HYDROGEOLOGY AND GROUNDWATER QUALITY IN MAKURDI METROPOLIS AND ITS ENVIRONS, PART OF MAKURDI (SHEET 251), NORTH CENTRAL NIGERIA

BY

THADDEUS ITANYI AKUH

(M.Sc./SCIEN/0680/2010 – 2011)

DEPARTMENT OF GEOLOGY

FACULTY OF SCIENCE

AHMADU BELLO UNIVERSITY, ZARIA

APRIL, 2014

HYDROGEOLOGY AND GROUNDWATER QUALITY IN MAKURDI METROPOLIS AND ITS ENVIRONS, PART OF MAKURDI (SHEET 251), NORTH CENTRAL NIGERIA

BY

Thaddeus Itanyi AKUH

B. Sc. (KSU, 2008)

(M.Sc./SCIEN/0680/2010 – 2011)

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY IN PARTIAL FULFILMENT OF REQUIREMENTS FOR THE AWARD OF A MASTERS DEGREE IN GEOLOGY (HYDROGEOLOGY)

DEPARTMENT OF GEOLOGY

AHMADU BELLO UNIVERSITY,

ZARIA, NIGERIA

APRIL, 2014

Declaration

I declare that the work in this thesis entitled "Hydrogeology and groundwater quality of Makurdi metropolis and its environs, part of Makurdi Sheet 251, north central Nigeria" has been carried out by me in the Department of Geology. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution.

_____ _____

Thaddeus Itanyi Akuh Date

Certification

This thesis entitled "Hydrogeology and groundwater quality of Makurdi metropolis and its environs, part of Makurdi Sheet 251, north central Nigeria" by Thaddeus Itanyi AKUH meets the regulations governing the award of Masters Degree in Geology (Hydrogeology) of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

_____ _____

Dr. S. A. Alagbe Date

Chairman, Supervisory Committee

_____ _____

Dr. A. A. Ibrahim Date
Member, Supervisory Committe

_____ _____

Dr. H. Hamza Date
Head of Department

_____ _____

Prof. A. A. Joshua Date
Dean, School of Postgraduate Studies

Acknowledgements

This research would not have been possible without the unequalled hands of God Almighty. It is in this light, that I wish to express my unmitigated gratitude to God for his guidance especially during the field work and for sustaining me during the course of my studies.

I am greatly indebted to my supervisors; Dr. S. A. Alagbe and Dr. A. A. Ibrahim who sacrificed time from their tight schedules to supervise this research putting me through when I am faced with challenges. For all their contributions to this research, I am sincerely grateful.

Many thanks to my lecturers, Professor K. Schoeneich, Professor P. M. Zaborski, Dr. E. A. Bala, Professor Dambatta, Dr. A. E. Ikpokonte, Dr. T. Najime, Dr. M. L. Garba and Dr. H. Hamza all of Geology Department Ahmadu Bello University Zaria and Professor O. J. Mudiare of Agricultural engineering Department Ahmadu Bello University Zaria. To all lecturers not mentioned and members of staff of Geology Department who have contributed or assisted me in the course of this research I say a big thank you.

I wish to appreciate my parents MWO Akuh Jerome (rtd) and Mrs. Agnes Akuh of blessed memory for their love, support and encouragements. God gave me life through you and you have done nothing less than love and provide my needs. For all you have been and done I say God bless you.

To my lovely and ever supporting siblings Rev. Fr. (Sqn Ldr) Cyril Akuh, Mr. Akuh Francis, Mrs. Christiana Akuh Idachaba, Mrs. Rosemary Akuh Urowayino, Mr. Akuh Anthony my little niece Urowayino Oritshemoyowa Agnes and my little Nephew Urowayino Wilfred, I say thank you for your unfathomable love and support I have enjoyed all these years. I love you all.

I am also indebted to my friends Alakpa Blessing, Ameh Clement, Maigida Victor, Ogenyi Pius, Cyril Enefola, Ojukwu Jennifer, Rosaline Anyebe, Mercy Ogbole, Dora Oluyole, V. O. Babatunde, ACM I. Garba and my fellow postgraduate geology students especially Mr. Ohiemi Fabian, Mall. Usman Maa'ji, Mr. Innocent Duru, Mrs. Apobiede Folake, Mrs. Abusu Christiana, Miss. Ngukposu Labe, Mr. Saaid Abdulkareem, Mallam Gidado, Mr. Aja Cletus Akpa, Mr. Nwanya Anthony. For all your contributions and support I remain eternally grateful.

ABSTRACT

Hydrogeological studies of Makurdi metropolis and environs were carried out using geophysical and hydrogeochemical methods of investigation. The Makurdi Sandstone forms the aquifer unit studied. Analysis of pumping test data and petrological studies of this sandstone aquifer were used to estimate some of its characteristics. Three to four layers of rock were identified from the interpretation of six vertical electrical sounding (VES) curves. Interpreted curves include the H, Q and K types. The third layer which is the fractured Makurdi Sandstone is identified to be the most prolific for groundwater development. The thickness of this aquifer varies from about 5.5 m to 29.25 m and resistivity varies from 3.414 to about 400 Ωm. Interpretation of configuration of groundwater table and thickness of dry zone maps reveal that the River Benue is effluent all year round and constitutes the major discharge area within the study area. Groundwater mounds which are the major recharge areas within the study area were also identified. The chemistry of groundwater with respect to pH, Total dissolved solids, Fe^{3+}, Cu^{2+}, Mn^{2+}, Zn^{+}, NH_3^{-}, NO_3^{-}, Cl^{-}, Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, HCO_3^{-} and SO_4^{2-} was used to determine its suitability for drinking, domestic and irrigation purposes. The results show elevated concentration of Fe^{3+}, Mn^{2+}, NH_3^{-}, NO_3 $Mg^{2+}$and SO_4^{2} in groundwater within most part of the study area and is considered unsafe for drinking and domestic uses (Standard Organization of Nigeria (SON), 2007). Water within the study area is of excellent quality for irrigation as regards its sodium adsorption ratio. However, high bicarbonate hazard and percentage sodium were observed in some areas making water from these areas unsafe for irrigation. Six water facies were identified using the Piper trilinear plot and these include the Mg – Na – HCO_3, Mg-K-HCO_3, K – HCO_3 – SO_4^{2-}, Mg-Ca-HCO_3, Mg-HCO_3 and Ca - Mg - HCO_3 fields. The proportion of some of the measured groundwater chemical

