3.2trilinear Piper Plot for the Analyzed Cations and Anions

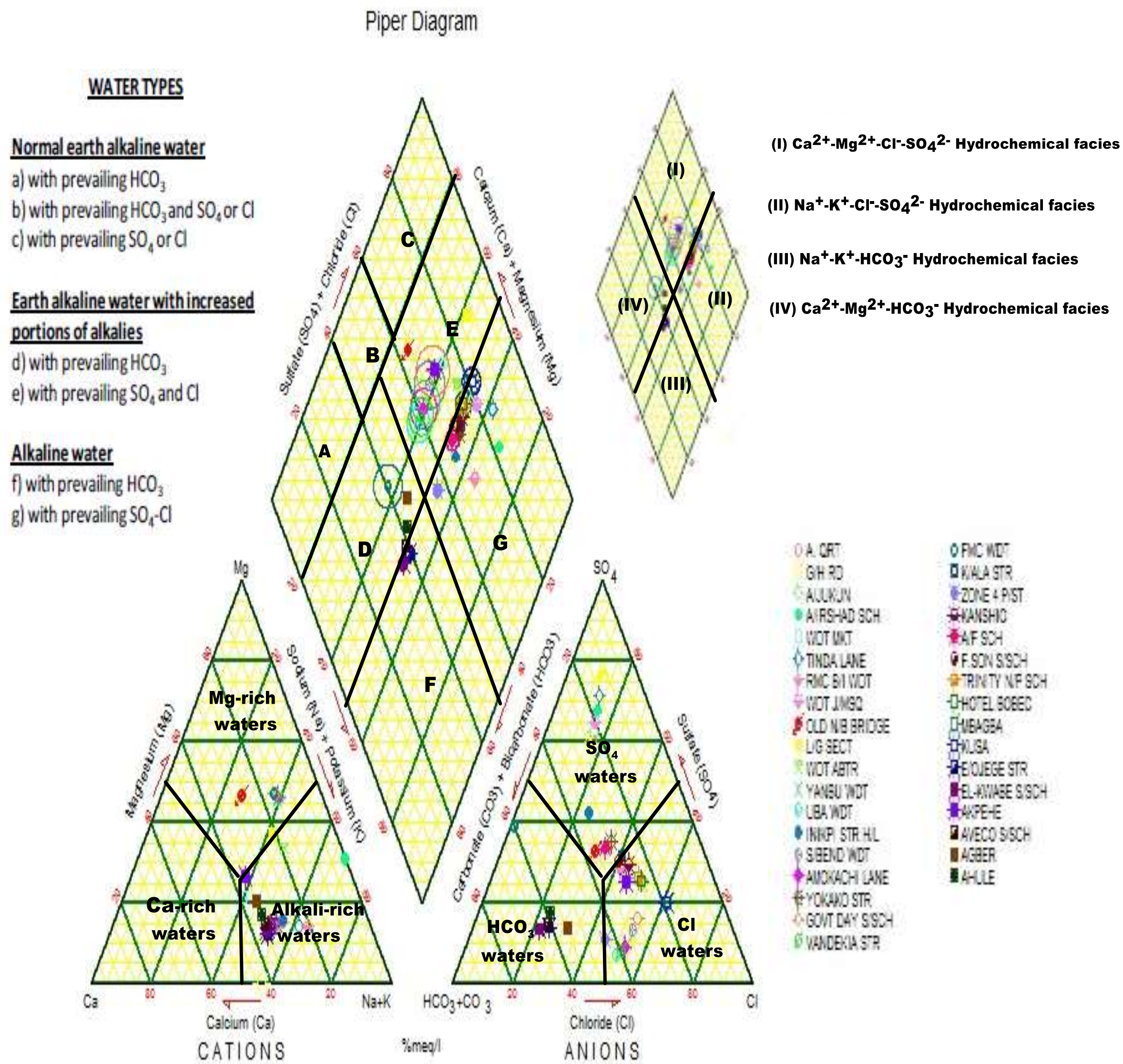


Figure 4.15: Piper trilinear plot for the analyzed cations and anions

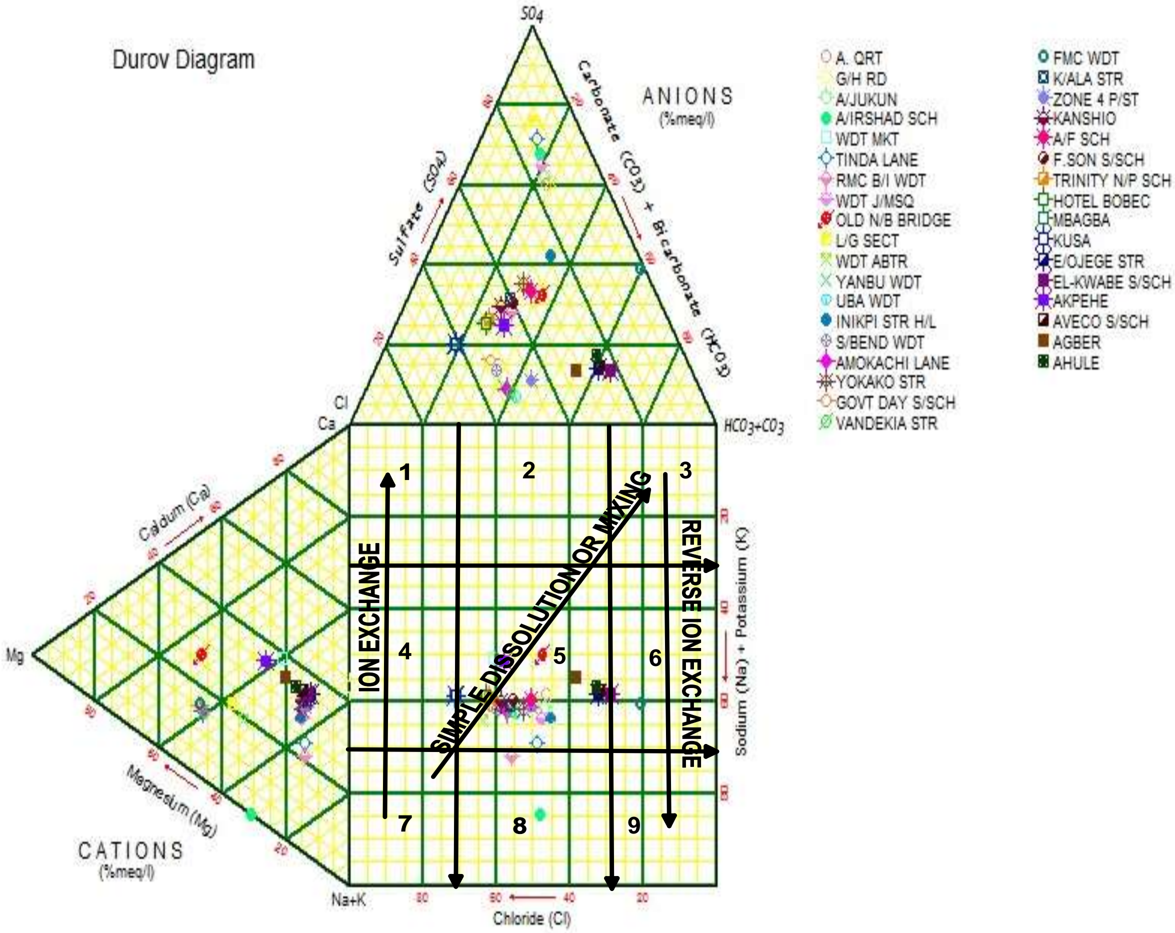


Figure 4.16: Durov hydrochemical plot for the analyzed cations and anions

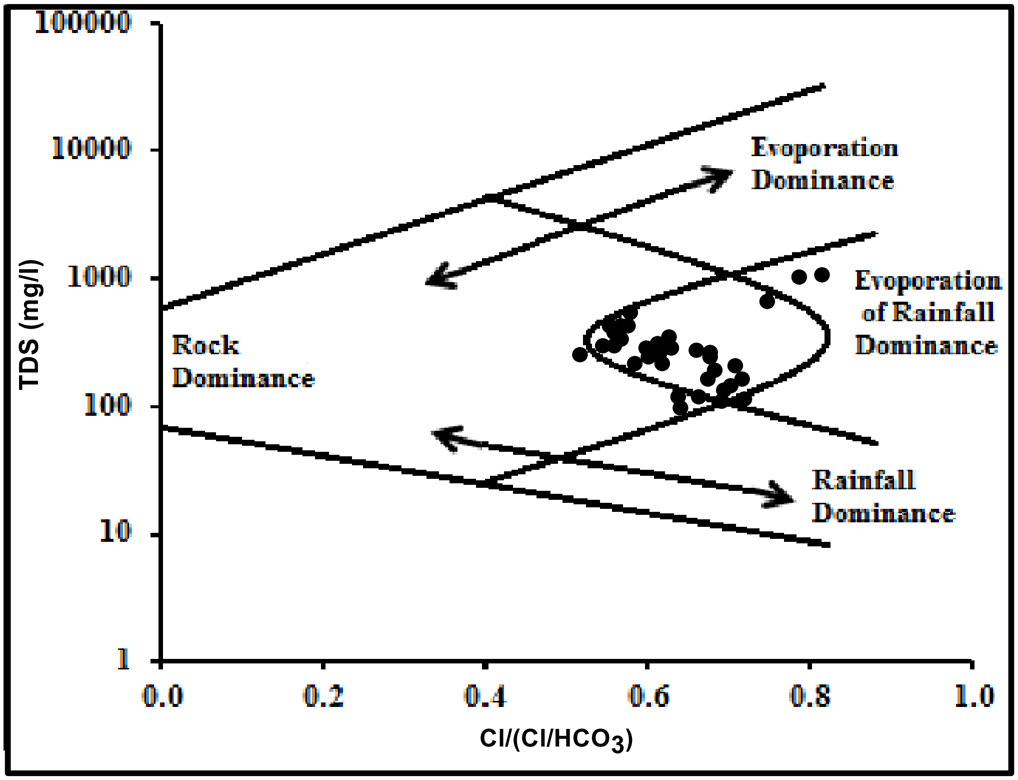


Figure 4.17: Gibb's hydrochemical plot using anion ratio

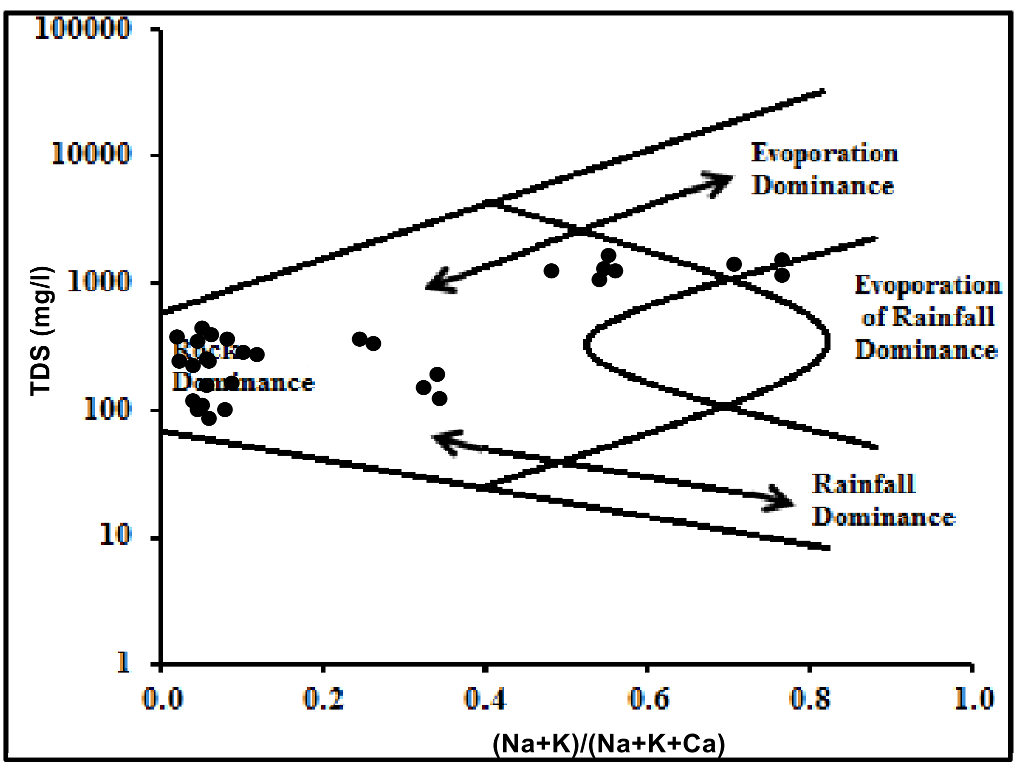


Figure 4.18: Gibb's hydrochemical plot using cation ratio

4.3 Discussion of Results

4.3.1 Geology

The study area falls within the sedimentary terrain of Nigeria and is composed entirely of sandstone formation; commonly known in most literatures as the Makurdi sandstone (Figure 4.1). It is indurated and where exposed appeared to be extremely weathered. Lots of structures such as iron concretions, mottling, lineations, dipping beds, laminations, bioturbation, fractures, graded bedding and ripple marks were depicted as shown in plates 4.1 – 4.10. Texturally the sandstone ranges from fine to coarse grain.

4.3.2 Field Hydrogeological Data

The well from which the water samples were collected were found to be either stone pitched or concrete lined except about eight wells which were open wells. The depth of the wells ranges from 0.71m to 8.4m with most of the wells falling between depths of 3.5m – 5.5m. The water level (WL) ranges from 0.3m – 8.3m while the water column ranges from 0 – 5.5m. Some of the wells were completely dry as can be seen from the water column readings. Information from residents of the study area revealed that most of the wells are seasonal with just a few exceptional cases. From the “Depth to Water” contour map (Figure 4.4), it can be inferred that water can be harnessed in the North-eastern parts and a few other areas of the study areas between a depth of 1 – 6m while in the other parts one would have to go to a depth of between 9 – 20m. From the “Water Table Elevation” contour map (Figure 4.5), it can be inferred that a dominant portion of the study area have a water table elevation of between 85 – 100m. However some parts have a water table elevation of between 70 – 80m while others between 90 – 125m.