parameters also reveals the intrusion of formation water from the stagnant belt into the near surface aquifer. Correlation of the measured parameters shows positive correlation between TDS and Na^+, Cl^-, K^+ and SO_4^{2-} with correlation coefficients of 0.96, 0.90, 0.62 and 0.56 respectively. Positive correlation also exists between Cl – Na (0.90), K – Na (0.63), K – Cl (0.63), NO_3 – NH_3 (0.5), NO_3 – Cl (0.92) and Na – Cl (0.90). This positive correlation indicates that the ions are derived from the same source. Analysis of pumping test data shows that transmissivity of the Makurdi Sandstone aquifer ranges from 1.144 $x10^{-2}$ m^2/day to 5.27 x 10^{-2} m^2/day while storage coefficient and hydraulic conductivity ranges from 6.18 $x10^{-3}$ to 1.27 x 10^{-2} and 5.20 × 10^{-4} to 3.20 × 10^{-2} m/day respectively. These values fall within the range of negligible to poor yield according to Gheorghe standards for transmissivity. Petrological studies also confirm this Sandstone aquifer to be a very indurated, well sorted, medium – coarse grained, texturally mature sub – arkose with only about 3 to 4% porosity.

TABLE OF CONTENTS

CHAPTER		PAGE
Cover Page		
Title Page		iii
Declaration		iv
Certification		v
Acknowledgement		vi
Abstract		vii
Table of Content		ix
List of Figures		xiii
List of Tables		xiv
List of Plates		xv
List of Appendices		xvi
CHAPTER ONE		
1.0	**Introduction**	1
1.1	**Justification**	2
1.2	**Aim of Study**	3
1.3	**Study Area**	3
1.3.1	Location, Extent and Accessibility	3
1.3.2	Relief and Drainage	4
1.3.3	Climate	5
1.3.4.	Vegetation	7
1.3.5.	People and Land Use	8

CHAPTER TWO

2.0 Literature Review 9

2.1 Review of Regional Geology of Benue State 9

2.2 Groundwater Occurrence in Benue State 13

2.3 Aquifers in Benue State 14

2.3.1. The Basement Aquifers 14

2.3.2. The Awe Formation 15

2.3.3. The Makurdi Sandstone Aquifer 15

2.3.4. The Ajali Sandstone 17

2.3.5. The Alluvium Aquifer 18

2.4. Groundwater Chemistry (Hydrogeochemistry) 18

2.5. Groundwater Quality in Benue State 19

CHAPTER THREE

3.0 Methodology 22

3.1 Desk Studies 22

3.2 Field Work 22

3.2.1. Water Level Measurement 22

3.2.2. Water Sampling 23

3.3 Laboratory Work 24

3.4 Field Data Evaluation 26

3.4.1. Geophysical Investigation 26

3.4.2. Groundwater Elevation Maps 26

3.4.3. Thickness of Dry Zone (Depth to Water Table) Map 27

3.5 Analysis of pumping test data 27

3.6 Evaluation of Dynamic Water Resource 28

3.7 Interpretation of Results From Groundwater Quality Analysis 29

3.7.1. Suitability of Water for Drinking and Domestic Uses 29

3.7.2. Suitability of Water for Irrigation Purpose 30

CHAPTER FOUR

4.0 Results and Discussion 31

4.1 Geophysical Investigation 31

4.2 Evaluation of Hydrogeological Maps 36

4.2.1 Map of Groundwater Configuration 36

4.2.2 Groundwater Movement 40

4.2.3 Thickness of Dry Zone 40

4.3 Suitability of Groundwater for Drinking and Domestic Use 41

4.3.1 Physical Parameters 42

4.3.2 Trace Elements 45

4.3.3. Anions 47

4.3.4 Cations 48

4.3.5 Heavy Metal 49

4.4 Indication of Salty Water in Shallow Aquifers 51

4.5 Statistical Analysis 52

4.6 Hydrochemical Facies 55

4.7 Suitability of Groundwater for Irrigation Purpose 58

4.7.1 Percentage Sodium 59

4.7.2 Sodium Adsorption Ratio 59

4.7.3 Bicarbonate Hazard 61

4.8 Evaluation of Dynamic Water Resources of Makurdi Metropolis and Environs 61

4.9 Aquifer Characteristics 65

CHAPTER FIVE

5.0 Conclusion and Recommendation 69

5.1 Conclusion 69

5.2 Recommendations 71

References 73

Appendices 76

LIST OF FIGURES

Figure 1.1: Location map of Makurdi metropolis and its environs 4

Figure 1.2: Topographical map of Makurdi Metropolis and environs 6

Figure 1.3: Monthly rainfall depths in Makurdi metropolis 7

Figure 2.1: Geological map of Makurdi Metropolis and environs 11

Figure 2.2: Proposed lithostratigraphical subdivisions for the cretaceous rocks of the lower Benue Trough. 13

Figure 4.4: Interpreted vertical electrical sounding curves 33

Figure 4.2: Groundwater configuration map of Makurdi metropolis and environs (end of rainy season) 37

Figure 4.3: Groundwater configuration map of Makurdi metropolis and environs (peak of dry season) 38

Figure 4.4: Depth to water table (thickness of dry zone) map of Makurdi metropolis and environs (peak of dry season) 39

Figure 4.5: Piper diagram of groundwater in Makurdi metropolis and environs 55

Figure 4.6: Durov plot of groundwater in Makurdi metropolis and environs 56

Figure 4.7: Distribution of dynamic water resources of the Makurdi metropolis and environs 62

Figure 4.8: Correlation between depth of rainfall and runoff coefficient in drainage basins 64

LIST OF TABLES

Table 1.1: Monthly rainfall depths in Makurdi metropolis 5

Table 4.1: Resistivity and thickness of geoelectrical sections 32

Table 4.2: Results of water analysis from Makurdi Metropolis and environs 43

Table 4.3: Classification of water based on total concentration of dissolved solids 44