4.3.3 Geophysics

From the geophysical investigations carried out, the apparent resistivity was calculated in ohm-meters (Ωm) by multiplying the resistance obtained in the field by the geometric factor. A maximum depth (AB/2) of 100m was investigated. The sounding model curves (Figures 4.6- 4.15) obtained from the various VES points show three and four layers earth models. The model curves are characterized by A, H and Q curve types. The layers comprise of the top soil which is either lateritic, sandy clay or loosed sand and the subsequent layers comprising of sandstone, clayey sandstone, clay or sandy clay (Figures 4.16 and 4.17).

The geoelectric sections were constructed from the geoelectric parameter derived from the iteration of the model curves (Tables 4.3a and 4.3b). From the geoelectric profiles/sections, a lithostratigraphic map was produced which would tell at a glance areas with similar lithostratification (Figure 4.21) and hence make exploration for groundwater easier and faster.

The isoresistivity maps (Figures 4.16 – 4.18) revealed that the area with the highest potential is the North-eastern and South-eastern portion of the study area. This assessment was based solely on the standard apparent resistivity readings (50 -120Ωm) for potential aquifers within the study area obtained from previous works on the study area.

4.3.4 Hydrochemistry

Twenty four (24) parameters comprising physical, chemical and microbial parameters were analysed in all the water samples collected. A total of thirty five (35) water samples from different locations were collected strategically across the study area. Comparing the mean value of the analyzed parameters with the Nigerian Standard Drinking Water Quality 2007, all the water samples were seen to fall within the permissible limits. However, when comparing the values individually according to locations, eleven (11) out of the thirty five (35) locations had concentrations of some of the parameters analysed above the permissible NSDWQ (2007) standard and hence not considered safe for drinking (refer to Appendix C). All the water samples from the remaining twenty four (24) locations are certified for drinking purposes and other domestic uses.

The eleven locations with some of their parameters beyond the NSDWQ (2007) permissible limits are Yanbu wadata, sharp bend wadata, Government day secondary school wadata, Federal Medical Center Wadata, Amokachi lane, Vandekia street, UBA bank wadata, RMC block industry, Wadata market, River bank wadata and beside old north bank bridge. Enlisted below are the various parameters whose concentrations were found to be above the NSDWQ (2007) standard; their health impact and possible treatment measures for their total removal or reduction in their concentration.

i. Total Dissolved Salts (TDS):

The maximum allowable NSDWQ (2007) standard for TDS is 500mg/L. Seven locations had TDS concentration beyond this limit ranging from 920mg/L – 1190mg/L. This could have a slight possibility of salt overload in sensitive groups (people who may have particular medical conditions which make them more susceptible to poor water quality; WHO, 2008). Treatment can be done through desalination or ion exchange processes but is very expensive and normally considered not viable.

ii. Electrical Conductivity

The maximum allowable NSDWQ (2007) value for electrical conductivity is 1000mS/m. However, seven locations (refer to Table 4.4e) within the study area have concentrations above this value ranging from 1456 – 1577mS/m. This could have health implications such as disturbance of the salt and water balance in children, increase in blood pressure of heart patients and renal patients and laxative effects when sulphate concentration is high. This can be treated through chemical adjustment of water pH through the addition of alkaline reagents or acidic reagents as the case may be (WHO, 2008).

iii. Total Hardness

The maximum permissible NSDWQ (2007) value for total hardness is 150mg/L. Seven locations within the study area (Table 4.4e) has concentrations above this value ranging from 389 – 461 mg/L. Concentrations like this could pose health threats to sensitive people with a history of kidney or gall-bladder stones and children under the age of one (WHO, 2008). It can be treated by cation exchange and mixed-bed-ion-exchange desalination to demineralise the water. Precipitation and sedimentation can also be used if a large volume of water is involved.

iv. Iron

The maximum permissible NSDWQ (2007) concentration for iron is 0.3mg/L. Seven locations within the study area (Table 4.4e) have concentrations above this value ranging from 0.5 – 0.65mg/L. Concentrations of this range could lead to health threats such as acute poisoning in babies and children and chronic iron poisoning over a long period of time can lead to Will's disease (Haemochromatosis). It can be treated through aeration for uncomplexed iron but strong chemical oxidation and lime will be necessary for complexed iron. Conventional coagulation and flocculation techniques are also effective for removal of iron (WHO, 2008).

v. Copper

The maximum NSDWQ (2007) permissible limit for copper is 1mg/L. Seven locations within the study area have concentrations above this value ranging from 1.16 – 1.37 (Table 4.4e). Very high concentration of copper can cause acute damage to the liver and kidneys. It can be treated using lime and a precipitation method whereby the copper is precipitated as copper hydroxide under alkaline conditions (WHO, 2008).

vi. pH

The NSDWQ (2007) permissible pH range is between 6.5 – 8.5. Eleven locations within the study area have pH value above the maximum scale limit ranging from 8.53 – 8.68 which proves to be alkalinic (Table 4.4e). direct health problems of pH extremes includes the irritation or burning effect on the mucous membranes. It can be treated through chemical adjustment of water pH through the addition of acidic reagents to reduce the alkalinity (WHO, 2008).

vii. Turbidity

The turbidity range maximum allowable limit in the NSDWQ (2007) is 5NTU (Nephelometric Turbidity Units). Four locations within the study area have values above this permissible limit ranging between 8.55 – 8.67NTU. Turbidity itself does not have any health risks for people but serves as an indicator of the cleanliness and clarity of the water. Hence, to properly disinfect water, all the suspended solids must be removed. The process of treatment of turbidity is in accordance to the degree of turbidity. The common processes used for decreasing turbidity, are flocculation, settlement and filtration (WHO, 2008).

viii. Nitrate

The Nitrate range permissible in the NSDWQ (2007) standard is 50mg/L. Seven locations within the study area have nitrate concentration beyond the above mentioned value ranging from 65.2 – 69.1mg/L (Table 4.4e). It has no effect on the appearance of water (no taste, colour or smell). However, in concentrations above the permissible limits could cause chronic fatigue and stunted growth in humans. It can be treated using ionic-exchange, reverse osmosis and denitrification processes (WHO, 2008).

ix. Magnesium

The maximum NSDWQ (2007) permissible concentration for magnesium is 20mg/L. Seven locations within the study area have magnesium concentration beyond the above mentioned permissible limit ranging from 6.19 – 94.3mg/L. High concentrations like this could have health side effects such as suppression of the central nervous system and when in combination with sulphate can result in diarrhoea. It can be treated by lime softening followed by recarbonation. However, ion exchange resins or precipitation of magnesium at high pH are also effective (WHO, 2008).

x. Total coliforms

The maximum NSDWQ (2007) permissible limit for total coliforms is 10. Eleven locations have total coliforms beyond the above mentioned limit ranging from 65-190. The presence of total coliforms in high numbers such as this is an indication of the presence of other disease-causing micro organisms which can cause several gastro-intestinal diseases whose symptoms include diarrhoea and fever. It can be treated through flocculation, coagulation and filtration. However for total removal of total coliforms, the water can be treated chemically (chlorination) or physically through ultra filtration or ultraviolet light (WHO, 2008).

xi. Faecal coliform

The presence of faecal coliforms is totally not allowed in the NSDWQ (2007). Eleven locations have varying amounts of faecal coliforms ranging from 2 – 57 per 100ml of water. It forms part of the total coliforms and hence have the same health impact. The presence of faecal coliforms is an indication of the presence of other disease-causing micro organisms which can cause several gastro-intestinal diseases whose symptoms include diarrhoea and fever (WHO, 2008). It can be treated through flocculation, coagulation and filtration. However for total removal of total coliforms, the water can be treated chemically (chlorination) or physically through ultra filtration or ultraviolet light.

From the Piper plot (Figure 4.15), 57.1% of the water samples belong to the Alkaline water type while 42.9% belong to the Earth Alkaline Water type. The piper plot also identified four hydrochemical facies; 51.4% belonging to the Ca-Mg-Cl-SO_4 facies, 31.4% to the Na-K-Cl-SO_4 facies, 11.5% belonging to the Ca-Mg-HCO_3 facies and finally 5.7% to the Na-

$K\text{-}HCO_3$ facies. The Durov plot (Figure 4.16) indicated that 85.7% of the water samples falls under the mixed water type indicating no dominant cation or anion, 5.7% indicates a water type where Ca and SO_4 are dominant, 5.7% also indicates a water type that has Na and Cl as the dominant ions and finally 2.9% of the samples indicates a water type dominant in HCO_3 and Ca ions. The Durov plot also indicated that the basic hydrochemical process responsible for the chemistry of the groundwater is simple dissolution or mixing with subordinate hydrochemical process of reverse ion exchange of Na-Cl waters.

The Gibb's plot indicates that the major geological process controlling the water quality or chemistry is rock weathering with influence of evaporation.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

An integrated geological, geophysical and hydrogeological studies was carried out on the North-western flank of Makurdi, North-central Nigeria (Makurdi sheet 251 S.W) covering a total area of about 16.25km^2. The study area is entirely sedimentary and is dominantly sandstone with varying amounts of silt and clay. The sandstone is indurated though has undergone a relative amount of weathering as seen in some exposures. The texture ranges from fine to coarse grain. A geological and lithostratigraphic map was produced in other to have an insight on both the surface and subsurface geology. The geophysical investigation revealed that the study area comprises about three to four subsurface stratification comprising the top soil (laterite, clay or loosed sand) and the subsequent layers comprising of sandstone, clayey sandstone, clay or sandy clay. The thickness of these various layers varies with location. The isoresistivity maps generated revealed that a dominant part of the study area has a very good groundwater potential at shallow depths of about 20m – 30m while at a depth of 50m, only the North-Eastern and South-Eastern parts of the study area have a good groundwater potential.

Comparing the mean value of the analysed parameters with the Nigerian Standard Drinking Water Quality (2007), all the water samples were seen to fall within the permissible limits. However, when comparing the values individually according to locations, eleven (11) out of the thirty-five (35) locations had concentrations of some of the parameters analysed above the permissible NSDWQ (2007) standard and hence not considered safe for drinking

(Appendix C). The Durov plot indicated that the basic hydrochemical process responsible for the chemistry of the groundwater is simple dissolution or mixing with subordinate hydrochemical process of reverse ion exchange of Na-Cl waters. It was deduced from the Gibb's plot that the major geological process controlling the water quality or chemistry is rock weathering with influence of evaporation.

5.2 Recommendations

Most of the hand dug wells in the study area are very shallow and hence seasonal in nature; the depth of the hand dug wells should be increased to reach the water table and hence make it productive all year round.

From the geophysical investigation carried out; the aquiferous formation for some of the areas is about 30 -50m and hence cannot be easily exploited by hand dug wells. In such areas public boreholes can be drilled by the government or individuals as a means of augmenting the seasonal wells in such localities.

From the hydrochemical analysis carried out; some locations have water that is not safe for drinking except after treatment. Consumption of water from such localities could pose health threats such as suppression of the central nervous system, gastro-intestinal diseases, acute damage to the liver and kidney, Will's disease just to mention a few. Adequate treatment measures have been recommended in the research work.

The abandoned waterworks project for the supply of pipe borne water should be revisited and completed by the government. This would go a long way in curtailing the water supply issues. Furthermore, the data in this research work can be used as a bench mark for groundwater resource development within the study area.

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APPENDIX A

Hydrologic well data

S/No	Latitude (N)	Longitude (E)	Elevation (M)	Well type	WL	Well depth	Well diameter	Water column
1	7º43'35.8"	8º32'21.7"	93	Stone pitched	20	20.18	0.57	0.18
2	7º43'37.0"	8º32'16.3"	96	Stone pitched	5.7	5.88	0.66	0.18
3	7º44'37.4"	8º31'08.6"	76	Stone p itched	1.3	1.55	0.84	0.71
4	7º44'34.6"	8º31'07.3"	76	Stone pitched	1.7	1.84	0.72	0.14
5	7º44'33.0"	8º31'08.8"	77	Concrete lined	4.25	4.30	0.90	0.05
6	7º44'33.1"	8º31'08.7"	79	Concrete lined	1.3	1.80	0.90	0.5
7	7º44'32.7"	8º31'09.9"	83	Stone pitched	4.05	4.25	1.23	0.2
8	7º44'33.2"	8º31'09.9"	80	Concrete lined	1.35	1.40	0.9	0.05
9	7º44'34.1"	8º31'04.5"	75	Concrete lined	2.99	3.0	0.9	0.01
10	7º44'34.2"	8º31'03.3"	84	Concrete lined	3.85	3.86	0.9	0.01
11	7º44'37.0"	8º30'51.7"	89	Stone pitched	4.02	4.0	0.9	0.02
12	7º44'38.6"	8º30'53.0"	90	Stone pitched	3.47	3.5	1.2	0.03
13	7º44'40.3"	8º30'51.8"	84	Stone pitched	4.20	4.21	0.7	0.01
14	7º44'43.8"	8º30'52.5"	78	Stone pitched	5.8	6.10	0.9	0.4
15	7º44'44.3"	8º30'53.8"	77	Concrete lined	0.9	1.12	0.7	0.22
16	7º44'44.0"	8º30'53.9"	76	Concrete lined	1.7	1.85	0.7	0.15
17	7º44'43.7"	8º30'55.4"	81	Stone pitched	4.9	6.1	0.9	1.2
18	7º44'45.8"	8º30'44.3"	78	Stone pitched	1.1	1.65	0.8	0.55
19	7º44'46.0"	8º30'44.4"	77	Stone pitched	6.3	6.5	0.56	0.2
20	7º44'34.3"	8º30'47.5"	93	Stone pitched	1.0	1.9	0.8	0.9
21	7º44'46.7"	8º30'40.1"	77	Concrete lined	2.18	2.46	0.9	0.28
22	7º44'34.0"	8º30'41.0"	90	Concrete lined	3.64	4.0	0.9	0.36
23	7º43'31.3"	8º31'30.7"	94	Concrete lined	3.35	3.95	0.55	0.60
24	7º42'31.1"	8º31'29.5"	91	Stone pitched	3.35	3.55	1.06	0.20
25	7º42'31.2"	8º31'31.9"	93	Stone pitched	2.6	3.10	0.7	0.50
26	7º42'29.8"	8º31'31.0"	87	Stone pitched	1.8	2.20	0.9	0.40
S/No	**Latitude (N)**	**Longitude (E)**	**Elevation (M)**	**Well type**	**WL**	**Well depth**	**Well diameter**	**Water column**
27	7º42'29.3"	8º31'31.2"	93	Stone pitched	1.8	2.0	0.75	0.20