Table 4.4: Statistical summary of measured parameters 53

Table 4.5: Correlation matrix for measured parameters 54

Table 4.6: Water classification based on percentage of equivalents per million 57

Table 4.7: Classification of groundwater based on Na %, SAR and bicarbonate hazard 58

Table 4.8:Calculated values of Bicarbonate hazard, sodium percentage and sodium adsorption ratio for groundwater in Makurdi metropolis and environs 60

Table 4.9: Estimated values of renewable water resources for the Makurdi metropolis and environs 63

Table 4.10: Aquifer characteristics of some boreholes in Makurdi metropolis 65

Table 4.11: Gheorghe standards for transmissivity 66

LIST OF PLATES

Plate 1: A view of the Makurdi Sandstone under crossed polarized light 67

LIST OF APPENDICES

Appendix 1:	Co – ordinates, Depth to water table and elevation of hand dud wells measured at the end of rainy season	76
Appendix 2:	Plots of concentrations of measured parameters and background values	93
Aappendix 3:	Plots of concentrations of measured parameters and standard organization of Nigeria's (SON) permissible limit	100
Appendix 4:	Rock source deduction for some groundwater chemical parameters	106
Appendix 5:	Radial plots of groundwater in Makurdi metropolis and environs	125
Appendix 6:	Borehole logs of some drilled boreholes within Makurdi metropolis	129

CHAPTER ONE

1.0 INTRODUCTION

Water is a vital need for life, nature and civilization. Nature, ecosystems and biodiversity are essential to decrease vulnerability to extreme hydrological events. Groundwater is the largest source of fresh water in the world and accounts for about one third of one percent of the earth's water. It is of major importance to civilization being the largest reserve of drinkable water that can be used by humans.

Before 1980, there was only minor development of groundwater resources in Benue State. The population depended on surface water and a few number of hand-dug wells as sources of water. Hand dug wells are less than 15 m deep and only sustain their users adequately during the rainy season. As a result of this the water needs of the population have not been adequately met especially during the dry season. Efforts have been made over the years to meet the water needs of the population and this included establishment of Government agencies such as the Water Board, Benue State Rural Water Supply and Sanitation Agency (BERWASSA), UNICEF (intervention programme) as well as private companies involved in the exploration and exploitation of sustainable water supply for the increasing population.

Increasing industrialization and growth of large urban centers have been accompanied by increase in the population stress on the aquatic environment. Water in rivers and lakes as well as abandoned wells has been considered as convenient receiver of waste. This abuse conflicts with almost all other uses of water and most seriously with the use of freshwater for drinking, personal hygiene and food processing (Jamie and Richard, 1996).

The chemical composition of groundwater is related to the soluble products of rock weathering, decomposition and changes with respect to time and space (Raghunath, 2007). Some constituents of groundwater are also derived from the atmosphere as rain water takes some atmospheric gases and ions into solution; others are induced by human activities such as agriculture and waste disposal which often results in groundwater pollution. Water pollution in Makurdi metropolis and environs could be mainly from human activities which affects the physical, chemical and biological properties of water. Animal feaces and vegetable materials decompose and are brought into the water sources thus polluting them.

1.1. Justification

Makurdi metropolis has experienced a rapid growth in population over the past decades and the population is presently experiencing challenges of insufficient water supply especially during the dry season. The population depends mainly on groundwater abstracted through boreholes and hand dug - wells for drinking and other domestic purposes. Many boreholes within the study area are either unproductive or of poor yield. The depth of hand - dug wells within this area is limited by geology and the quality of water from these well seems to be impaired as some users complain of salty taste.

Periodic groundwater quality monitoring is essential especially within areas where the population may have impacted the quality of groundwater. Makurdi metropolis however has no groundwater monitoring program put in place to monitor changes in the concentration of hazardous constituents. It is also imperative to estimate the utilizable dynamic water resources of the drainage basin within which settlements are located as this will aid proper water budget and distribution of the available water resources. These information are lacking in Makurdi metropolis despite their importance in the assessment

of; a) the changes in the quality of groundwater, b) the suitability of groundwater for drinking, domestic and agricultural purposes, c) the availability of sufficient water for the population and d) proper siting of boreholes.

1.2. Aim of Study

The aim of this study is to carry out hydrogeological investigations of Makurdi metropolis and environs. This will lead to the determination of the following: a) Groundwater availability in the study area; b) The aquifers suitable for groundwater development in the study area; c) The hydrogeochemistry of the study area and d) The groundwater quality of the study area.

1.3. Study Area

1.3.1. Location, Extent and Accessibility

The study area, Makurdi metropolis and environs, is bounded by latitudes 8°30'00" and 8°41'00"N and longitudes 7°40'00" and 7°50' 00"E (Figure 1.1). It is located within the Middle Benue Trough and covers an area of about 370 km^2.

It is accessible by the intra state roads such as the Makurdi – Oturkpo road, Makurdi - Gboko road as well as footpaths with many rural road networks linking the rural areas to Makurdi town and the Makurdi – Lafia road.

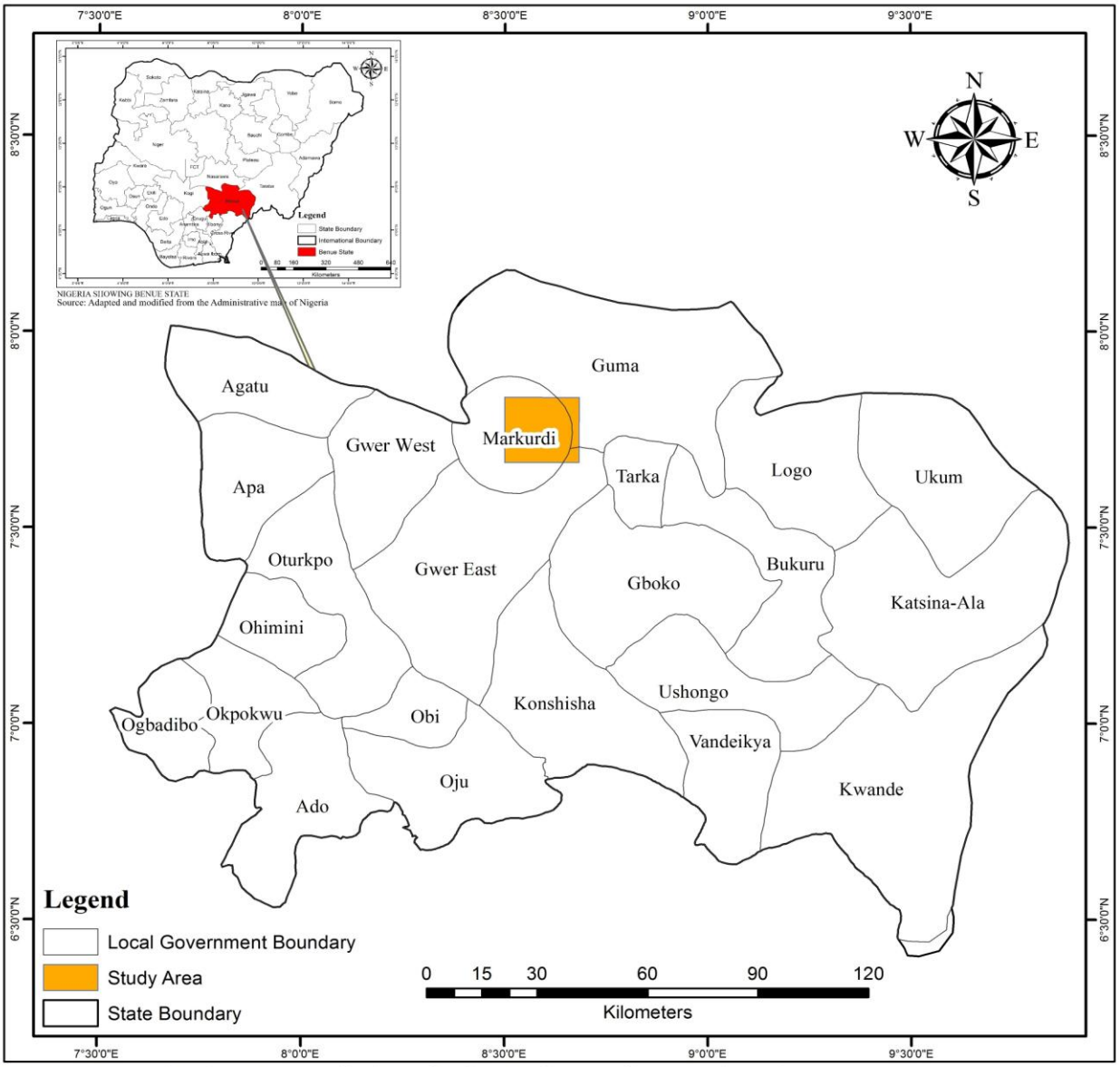


FIGURE 1.1: MAP OF BENUE STATE SHOWING THE STUDY AREA
Source: Adapted and modified from the administrative map of Benue State

1.3.2. Relief and Drainage

The study area is generally undulating with sparse hills and valleys, elevations within this area range from 76 m on the flood plains of River Benue to about 182 m above mean sea level at the northern and southern part of the study area. There are also some undulations which mark the main water sheds in the area. Makurdi metropolis is drained by the River Benue which flows from the eastern to the western part of the study area and its numerous

seasonal tributaries. The drainage pattern of the area is dendritic with medium drainage density (Figure 1.2).

1.3.3. Climate

The study area falls within the southern Guinea climatic zone of Nigeria and like other parts of the country, two distinct seasons occur, these are; the dry season which lasts from November to April and the rainy season which starts in April and lasts till the end of October. The annual rainfall depth ranges from about 1,200 mm to 1,500 mm with an average depth of about 1350 mm (Table 1.1 and Figure 1.3).

Table 1.1: Monthly rainfall depths in Makurdi metropolis for 1996, 2003 and 2004. (Source: Lower Benue River Basin Development Authority).

Monthly Rainfall Depths (mm)											
Year		Mar	April	May	June	July	Aug	Sept	oct	Nov	ADR (mm)
1996	Min			54.3	43.3	27.5	13.5	10.3	10.2		1467.0
	Max			75.0	72.0	72.6	90.0	68.0	68.9		
	Total			197.6	170.5	172.4	263.5	264.0	246.0		
2003	Min			24.0	6.8	8.5.0	4.5	2.3	2.0	8.8	1204.5
	Max			41.2	89.0	44.0	60.0	51.3	49.0	18.6	
	Total			65.2	213.1	140.0	291.0	278.0	93.4	37.0	
2004	Min	10.5	3.5	2.0	6.0	2.4	4.5	6.0	9.2	33.5	1388.9
	Max	10.5	27.0	50.4	48.5	137.0	76.5	101.0	28.5	33.5	
	Total	10.5	100.0	170.0	153.0	343.0	243.4	208.0	86.0	33.5	