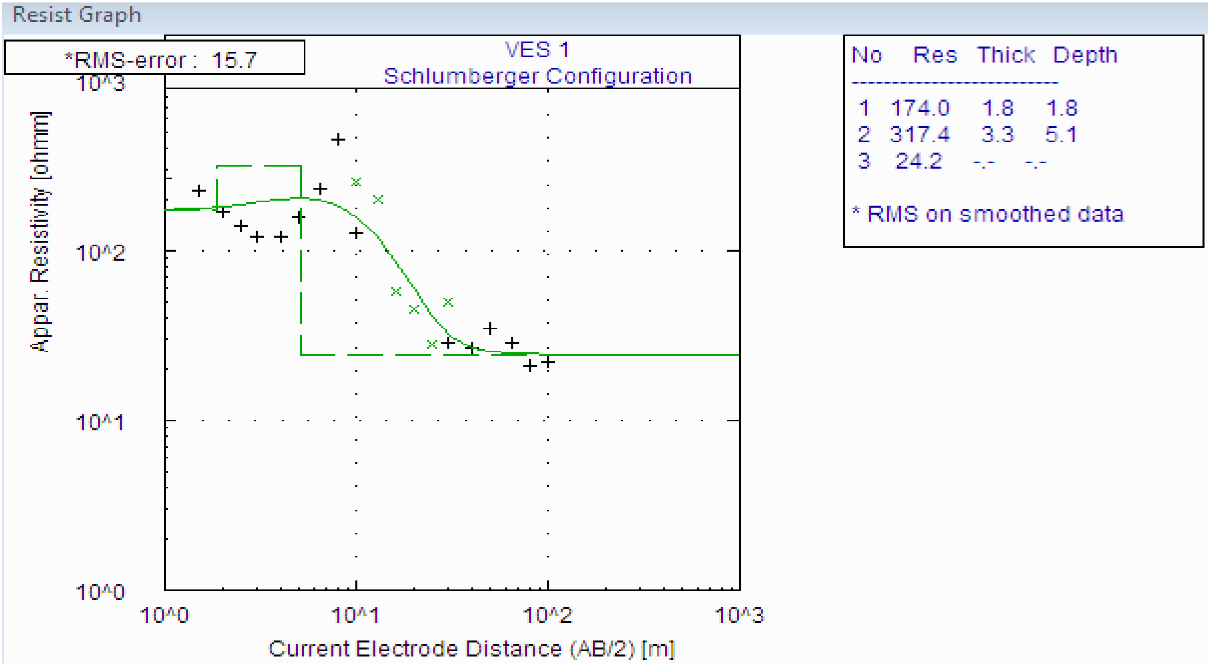
28	7º42'27.4"	8º31'33.0"	86	Stone pitched	6.4	7.1	0.7	0.70
29	7º42'28.4"	8º31'32.9"	99	Stone pitched	5.9	6.9	0.8	1.0
30	7º42'27.7"	8º31'33.7"	90	Stone pitched	6.0	6.5	0.6	0.5
31	7º42'29.4"	8º31'30.5"	90	Stone pitched	1.7	2.4	0.6	0.7
32	7º42'30.3"	8º31'27.8"	103	Stone pitched	4.2	4.4	0.55	0.2
33	7º43'05.4"	8º31'01.2"	100	Stone pitched	4.2	4.4	0.58	0.2
34	7º43'09.9"	8º30'42.1"	90	Stone pitched	6	8.1	8.8	2.1
35	7º43'12.0"	8º30'36.7"	105	Stone pitched	8.4	8.5	0.9	0.1
36	7º43'26.3"	8º30'11.5"	97	Stone pitched	4.5	4.6	0.7	0.1
37	7º43'13.5"	8º31'09.6"	109	Stone pitched	6.0	6.1	0.55	0.1
38	7º43'16.9"	8º31'08.4"	108	Stone pitched	6.65	7.85	1.1	1.2
39	7º43'18.4"	8º31'09.0"	99	Stone pitched	6.5	6.6	0.97	0.1
40	7º43'18.8"	8º31'07.6"	103	Stone pitched	4.2	4.2	0.72	0.0
41	7º43'17.7"	8º31'07.3"	93	Stone pitched	4.6	4.7	0.58	0.1
42	7º43'17.0"	8º31'07.2"	101	Stone pitched	6.0	6.1	0.72	0.1
43	7º43'12.0"	8º31'10.4"	103	Stone pitched	5.5	5.5	0.82	0.0
44	7º43'08.6"	8º31'18.1"	119	Stone pitched	7.7	7.8	0.85	0.1
45	7º43'08.1"	8º31'21.1"	111	Stone pitched	6.5	7.5	0.94	1.0
46	7º43'03.3"	8º31'14.6"	117	Stone pitched	6.0	6.1	1	0.1
47	7º43'04.2"	8º31'12.9"	113	Stone pitched	5.6	6.5	1	0.9
48	7º43'19.3"	8º31'16.5"	127	Open well	8.3	8.4	1.1	0.1
49	7º43'19.1"	8º31'17.9"	104	Stone pitched	7.75	8.0	1.14	0.25
50	7º43'20.0"	8º31'16.9"	110	Open well	6.5	6.5	1	0.0
51	7º43'20.6"	8º31'15.6"	101	Open well	6.2	6.2	0.55	0.0
52	7º43'21.7"	8º31'18.5"	102	Open well	5.75	6.3	1.1	0.55
53	7º43'23.2"	8º31'16.1"	113	Open well	4.4	5.0	1.35	0.6
54	7º43'23.6"	8º31'14.0"	130	Stone pitched	3.35	3.95	1	0.6
S/No	**Latitude (N)**	**Longitude (E)**	**Elevation (M)**	**Well type**	**WL**	**Well depth**	**Well diameter**	**Water column**
55	7º43'50.9"	8º32'15.9"	79	Stone pitched	1.75	2.75	0.9	1.0
56	7º43'55.6"	8º32'07.9"	85	Stone pitched	2.10	2.6	1	0.5
57	7º43'57.7"	8º32'04.6"	87	Stone pitched	2.6	3.3	0.6	0.7
58	7º43'55.9"	8º32'07.7"	83	Stone pitched	1.1	6.6	0.7	5.5

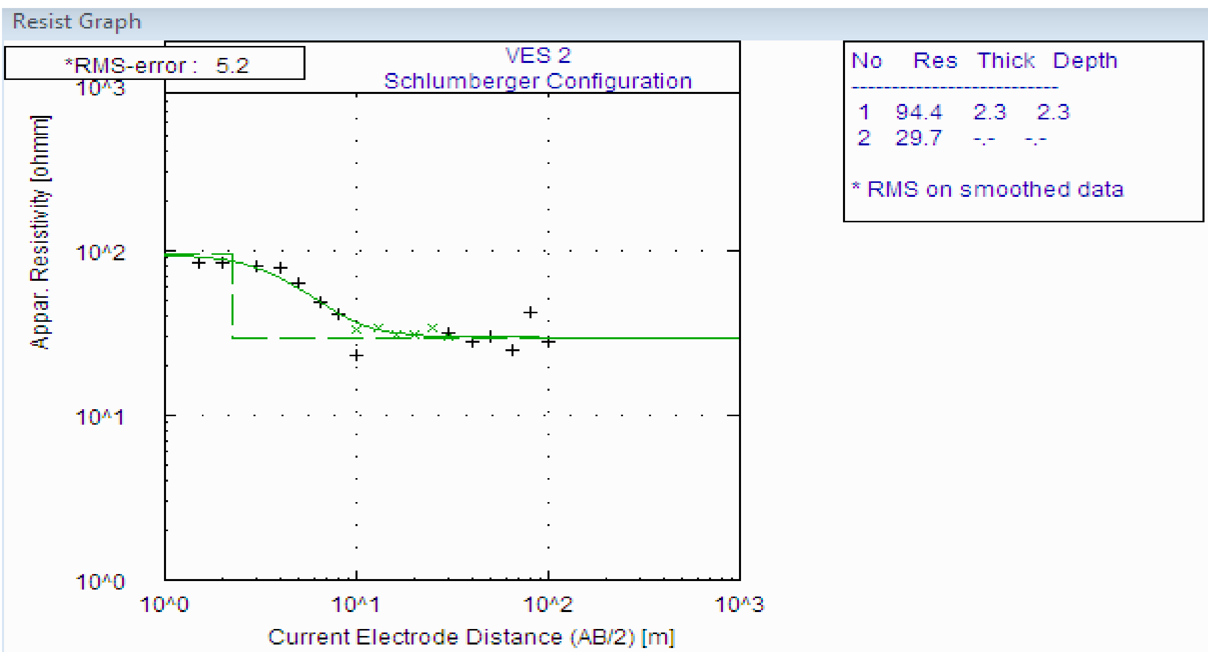
59	7º43'49.1"	8º32'01.6"	84	Stone pitched	1.5	4.7	0.5	3.2
60	7º43'39.2"	8º31'56.3"	78	Concrete lined	2.1	2.4	0.5	0.3
61	7º44'36.8"	8º30'22.2"	82	Stone pitched	3.0	3.1	0.6	0.1
62	7º44'31.0"	8º30'17.9"	82	Stone pitched	3.8	3.82	0.9	0.02
63	7º44'39.2"	8º30'19.1"	91	Open well	4.8	6.9	1.3	2.1
64	7º44'27.4"	8º30'17.8"	89	Stone pitched	5.6	7.0	0.81	1.4
65	7º44'24.1"	8º30'18.7"	89	Stone pitched	4.1	4.1	0.56	0.0
66	7º44'21.6"	8º30'18.6"	89	Stone pitched	4.2	4.3	0.69	0.1
67	7º44'19.8"	8º30'19.3"	90	Stone pitched	6.4	6.5	0.58	0.1
68	7º44'37.7"	8º30'16.5"	103	Stone pitched	3.2	3.7	0.67	0.5
69	7º44'39.0"	8º30'16.1"	91	Stone pitched	1.6	1.7	0.98	0.1
70	7º44'38.4"	8º30'14.9"	99	Stone pitched	2.4	2.8	0.86	0.4
71	7º44'35.8"	8º30'13.6"	91	Concrete lined	4.7	4.78	0.77	0.08
72	7º44'18.7"	8º30'13.7"	87	Stone pitched	1.1	3.4	0.71	2.3
73	7º44'34.0"	8º30'17.3"	91	Stone pitched	4.3	4.4	0.56	0.1
74	7º44'36.4"	8º30'18.9"	89	Stone pitched	6.2	6.3	0.81	0.1
75	7º44'20.4"	8º30'27.7"	96	Stone pitched	1.2	1.27	0.58	0.07
76	7º44'20.3"	8º30'29.4"	91	Stone pitched	7.8	7.9	0.73	0.1
77	7º44'20.4"	8º30'30.0"	94	Stone pitched	1.9	2.0	0.8	0.1
78	7º44'19.9"	8º30'30.0"	85	Open well	4.0	4.0	0.8	0.0
79	7º44'22.4"	8º30'28.6"	83	Stone pitched	6.9	7.0	0.66	0.1
80	7º44'22.4"	8º30'29.6"	86	Stone pitched	2.2	2.3	0.74	0.1
81	7º44'24.2"	8º30'28.3"	91	Stone pitched	0.7	3.2	1.26	2.5
82	7º44'23.7"	8º30'28.9"	88	Stone pitched	3.7	3.83	0.76	0.13
S/No	**Latitude (N)**	**Longitude (E)**	**Elevation (M)**	**Well type**	**WL**	**Well depth**	**Well diameter**	**Water column**
83	7º44'26.3"	8º30'34.3"	88	Stone pitched	1.0	2.7	0.63	1.7
84	7º44'23.5"	8º30'34.3"	83	Stone pitched	1.23	1.24	0.58	0.01
85	7º44'31.6"	8º30'35.5"	87	Stone pitched	1.1	1.6	0.65	0.5
86	7º44'18.9"	8º30'41.9"	90	Concrete lined	0.7	0.71	0.77	0.01
87	7º44'18.1"	8º30'42.4"	111	Concrete lined	2.3	2.31	0.78	0.01
88	7º44'17.8"	8º30'42.5"	92	Stone pitched	1.8	1.95	0.71	0.15
89	7º44'18.6"	8º30'43.7"	88	Stone pitched	2.3	2.4	0.88	0.1