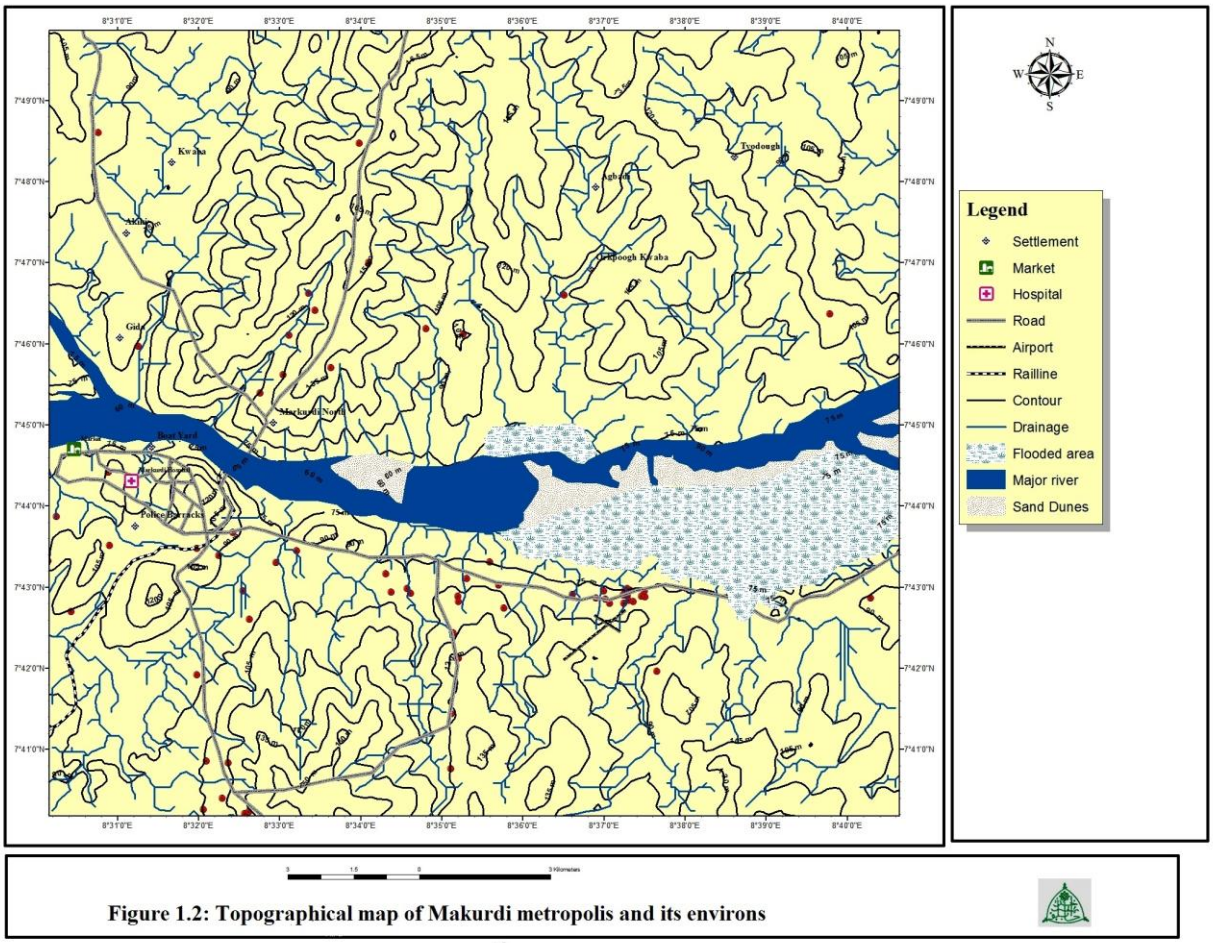


Figure 1.2: Topographical map of Makurdi metropolis and its environs

Temperatures are generally very high during the day, particularly in March and April. Along the river valleys, these high temperatures together with high relative humidity produce debilitating weather conditions. Makurdi metropolis records average maximum and minimum daily temperatures of 35°C and 21 °C during the rainy season and 37°C and 16°C during the dry season respectively.

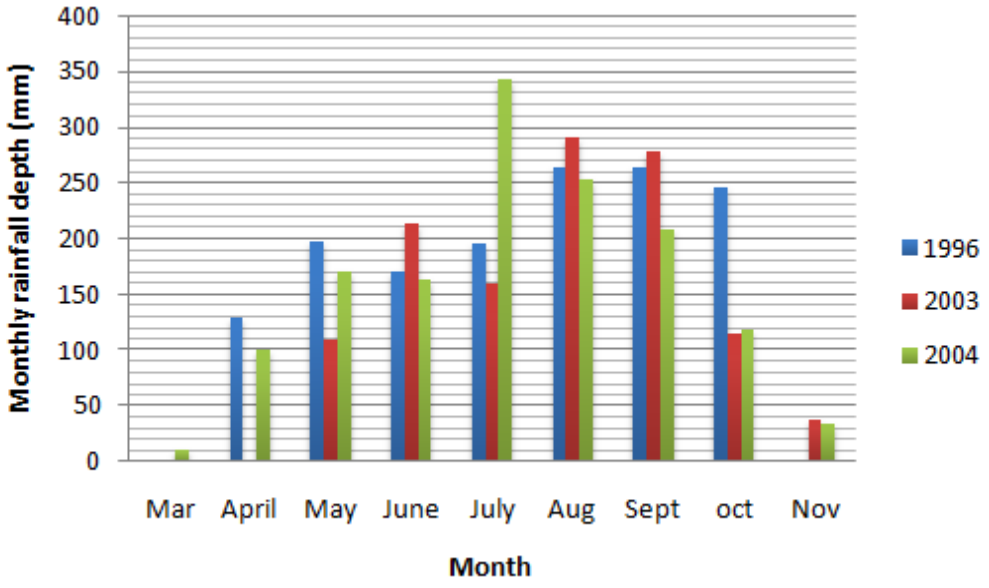


Figure 1.3: Monthly rainfall depths in Makurdi metropolis for 1996, 2003 and 2004. (Source: Lower Benue River Basin Development Authority).

1.3.4. Vegetation

The study area falls within the Guinea Savannah with a scattering of shrubs, small and large trees. Persistent clearing of the vegetation has led to the development of modified vegetation at various levels, but more importantly, parklands with grasses ideal for animal grazing during their early growth. These succulent grasses can be cut with machinery, dried and baled for dry season livestock feeding. The grasses however grow very tall, coarse and tough at maturity. The scattered trees are mainly those of economic value and include

locust bean (*Ceratonia siliqua*), shear butter (*Vitallaria paradoxa*), mango (*mangifera indica*), silk cotton, African iron, doka savanna (*Isoberlinia doka*), cashew (*Anacardium occidentale*), orange (*citrus spp*), oil palm (E*laeis oleifera),* African copaiba balsam tree (*Daniellia Oliveri),* gmelina, and neem (*Azadirachta indica*) as well as other commercial trees such as mahogany, Obeche, Iroko and Afara. These trees produce valuable fruits, wood and fibre which can be utilized for small scale cottage industries and large industries.