90	7º44'17.9"	8º30'43.3"	91	Concrete lined	2.7	2.7	0.78	0.0
91	7º44'09.7"	8º30'39.2"	93	Concrete lined	2.1	2.85	0.8	0.75
92	7º44'02.3"	8º30'39.0"	89	Open well	1.1	1.4	0.61	0.3
93	7º44'01.6"	8º30'41.0"	87	Stone pitched	0.9	1.0	0.68	0.1
94	7º43'57.0"	8º30'40.9"	115	Stone pitched	1.6	3.9	0.98	2.3
95	7º43'53.5"	8º30'38.1"	94	Stone pitched	3.6	5.65	0.56	2.05
96	7º43'52.1"	8º30'33.4"	91	Stone pitched	2.29	2.3	0.7	0.01
97	7º43'52.8"	8º30'25.3"	82	Stone pitched	3.6	4.3	0.84	0.7
98	7º43'52.7"	8º30'23.5"	87	Stone pitched	1.7	5.5	0.61	3.8
99	7º43'41.7"	8º30'26.8"	87	Stone pitched	1.0	1.2	0.77	0.2
100	7º43'30.8"	8º30'23.5"	82	Stone pitched	0.8	0.9	0.58	0.1
101	7º43'30.7"	8º32'24.2"	105	Concrete lined	3.1	3.3	0.62	0.2
102	7º43'23.3"	8º32'22.5"	82	Stone pitched	1.9	1.92	0.5	0.02
103	7º43'23.9"	8º32'15.9"	92	Concrete lined	0.5	1.2	0.6	0.7
104	7º43'22.3"	8º32'14.2"	96	Concrete lined	1.2	1.4	0.45	0.2
105	7º43'19.0"	8º32'08.0"	90	Stone pitched	3.5	4.8	0.62	1.3
106	7º43'14.7"	8º32'10.5"	83	Stone pitched	1.4	1.8	0.6	0.4
107	7º43'16.4"	8º32'09.1"	84	Stone pitched	2.5	2.6	0.63	0.1
108	7º43'20.4"	8º32'16.0"	103	Concrete lined	0.3	0.9	0.57	0.6
109	7º43'22.4"	8º32'21.1"	84	Stone pitched	1.7	1.7	0.18	0.0
110	7º43'24.6"	8º32'23.2"	86	Stone pitched	1.5	1.9	1.0	0.4

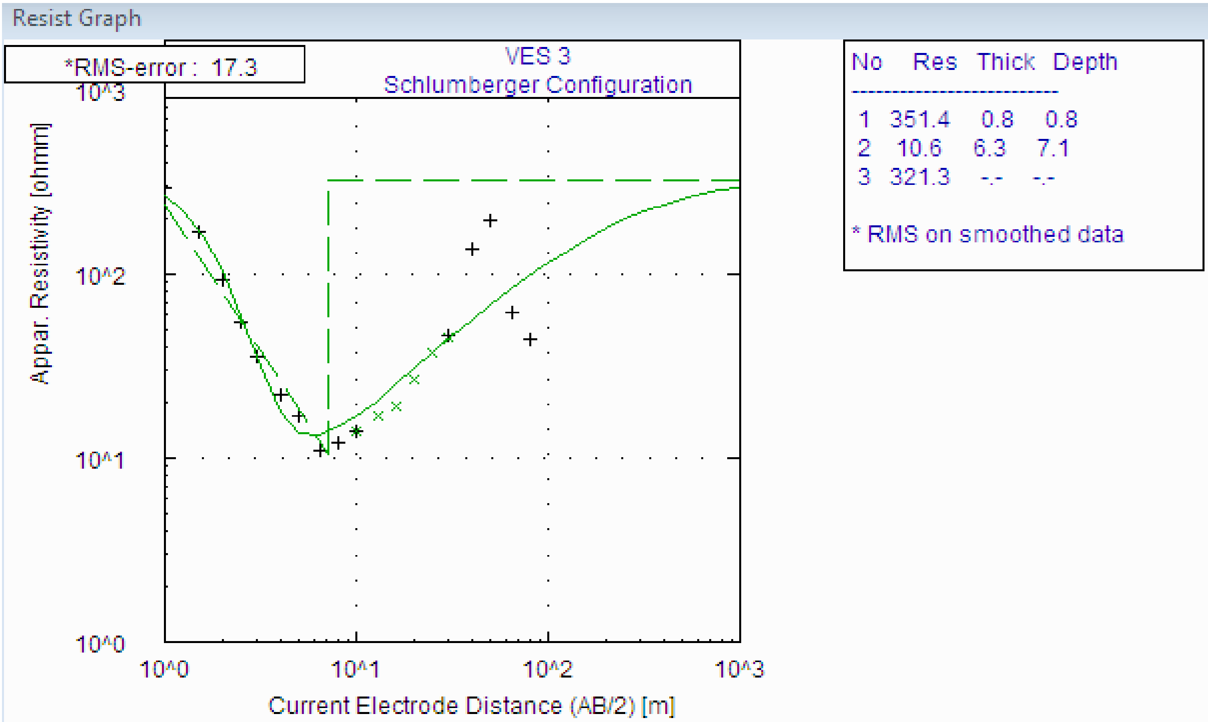
APPENDIX B

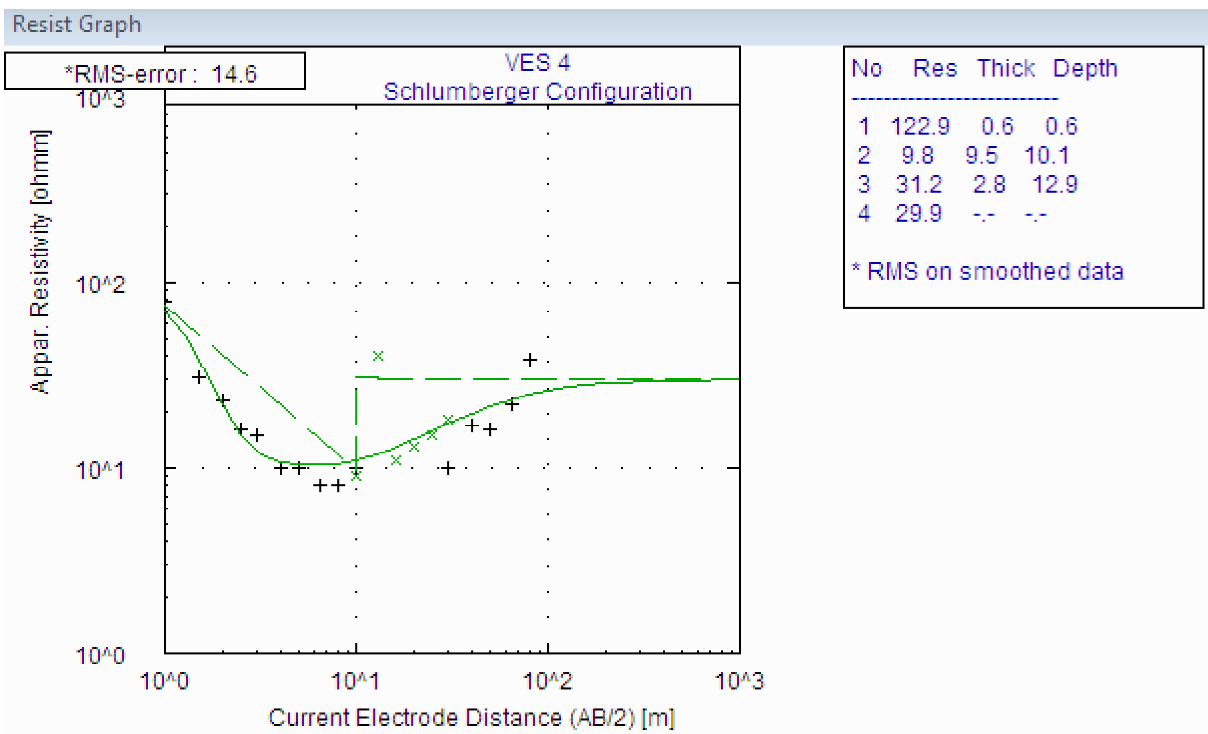
Geoelectric resistivity curves of all the VES points.



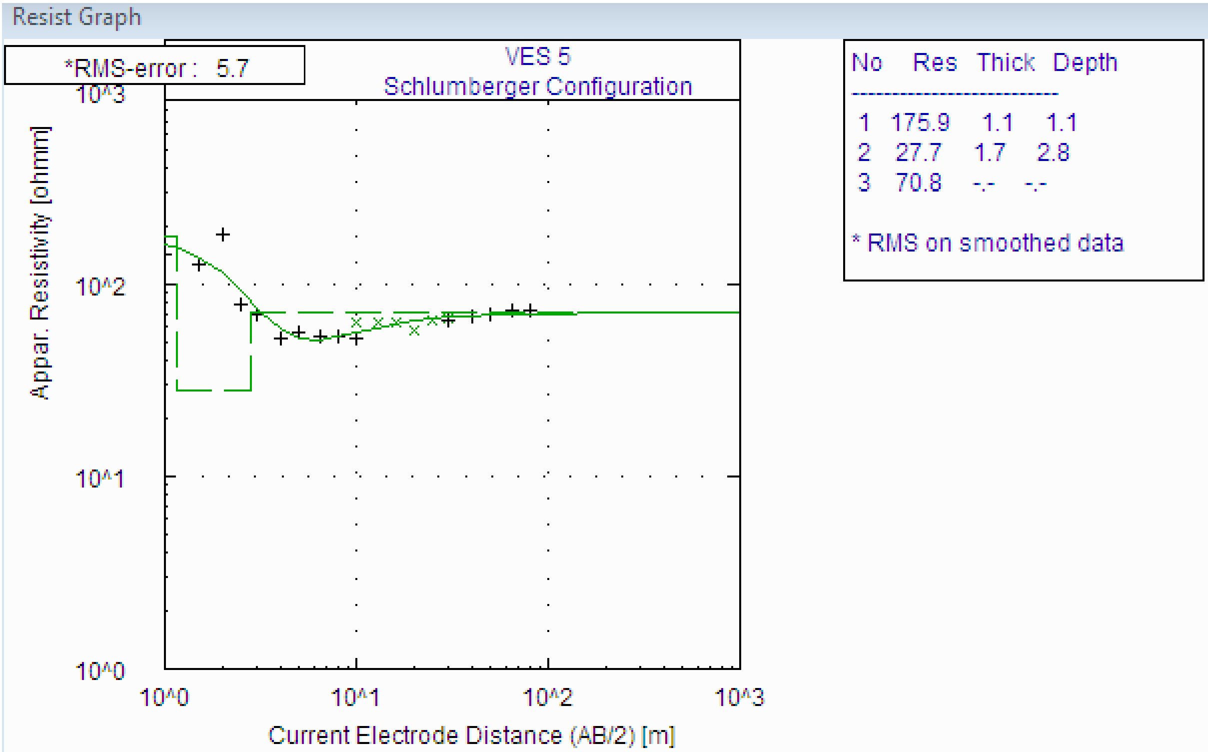


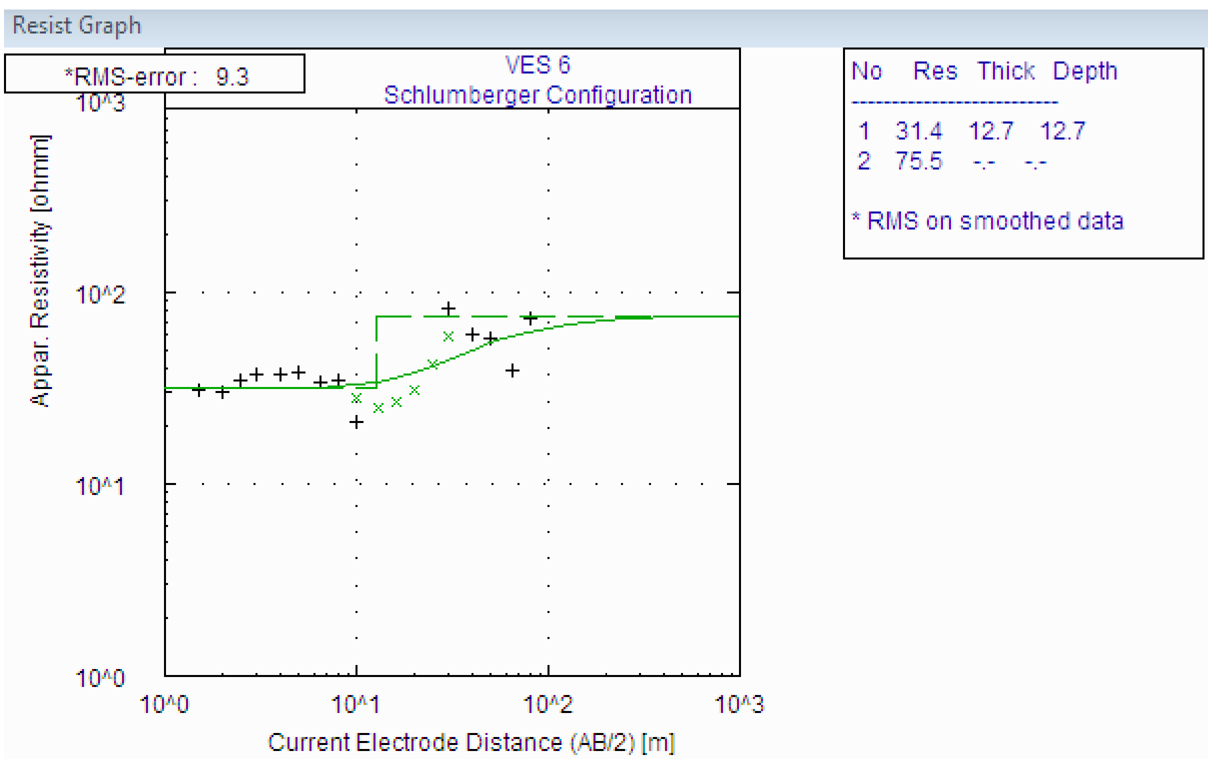
Geoelectric curves for VES points 1 and 2 respectively