1.3.5. People and Land Use

Makurdi is a fast growing urban centre and accommodates people from many states and ethnic groups with the majority being the Tiv, Idoma and Egede who are the indigenes of the state. The neighboring villages around Makurdi metropolis are Tiv settlements and the Tiv being farmers produce crops like yam, cassava, rice, maize, oranges, tobacco, mangoes and beans. The inhabitants also engage in civil service jobs, fishing, bricks making, small scale livestock farming, petty trading and hunting which results in the burning of grasses during the dry season accelerating the rate of erosion during the rainy season.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Review of Regional Geology of Benue State

Much of Benue State falls within the intra cratonic sedimentary basin known as the Benue Trough which is believed to be structurally developed. The Benue Trough is a linear sedimentary basin which is filled with Cretaceous rocks whose ages range from Middle Albian to Maastrichtian. It is bounded on either side by granite and gneisses which make up the crystalline basement (Cratchley and Jones, 1965). Many others like Najime (2010), Obaje (1994) and Zaborski (1998) described the Benue Trough as a NE – SW trending intracratonic basin ranging between 150 km wide and 800 km long. Lithologies identified in the Benue Trough include; the Ezeaku shale, the Makurdi Formation, the Ajali Formation, the Agwu Formation and the alluvial deposit.

Radiometric dating indicates that the Nigerian Basement Complex is polycyclic and indicates rocks of Liberian (2700 ± 200 Ma), Eburnean (2000 ± 200 Ma), Pan African (600 ± 200Ma), and questionably Kibaran (1100 ± 200 Ma) ages (Ajibade and Woakes, 1989).

Three broad lithological groups are distinguished within the Nigerian Basement Complex viz;

a) A polymetamorphic Migmatite-Gneiss Complex (Ajibade and Woakes,1989; Dada,1998) composed of gneisses of various compositions and amphibolites. Relicts of metasedimentary rocks represented by medium to high grade calcareous, pelitic and quarzitic rock occur within the migmatite and gneiss. Dada (1998) however reported that geochronological and structural evidence is available only for

the Pan-African. The author also reported that more recent studies of the Nigerian Basement Complex confirms earlier indications of Early to Mid-Archean (3.5 – 3.0 Ga) ages for this rock, late Archean (2.4 – 2.5 Ga) U-Pb ages and Early Proterozoic (2.1 – 1.8 Ga) ages have been obtained on the gneisses and Late Proterozoic (~ 600 Ma) U-Pb ages from both migmatite-gneisses and granitoids in all the shield areas in Nigeria.

b) A low grade sediment dominated schist. Unequivocal Palaeo-Proterozoic tectonic landmarks that can be widely applied within the schist belt are yet to be identified (Dada,1998), and that the same sequence of deformation and metamorphic events that affected the Archean gneisses have been recognized in the 2.1 – 1.8 Ga gneisses and the metasediments of the schist belt.

c) Syn - tectonic to late - tectonic granitic rocks which cut both the migmatite-gneiss complex and schist belts, these rocks are popularly referred to as the Older Granites.

The deposition of the Ezeaku Formation is attributed to the beginning of the marine transgression in the Cenomanian (Obaje, 1994). The Ezeaku Formation consists of thick flaggy calcareous and non-calcareous shale, sandy or shally limestone and calcareous Sandstones. Outcrops of this occur in the area south of Otukpo (Egede – Oju area). It is reported to be 304.8 m thick in this region and ranges up to 609.6 m towards the south of the state (Offodile, 1989). The Makurdi sandstones consists of a thick mass of current bedded coarse grained deposit described as the Makurdi Sandstone (Figure 2.1) Geological and mineral resources map of Benue State adopted from Nigerian Geological survey agency (NGSA) 2006. It attains a thickness of up to 900 m and its basal parts are lateral equivalent to the Keana Sandstone of the Middle Benue Trough.