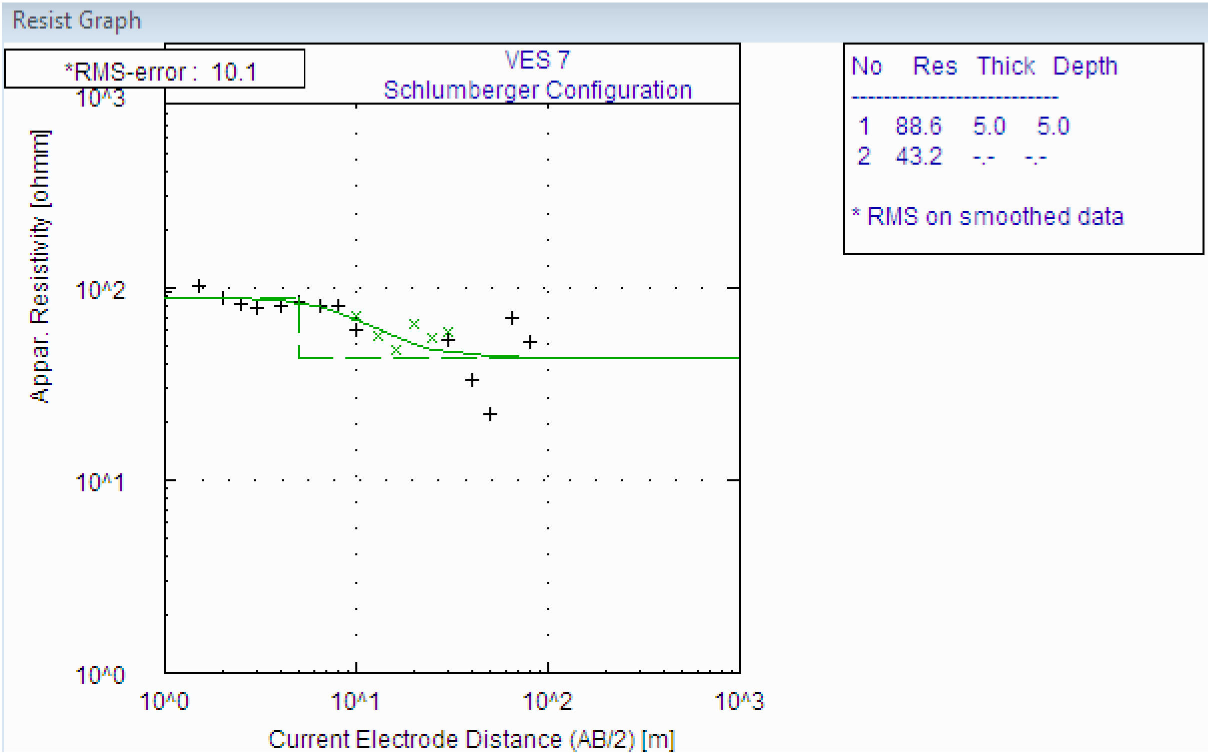


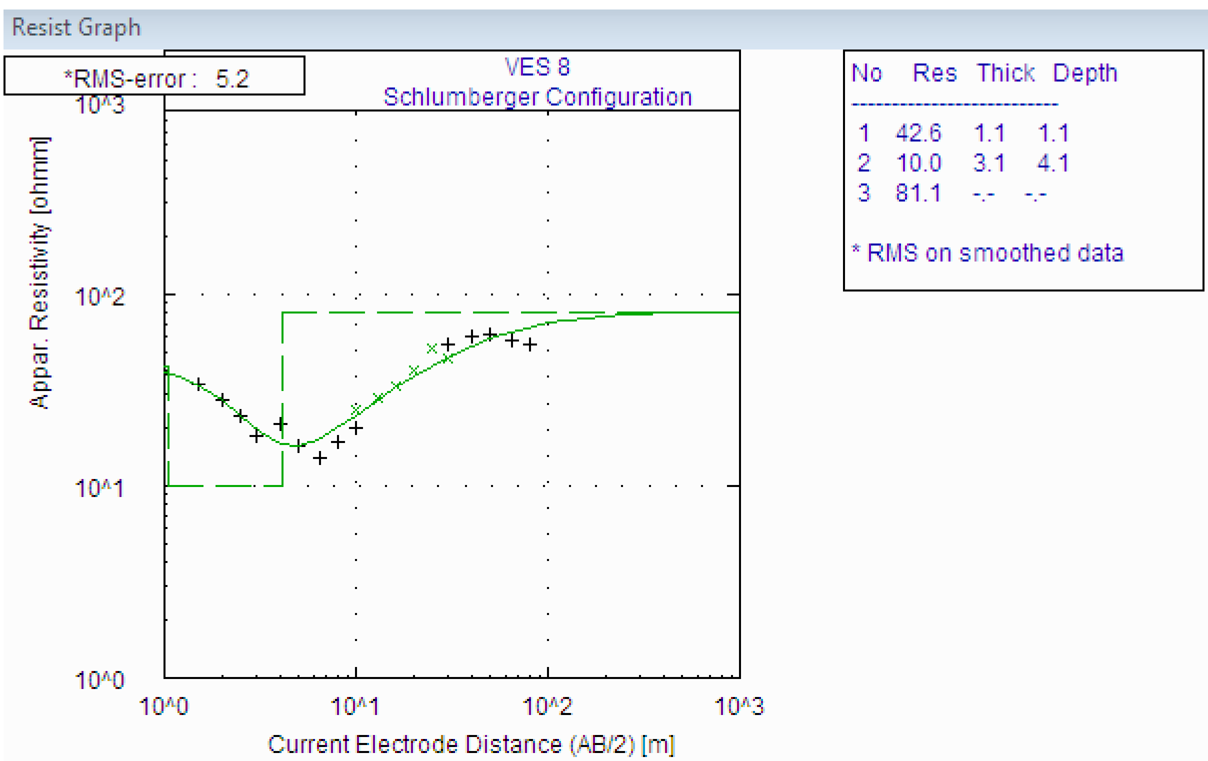
Geoelectric curves for VES points 3 and 4 respectively



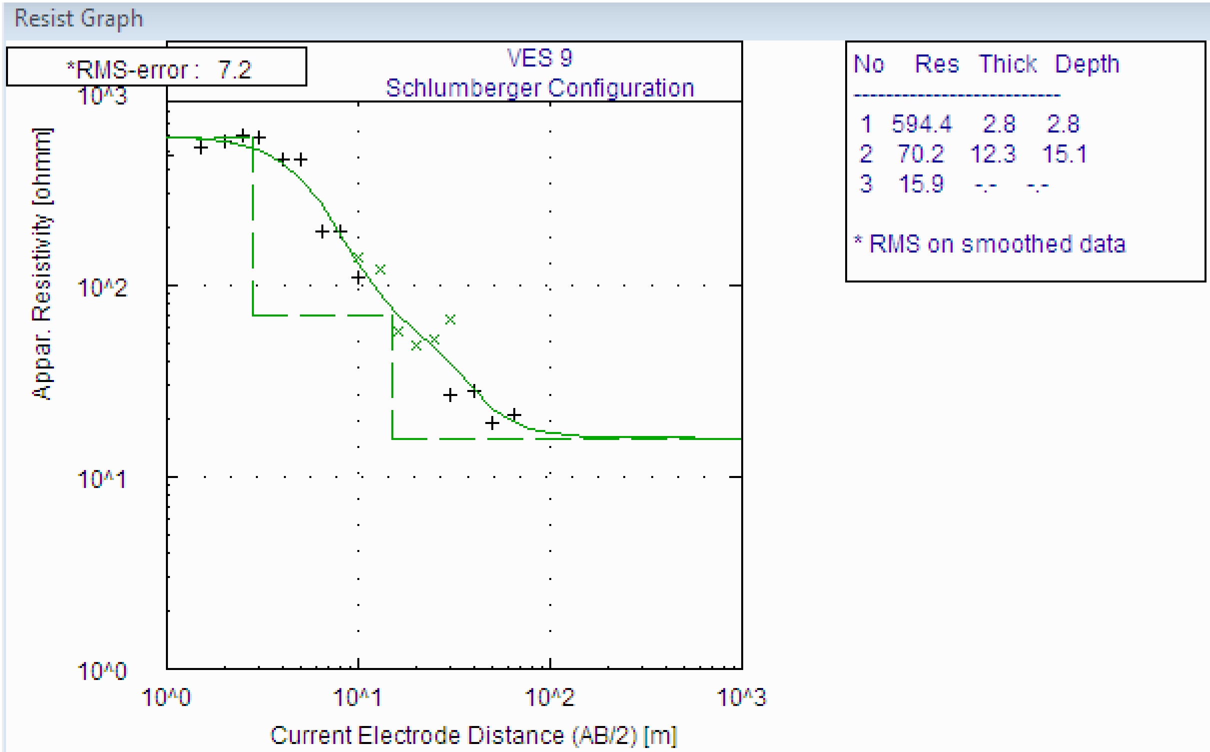


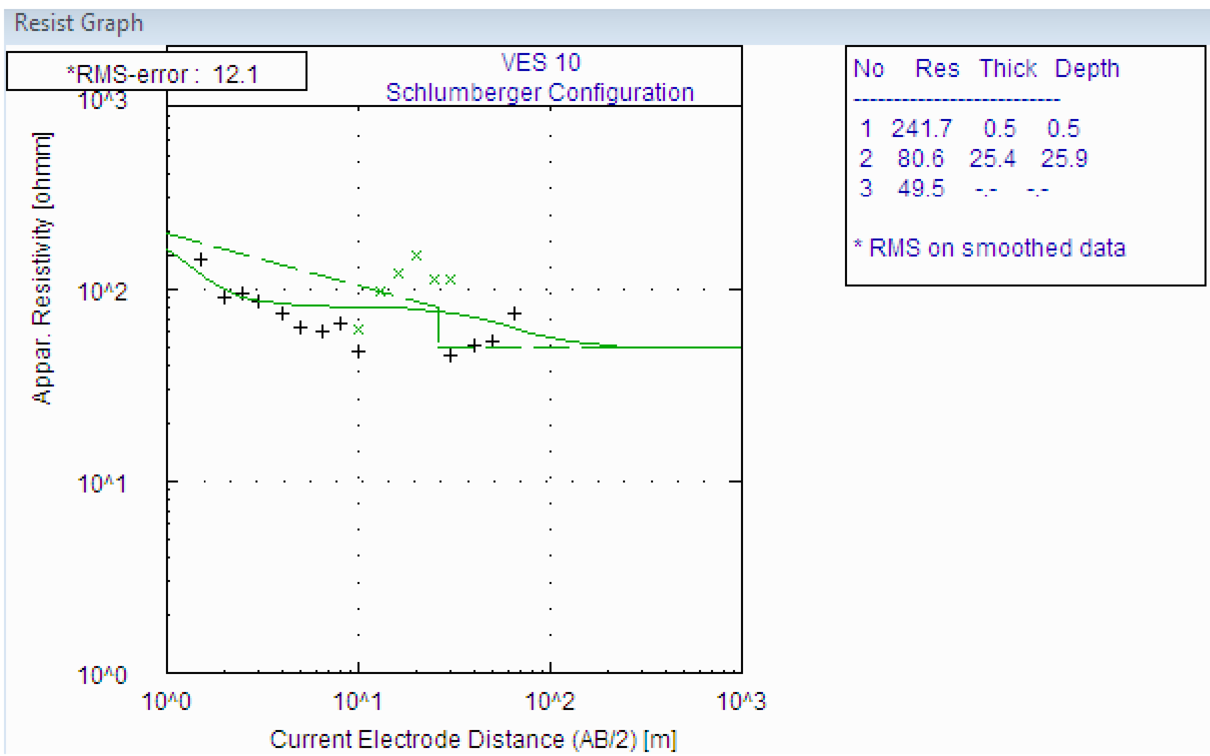
Geoelectric curves for VES points 5 and 6 respectively



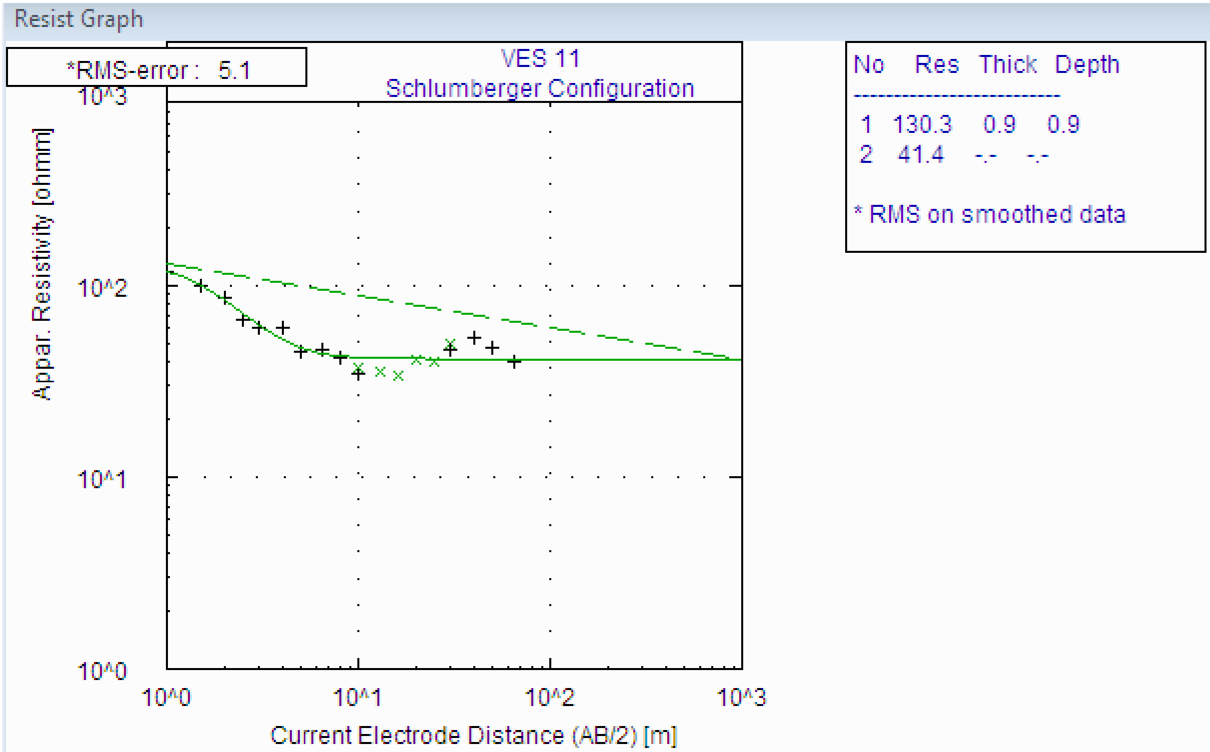


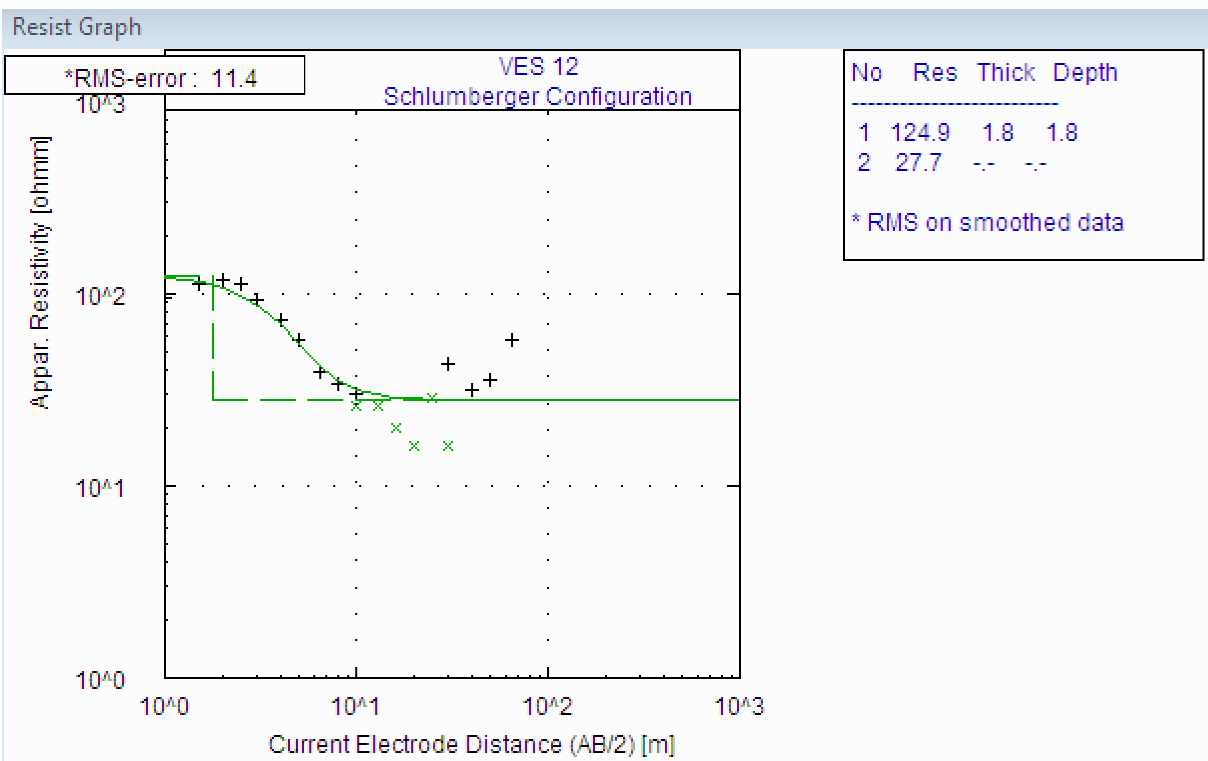
Geoelectric curves for VES points 7 and 8 respectively



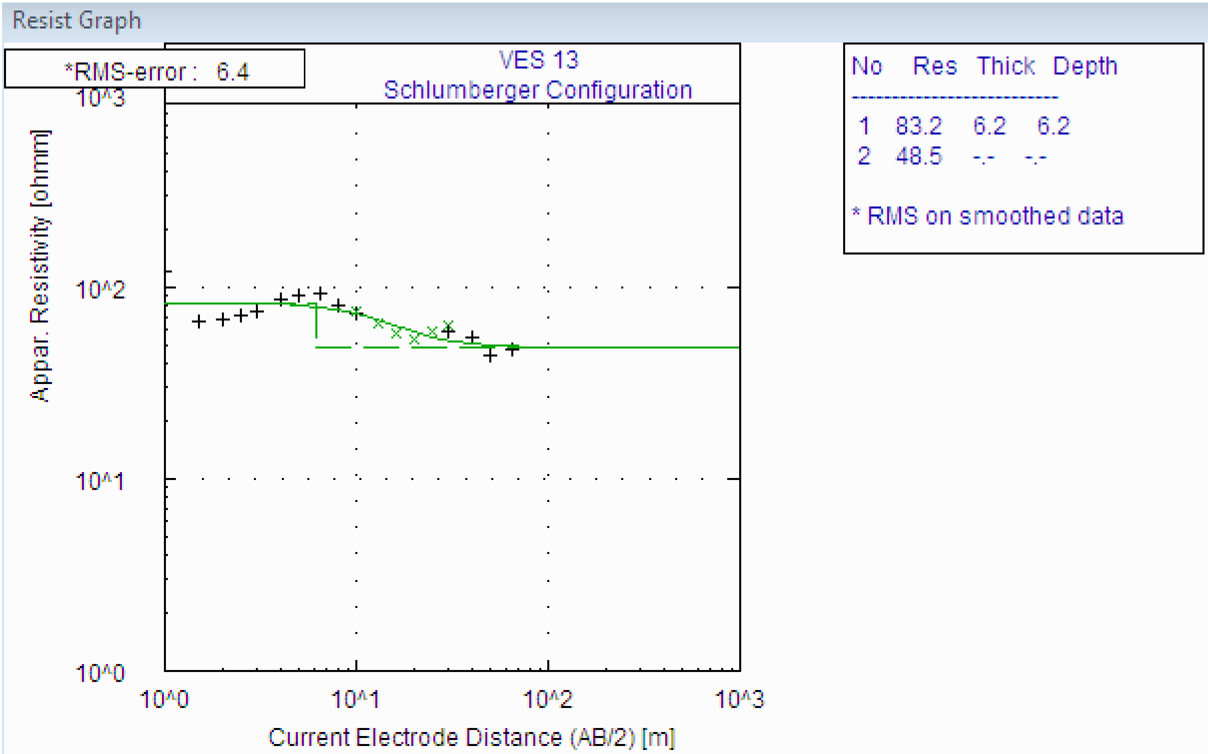


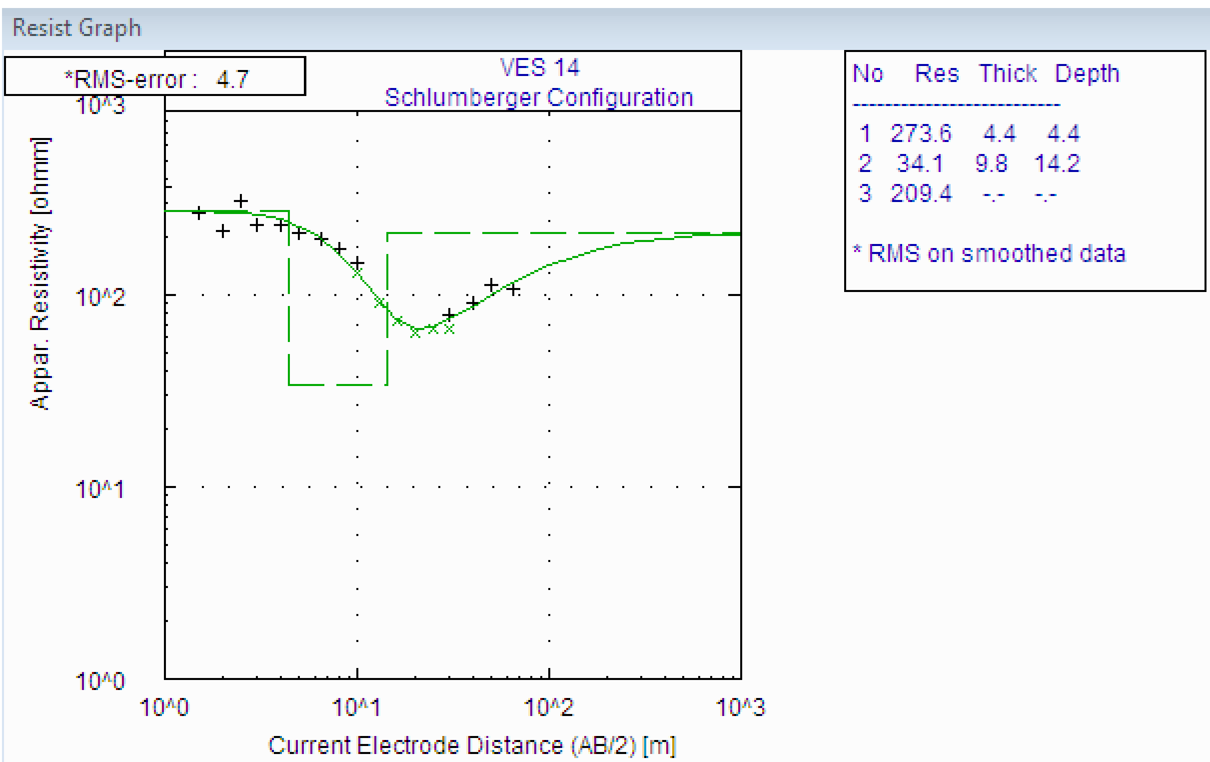
Geoelectric curves for VES points 9 and 10 respectively



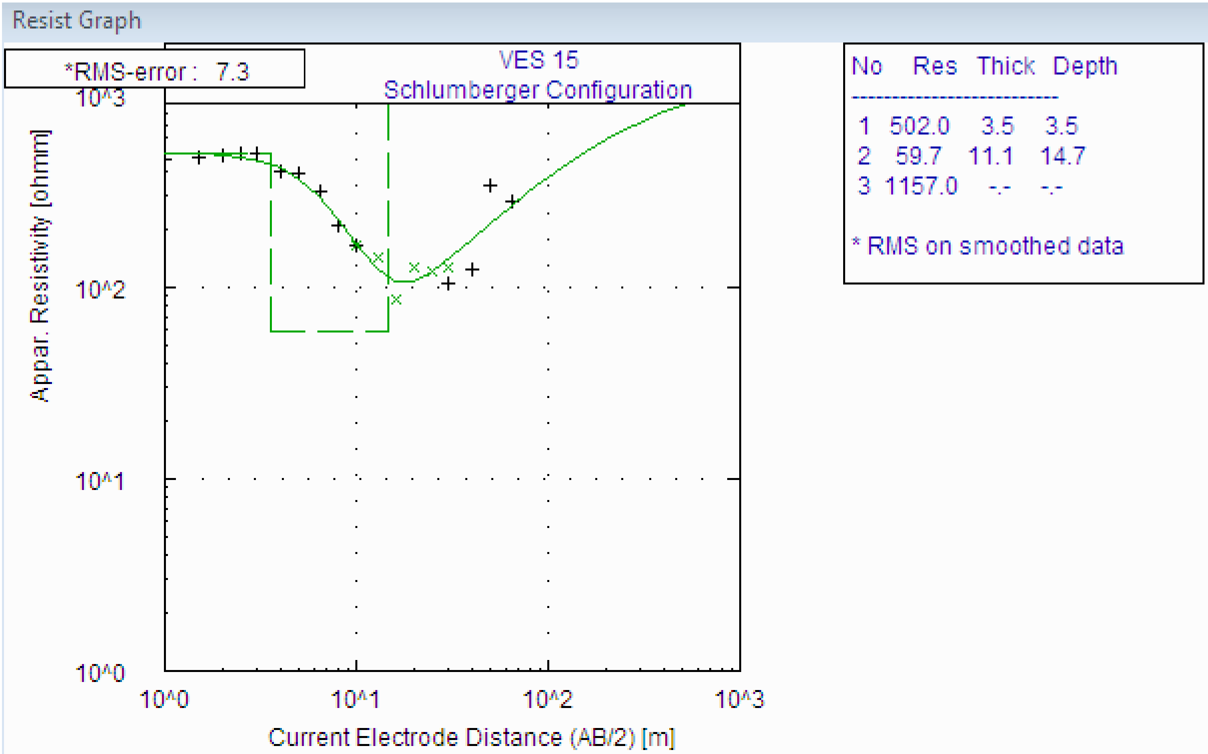


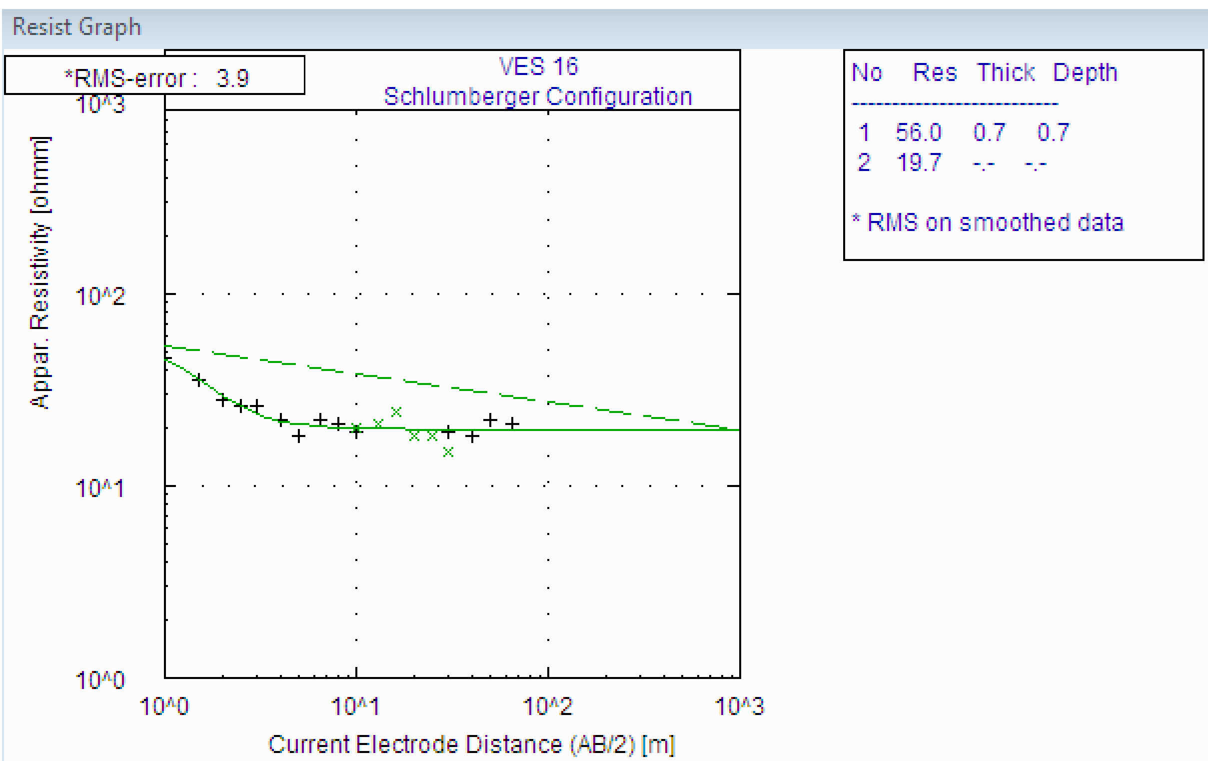
Geoelectric curves for VES points 11 and 12 respectively