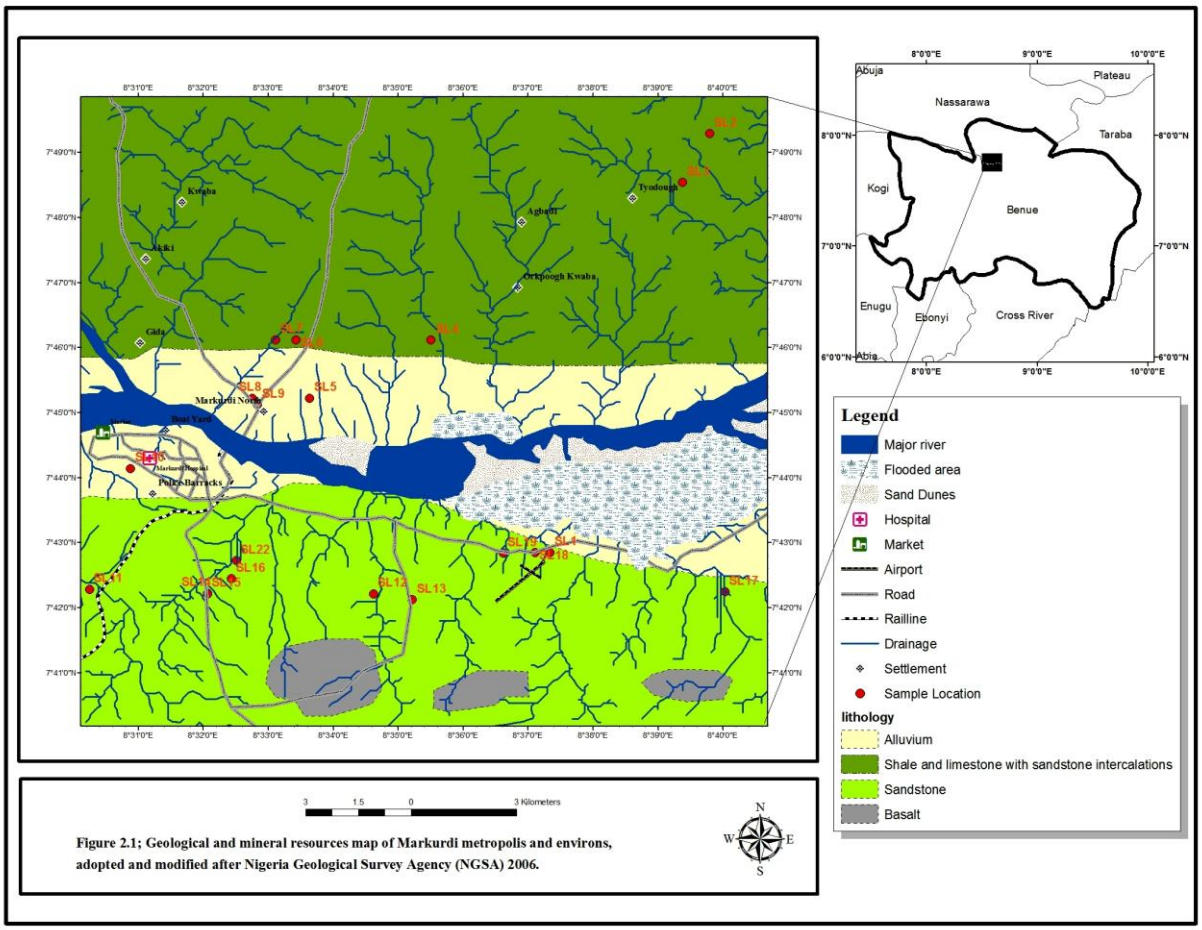


Figure 2.1; Geological and mineral resources map of Markurdi metropolis and environs, adopted and modified after Nigeria Geological Survey Agency (NGSA) 2006.

Adanu, (1981) described the Makurdi Sandstone as a fine grained rock with randomly packed anhedral grains. It contains ferruginous cement which has given it a reddish brown colour.

The Ajali Formation overlies the Mamu Formation which consists of sandstones, carbonaceous shales, sandy shales and some coal seams. It consist of about 330 m of coarse grained characteristically current bedded sandstones also referred to as false - bedded Sandstone (Offodile, 1989). The area is generally covered by materials derived from the underlying strata. The texture and colour of these superficial deposits vary from one place to another depending on the formation underlying it (Adanu, 1981).

The Agwu formation overlies the Makurdi Formation and outcrops southwest of Awajir and the west of Gungul in the Gboko area (Najime, 2010). This formation as reported by Obaje (1994), consists of alternating bluish grey to dark carbonaceous shales, calcareous shales, shally limestone, limestone, siltstone and coal seams.

The major flood plains of Benue State are Rivers Benue, Katsina Ala and other smaller rivers, alluvial deposits, comprising an assortment of clays, sand, gravels and pebbles, overlie the metamorphosed sediments and form the superficial geology.

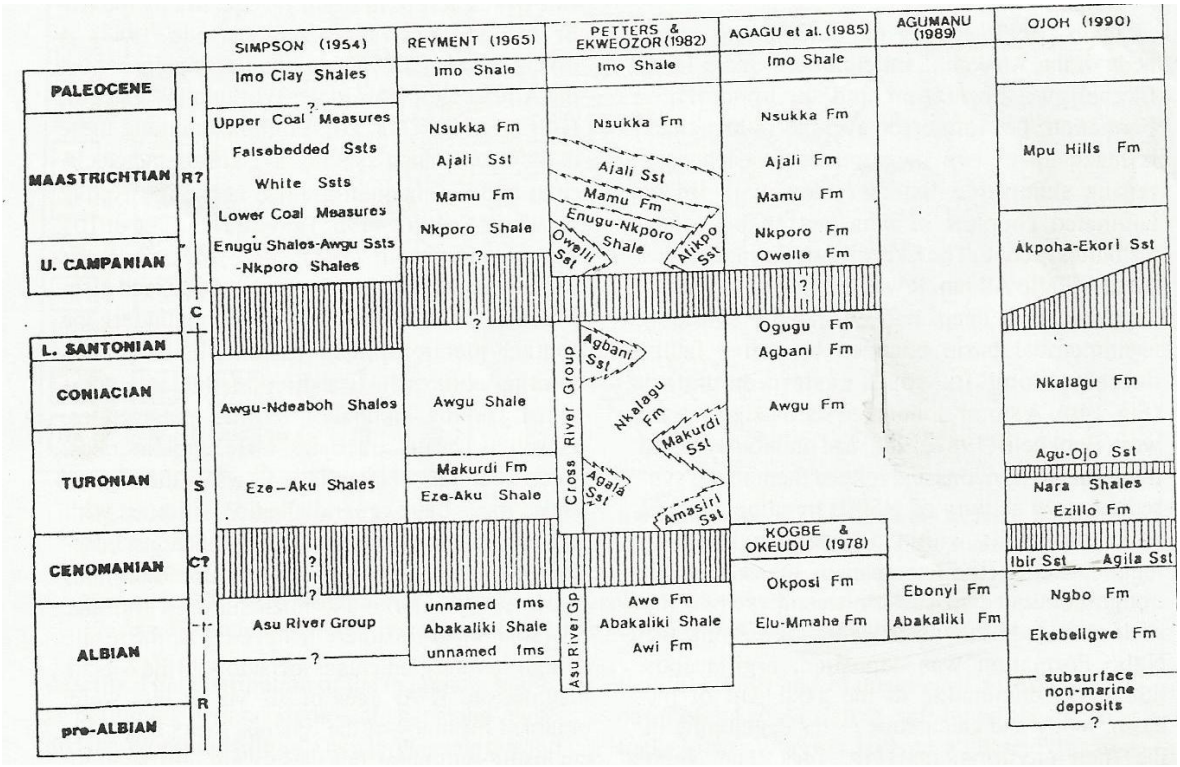


Figure 2.2: Proposed lithostratigraphical subdivisions for the cretaceous rocks of the lower Benue Trough. R, rifting episodes; S, thermo – tectonic sag phase; C. compressional episodes. (Source; Zaborski, 1998)

The Awe Formation was deposited as passage (transitional) beds during the Late Albian-Early Cenomanian regression. This formation overlies the Asu River Group. Offodile (1976) estimated the thickness of the formation to be about 1000 m. The formation consists of flaggy, pale – colored medium to fine grained Sandstone with interbedded carbonaceous shale and clay (Offodile, 1976).

2.2 Groundwater Occurrence in Benue State

Groundwater is that part of the subsurface water that is in the zone of saturation including underground streams. Almost all groundwater can be thought of as part of the hydrological cycle (Todd, 1980). The zone of saturation in the sedimentary basins extends from a depth of about 10 m to more than 10,000 m below ground level (Schoeneich and Garba, 2010).