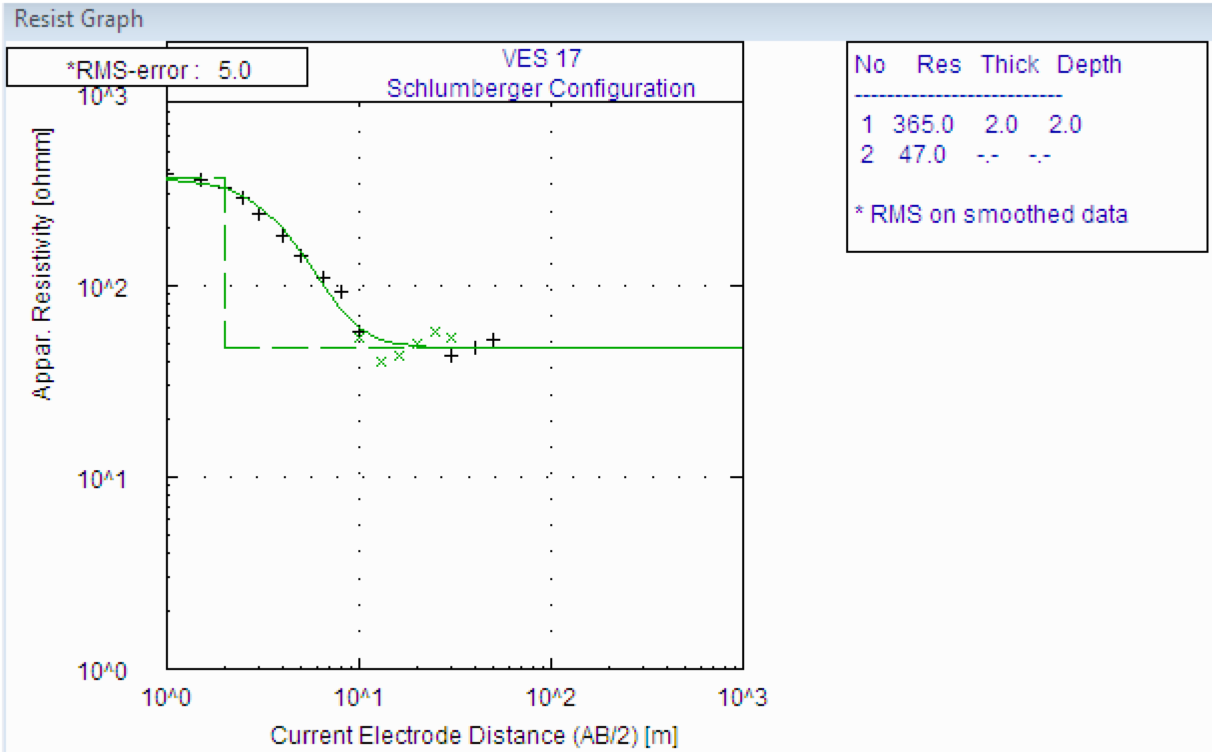


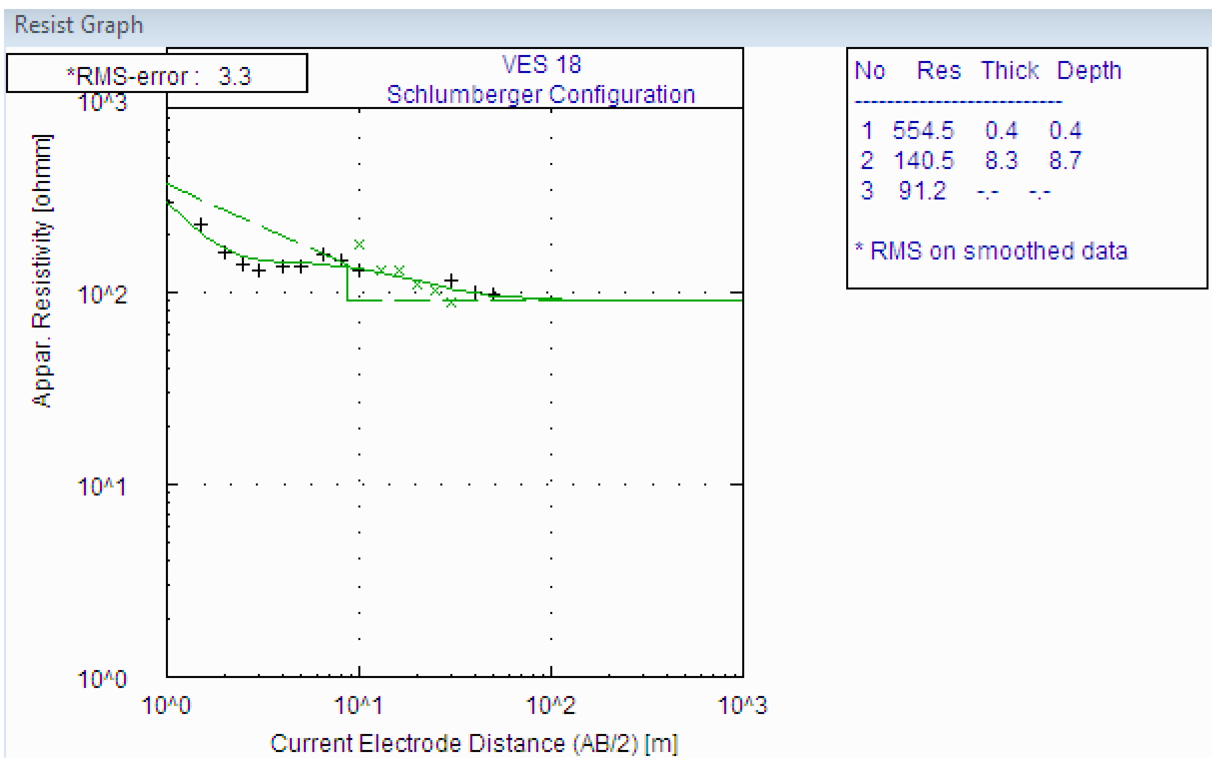
Geoelectric curves for VES points 13 and 14 respectively



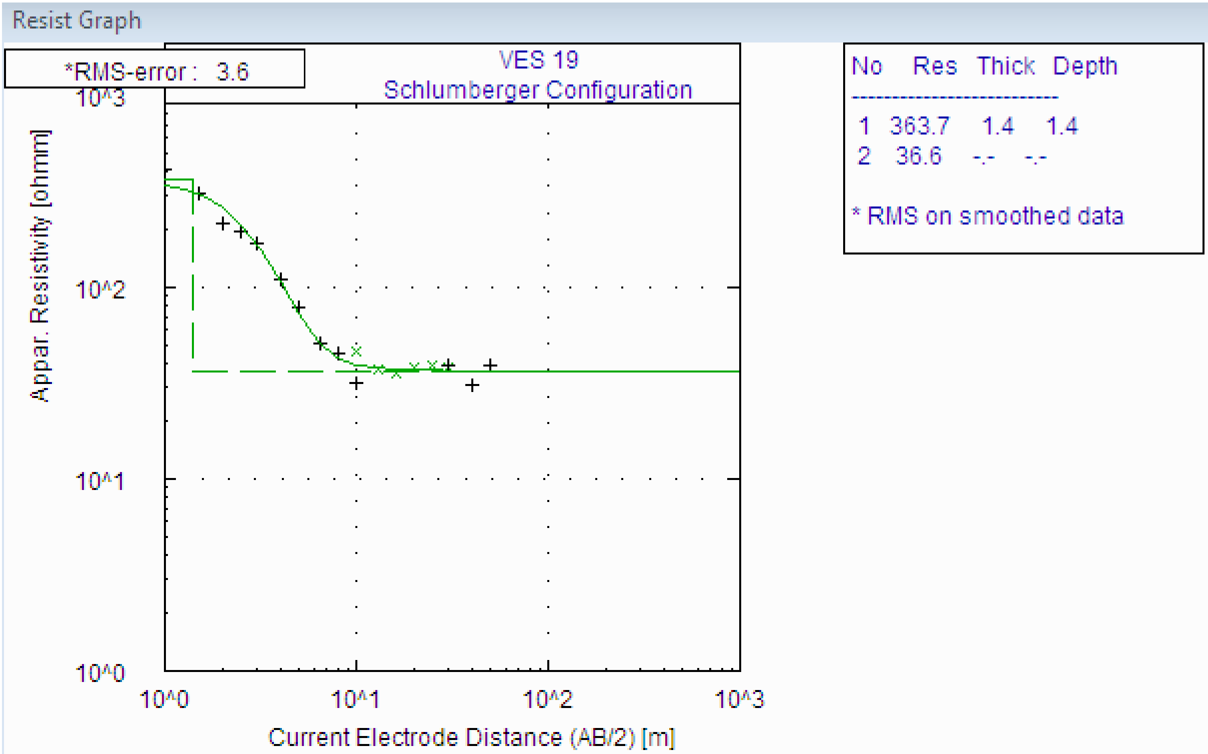


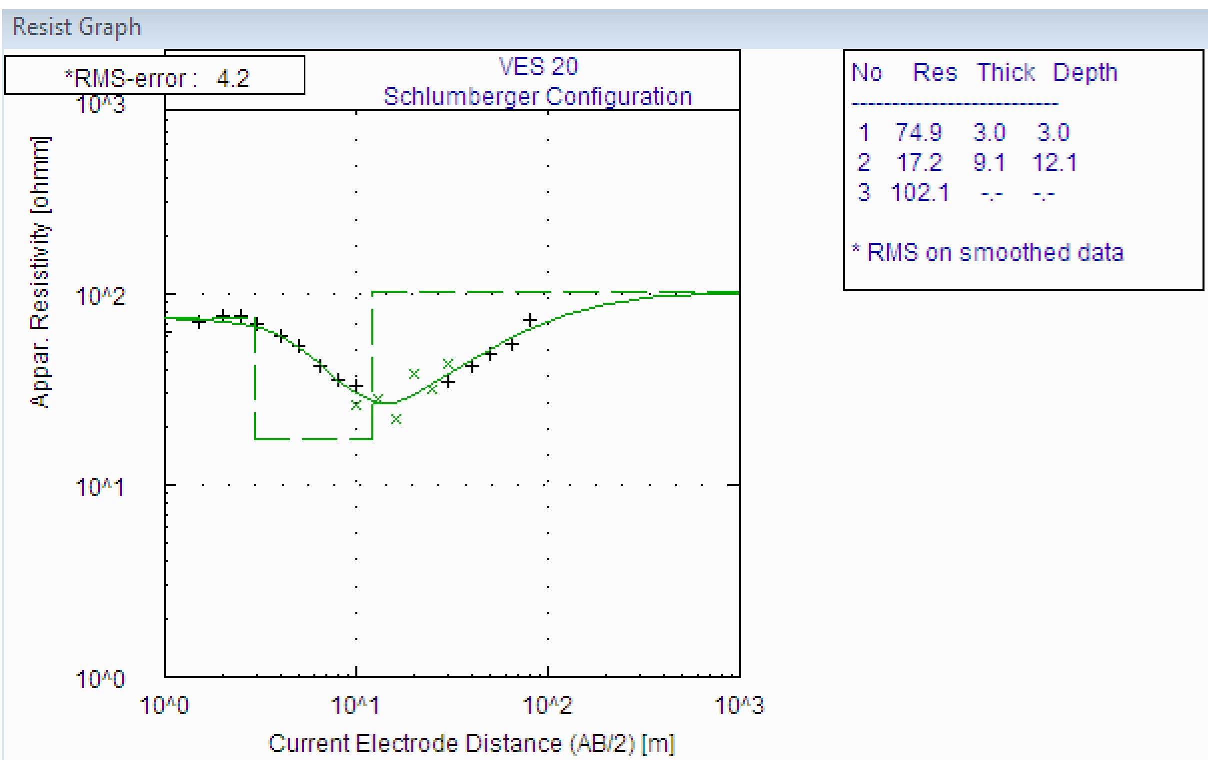
Geoelectric curves for VES points 15 and 16 respectively





Geoelectric curves for VES points 17 and 18 respectively





Geoelectric curves for VES points 19 and 20 respectively

Appendix C

Result of the physico-chemical and bacteriological analysis of the water samples in the study area

PARAMETER	METHOD	NSDWQ (2007)	A.QRTS	G/H RD	A/JUKUN	A/IRSHAD N/P SCH	WDT MKT	TINDA LANE	RMC B/I WDT	WDT J/MSQ	OLD N/B BRIDGE	L/G SECT
TDS (mg/L)	APHA 2510B	500	184	192	178	166	74	160	61	172	48	154
Conductivity (μS/cm)	APHA 2510B	1000	274	283	267	253	99.5	246	86	260	72.5	239
Dissolved Oxygen (mg/L)	DO_2 Meter	-	6.93	7.15	6.73	6.33	5.61	6.13	5.73	6.53	5.85	5.93
Temperature (°C)	APHA 2550B	AMBIENT	30.8	30.9	30.7	30.7	30.2	30.6	30.1	30.7	30	30.5
pH	APHA 4500H^+B	6.5-8.5	7.61	7.68	7.54	7.4	8.61	7.33	8.58	7.47	8.56	7.26
Turbidity (NTU)	Turbidity Meter	5	1	1.2	0.96	0.88	8.63	0.84	8.59	0.92	8.55	0.8
Total Hardness (mg/L)	APHA 2340C	150	72	77	67	57	70	52	58	62	46	47
Total Alkalinity (mg/L)	APHA 2320B	-	22	24	20	16	20	14	17	18	14	12
Iron (mg/L)	APHA 3500-Fe D	0.3	0.08	0.11	0.07	0.05	0.11	0.04	0.07	0.06	0.04	0.03
Copper (mg/L)	APHA 3500 Cu D	1	0.1	0.94	0.16	0.28	0.07	0.34	0.08	0.22	0.09	0.4
Sulphate (mg/L)	APHA 4500 SO_4^{2-}E	100	45	47	43	39	14	37	12	41	10	35
Phosphate (mg/L)	APHA 4500-P D	-	0.65	0.69	0.61	0.53	2.5	0.49	2.39	0.57	2.28	0.45
Phosphorus (mg/L)	APHA 4500-P D	-	0.21	0.12	0.3	0.48	0.84	0.57	0.79	0.39	0.74	0.66
Nitrate (mg/L)	APHA 4500NO_3^-B	50	8.84	8.44	9.24	10.04	2.03	10.44	1.95	9.64	1.87	10.84
Bicarbonate (mg/L)	APHA 2320B	-	22	25	19	13	18	10	16	16	14	7
Nitrite (mg/L)	APHA 4500NO_2^-B	0.2	0.009	0.007	0.013	0.019	0.06	0.022	0.05	0.016	0.04	0.025
Fluoride (mg/L)	APHA	1.5	0	0	0	0	0.07	0	0.05	0	0.03	0
Chloride (mg/L)	APHA	250	9	9	8	6	19	5	13	7	7	4
Sodium (mg/L)	APHA 3500 Na-D	200	25	26	24	22		21	20	23	5	9
Potassium (mg/L)	APHA 3500 K-D	-	16	12	21		31	36	41	26	4	10
Calcium (mg/L)	APHA 3500 Ca-D	-	20	22	18.5		15.5	14	12.5	17	6.41	6.49
Magnesium (mg/L)	APHA 3500 Mg-E	20	5.36		5.3	5.24	5.18	5.12	5.06	5.42	6.83	6.95
Total Coliforms (cfu/100ml)	APHA 9222	10	23		21	19	17	15	13	26	120	166
Faecal Coliforms (cfu/100ml)	APHA 9222	Nil	0		0	0	0	0	0	0	20	52

Result of the physico-chemical and bacteriological analysis of the water samples in the study area

PARAMETER	METHOD	NSDWQ (2007)	WDT ABTR	YANBU WDT	UBA WDT	INIKPI STR H/L	S/BEND WDT	AMOKACHI LANE	YOKAKO STR	GVT DAY SEC SCH	VANDEKIA STREET	FMC WDT
TDS (mg/L)	APHA 2510B	500	87	1010	920	103	1070	980	126	1130	950	1190
Conductivity ($\mu S/cm$)	APHA 2510B	1000	113	1507	1456	152.9	1527	1490	166.1	1547	1473	1577
Dissolved Oxygen (mg/L)	DO_2 Meter	-	5.49	6.42	6.54	6.57	6.3	6.46	6.69	6.18	6.5	6.06
Temperature (^oC)	APHA 2550B	AMBIENT	30	30.7	30.4	30.5	30.7	30.6	30.6	30.8	30.5	30.9
pH	APHA 4500H^+B	6.5-8.5	8.64	8.62	8.53	7.54	8.64	8.59	7.59	8.66	8.56	8.68
Turbidity (NTU)	Turbidity Meter	5	8.67	0.85	0.79	0.55	0.91	0.83	0.58	0.97	0.81	1.03
Total Hardness (mg/L)	APHA 2340C	150	82	422	389	34	435	411	41	448	400	461
Total Alkalinity (mg/L)	APHA 2320B	-	23	103	91	12	111	99	14	119	95	127
Iron (mg/L)	APHA 3500-Fe D	0.3	0.15	0.56	0.5	0.05	0.59	0.54	0.05	0.62	0.52	0.65
Copper (mg/L)	APHA 3500 Cu D	1	0.06	1.25	1.16	0.08	1.29	1.22	0.11	1.33	1.19	1.37
Sulphate (mg/L)	APHA 4500 SO_4^{2-}E	100	16	22	13	12	34	19	15	46	16	58
Phosphate (mg/L)	APHA 4500-P D	-	2.61	3.26	3.05	3.26	3.39	3.19	3.29	3.52	3.12	3.65
Phosphorus (mg/L)	APHA 4500-P D	-	0.89	1.06	0.94	1.06	1.11	1.02	1.11	1.16	0.98	1.21
Nitrate (mg/L)	APHA 4500NO_3^-B	50	2.11	67	65.2	7.48	67.7	66.4	7.53	68.4	65.8	69.1
Bicarbonate (mg/L)	APHA 2320B	-	20	103	97	12	106	101	16	109	99	112
Nitrite (mg/L)	APHA 4500NO_2^-B	0.2	0.07	1.102	0.902	0.006	1.201	1.002	0.013	1.3	0.952	1.052
Fluoride (mg/L)	APHA	1.5	0.01	0.11	0.5	0.08	0.17	0.9	0.08	0.24	0.7	0.31
Chloride (mg/L)	APHA	250	25	87	69	5	99	81	11	111	75	1.23
Sodium (mg/L)	APHA 3500 Na-D	200	11	105	87	15	109	99	22	113	93	117
Potassium (mg/L)	APHA 3500 K-D	-	13	33	24	8	34	30	11	36	27	38
Calcium (mg/L)	APHA 3500 Ca-D	-	6.53	40.8	32.7	8.82	44.4	38.1	14.13	48	35.4	51.6
Magnesium (mg/L)	APHA 3500 Mg-E	20	7.01	78.1	61.9	2.93	83.5	72.7	4.14	88.9	67.3	94.3
Total Coliforms (cfu/100ml)	APHA 9222	10	190	80	65	6	86	75	6		92	98
Faecal Coliforms (cfu/100ml)	APHA 9222	Nil	57	4	2	0	8	6	0		12	16

Result of the physico-chemical and bacteriological analysis of the water samples in the study area

PARAMETER	METHOD	NSDWQ (2007)	K/ALA STR	ZONE 4 P/STN	KANSHIO	A/F SCH	F/SON SEC SCH	TRINITY N/P SCH	HOTEL BOBEC	MBAGBA	KUSA	E/OJEGE STR
TDS (mg/L)	APHA 2510B	500	149	364	172	310	287	241	264	195	218	352
Conductivity (μS/cm)	APHA 2510B	1000	179.3	544	192.5	271.7	258.5	232.1	245.3	205.7	218.9	529
Dissolved Oxygen (mg/L)	DO_2 Meter	-	6.81	6.32	6.93	7.65	7.53	7.29	7.41	7.05	7.17	6.24
Temperature (^oC)	APHA 2550B	AMBIENT	30.7	30.9	30.6	30.5	30.9	30.9	30.8	30.8	30.7	30.8
pH	APHA 4500H^+B	6.5-8.5	7.64	8.09	7.69	7.99	7.94	7.84	7.89	7.74	7.79	8.07
Turbidity (NTU)	Turbidity Meter	5	0.61	1.54	0.64	0.81	0.79	0.73	0.76	0.67	0.7	1.46
Total Hardness (mg/L)	APHA 2340C	150	48	132	55	97	90	76	83	62	69	123
Total Alkalinity (mg/L)	APHA 2320B	-	17	35	21	66	56	39	47	26	32	29
Iron (mg/L)	APHA 3500-Fe D	0.3	0.05	0.05	0.05	0.07	0.05	0.06	0.05	0.05	0.06	0.03
Copper (mg/L)	APHA 3500 Cu D	1	0.14	0.07	0.17	0.27	0.25	0.21	0.23	0.18	0.19	0.06
Sulphate (mg/L)	APHA 4500 SO_4^{2-}E	100	18	7	21	39	36	30	33	24	27	6
Phosphate (mg/L)	APHA 4500-P D	-	3.32	2.61	3.35	3.53	3.5	3.44	3.47	3.38	3.41	2.55
Phosphorus (mg/L)	APHA 4500-P D	-	1.15	0.85	1.19	1.43	1.39	1.31	1.35	1.23	1.27	0.81
Nitrate (mg/L)	APHA 4500NO_3^-B	50	7.58	15.7	7.63	7.97	7.92	7.82	7.87	7.68	7.73	15.67
Bicarbonate (mg/L)	APHA 2320B	-	20	35	24	48	44	36	40	28	32	33
Nitrite (mg/L)	APHA 4500NO_2^-B	0.2	0.02	0.01	0.033	0.111	0.098	0.072	0.085	0.046	0.059	0
Fluoride (mg/L)	APHA	1.5	0.08	0.08	0.08		0.07	0.07	0.08	0.1	0.09	0.06
Chloride (mg/L)	APHA	250	17		23	29	35	41	48	54	60	8
Sodium (mg/L)	APHA 3500 Na-D	200	29		36	43	50	57	63	70	77	43
Potassium (mg/L)	APHA 3500 K-D	-	14		17	20	23	26	29	32	35	30
Calcium (mg/L)	APHA 3500 Ca-D	-	19.44		24.75	30.06	35.37	40.68	45.99	51.3	56.61	35.58
Magnesium (mg/L)	APHA 3500 Mg-E	20	5.35		6.56	7.77	8.98	10.19	11.4	12.61	13.82	7.49
Total Coliforms (cfu/100ml)	APHA 9222	10	6		8	7	7	9	6	9	9	8
Faecal Coliforms (cfu/100ml)	APHA 9222	Nil	0		0	0	0	0	0	3	2	0

Result of the physico-chemical and bacteriological analysis of the water samples in the study area

PARAMETER	METHOD	NSDWQ (2007)	EL-KWABE SEC. SCH.	AKPHEHE	AVECO SEC. SCH	AGBER	AHULE
TDS (mg/L)	APHA 2510B	500	341	307	331	314	322
Conductivity (µS/cm)	APHA 2510B	1000	515	469	502	479	490
Dissolved Oxygen (mg/L)	DO_2 Meter	-	6.17	5.99	6.11	6.02	6.06
Temperature (°C)	APHA 2550B	AMBIENT	30.9	30.7	30.9	30.8	30.7
pH	APHA 4500H^+B	6.5-8.5	8.06	8.01	8.06	8.03	8.04
Turbidity (NTU)	Turbidity Meter	5	1.39	1.21	1.33	1.24	1.28
Total Hardness (mg/L)	APHA 2340C	150	115	93	108	97	102
Total Alkalinity (mg/L)	APHA 2320B	-	24	14	20	15	17
Iron (mg/L)	APHA 3500-Fe D	0.3	0.02	0.03	0.02	0.01	0.02
Copper (mg/L)	APHA 3500 Cu D	1	0.04	0.03	0.04	0.02	0.04
Sulphate (mg/L)	APHA 4500 SO_4^{2-}E	100	5	6	5	3	5
Phosphate (mg/L)	APHA 4500-P D	-	2.49	2.25	2.43	2.31	2.37
Phosphorus (mg/L)	APHA 4500-P D	-	0.77	0.61	0.73	0.65	0.69
Nitrate (mg/L)	APHA 4500NO_3^-B	50	15.63	15.37	15.58	15.45	15.52
Bicarbonate (mg/L)	APHA 2320B	-	30	9	26	15	21
Nitrite (mg/L)	APHA 4500NO_2^-B	0.2	0	0.01	0	0	0
Fluoride (mg/L)	APHA	1.5	0.03	0.07	0.03	0.02	0.03
Chloride (mg/L)	APHA	250	6	8	6	5	5
Sodium (mg/L)	APHA 3500 Na-D	200	39	13	34	21	28
Potassium (mg/L)	APHA 3500 K-D	-	23	5	17	8	12
Calcium (mg/L)	APHA 3500 Ca-D	-	31.06	12.98	26.54	17.5	22.02
Magnesium (mg/L)	APHA 3500 Mg-E	20	7.17	5.89	6.85	6.21	6.53
Total Coliforms (cfu/100ml)	APHA 9222	10	6	9	6	5	6
Faecal Coliforms (cfu/100ml)	APHA 9222	Nil	0	0	0	0	0

Sample locations with values of some parameters above the NSDWQ (2007) permissible limits

S/N	PARAMETER	NSDWQ (2007)	SAMPLE LOCATIONS FROM WELL							SAMPLE LOCATIONS FROM RIVER			
			Yanbu Wadata	Sharp Bend Wadata	Gov't Day Sec Sch	FMC Wadata	Amokachi Lane	Vandekia Street	UBA Bank Wadata	Beside Old Northbank Bridge	RMC Block Industry	Wadata Market	River Bank Wadata
1	TDS	500	1010	1070	1130	1190	980	950	920				
2	Conductivity	1000	1507	1527	1547	1577	1490	1473	1456				
3	pH	6.5-8.5	8.62	8.64	8.66	8.68	8.59	8.56	8.53	8.56	8.58	8.61	8.64
4	Turbidity	5								8.55	8.59	8.63	8.67
5	Total Hardness	150	422	435	448	461	411	400	389				
6	Iron	0.3	0.56	0.59	0.62	0.65	0.54	0.52	0.5				
7	Copper	1	1.25	1.29	1.33	1.37	1.22	1.19	1.16				
8	Nitrate	50	67	67.7	68.4	69.1	66.4	65.8	65.2				
9	Magnesium	20	78.1	83.5	88.9	94.3	72.7	67.3	61.9				
10	Total Coliforms	10	80	86	92	98	75	70	65	120	144	166	190
11	Faecal Coliforms	NIL	4	8	12	16	6	4	2	20	34	52	57