Here water alone occurs in the interstices of aquifer materials. The zone of saturation is further divided into the dynamic and stagnant belts

The dynamic belt consists of water that takes part in the hydrological cycle. It extends to an average depth of 500 m and contains fresh potable water (water containing less than 1000 mg/l of total dissolved solids).

The stagnant belt on the other hand, present only in the sedimentary hydrogeological province of Nigeria extends from a depth of about 500 m below the ground surface to more than 10,000m below ground surface (Schoeneich and Garba, 2010). Mineralization of water in this belt ranges from 1,000 mg/l to 320,000 mg/l.

2.3. Aquifers in Benue State

Aquifers are visualized as underground reservoirs. These reservoirs could be recharged naturally from precipitation, from surface water bodies that are in contact with these aquifers or artificially by injection through injection wells drilled into the aquifer. Five aquifer types are recognized in Benue State, namely: The Basement Complex rocks, the Awe Formation, the Makurdi Sandstone aquifer, Ajali Sandstone and alluvium aquifer.

2.3.1. The Basement Aquifers

The basement aquifer occurs within the weathered overburden (regolith) and the fractured bedrock. Aquifers within the fractured bedrock are rarely prolific because its storativity is dependent on the extent/depth of the fracture system. To be effective, development of the bedrock component requires interaction with the storage available in the overlying or adjacent regolith or other suitable formations such as alluvium (Wright, 1992). It identified some constraints to current development of basement aquifers viz; a) The frequent high

failure rate of boreholes occurs where the weathered overburden is thin. b) Shallow occurrence and fissure permeability of the bedrock aquifer component which makes it susceptible to surface pollutants and c) The low storativity may deplete significantly during sustained drought periods. The boreholes drilled in the basement Complex areas of Benue State around Gboko confirm that the most favorable groundwater areas are the weathered and fractured areas of the basement rocks (Offodile, 2002). Yields of 2.5 ltrs/sec, 2.4 ltrs/sec. and 2.5 ltrs/sec. at depths of 75 m, 18 m and 63 m respectively from boreholes in the Gboko area drilled into the basement complex rock of varying degrees of decomposition are reported by Offodile (2002).

2.3.2. The Awe Formation

The Awe formation comprises flaggy whitish, medium to coarse, sometimes calcareous Sandstones, with interbedded shales, thin limestone and clay from which brine issue. This formation occurs in part of Makurdi. The Sandstone beds, usually multi – layered appear highly porous and water yielding but the water from these aquiferous beds is contaminated by brines from the interbedded shales. The shale also confines the aquifer and present artesian to sub artesian situations (Offodile, 2002). A few boreholes drilled into this formation have produced good water yields, though often not potable due to the Brine contamination.

2.3.3. The Makurdi Sandstone Aquifer

The Makurdi Sandstone is a multilayered aquifer made up of series of Sandstone beds separated by intercalations of shales and limestone beds. It is highly indurated and cemented mainly by quartz and iron oxide (Adanu, 1981). This aquifer is almost impermeable in places; especially the western part of Makurdi metropolis where its

compact and indurated nature makes it difficult for the inhabitants to sink hand dug wells into it as the wells are terminated when the Sandstone is encountered. This Sandstone is medium to fine grained with anhedral grains (Adanu, 1981). It attains a thickness of up to 900 m (Offodile, 1989) and is generally semi confined (Offodile, 2002). Adanu (1981) reported artesian (confined) aquifer condition for the Makurdi Sandstone around Apir.

Obaje *et al*, (1994) described the sandstone as Turonian Sandstone comprising poorly sorted feldsparthic fluviodeltaic Sandstones, basal conglomerate, silts, mudstones and clay lenses. This sandstone unit is the lateral equivalent of the Ezeaku Formation and overlies the Albian shale (Offodile, 1989).

Where less fractured or less indurated, the formation is usually less compacting, more permeable and has better prospect as an aquifer (Offodile, 2002). The Makurdi Sandstone is the most important aquifer in the middle Benue trough.

Sandstones commonly have low porosity because of its compact nature and the cementing materials between the grains. Porosities could be less than 1 percent and hydraulic conductivity approaching 10^{-10} m/s (Freeze and Cherry 1979).

Adanu (1981) obtained hydraulic conductivity values of 0.132, 1.73, 3.5 and average porosities of 17.3%, 27.8% and 31.3%.for various samples of the Makurdi Sandstone. These properties influence the rate at which this aquifer is recharged.

According toNajime (2010) the sandstones are mainly arkosic composed of 40 % monocrystaline grains and 30 % orthoclase with other minerals such as muscovite and haematite making up 30 % of the rock.

Recharge into the aquifer is both direct and indirect. Where the aquifer is uncovered and permeable, the recharge is direct from precipitation, by seepage and along fractures and joints. This is the case in Yaiko and Airport village, Indirect recharge to this aquifer is by infiltration through weathered materials overlying the Sandstone aquifer (Adanu, 1981). Borehole success in the Makurdi sandstone is rather erratic and depends more on fracturing and deep weathering of the Sandstone, a number of them have been abandoned. The usefulness of the Makurdi Sandstone as a potential groundwater reservoir depends on its secondary permeability derived from weathering and fracturing (Offodile, 2002). It reported yields of 8.2ltr/sec. from a borehole drilled into the Makurdi Sandstone at the Army cantonment, yields between 2.5ltrs/sec. and 3.9ltrs/sec. were obtained in Aliade and 8.7ltrs/sec. from the borehole at the Lower Benue River Basin Estate.

2.3.4. The Ajali Sandstone

The Ajali Sandstone is coarse-grained with thin lenticular shale, beds of grit and pebbly gravel. It is generally coarse with variable texture. The Ajali Sandstone as sometimes described, is marked by bands of coarse and fine layers, and sometimes sparsely clayey and with less and less iron cement with depth and is therefore highly permeable and readily recharged in its outcrop areas. Outcrops of this Sandstone are found in the lower part of the Benue Trough in Otukpo – Otukpa area (Offodile, 2002). From the outcrop area the aquifer is recharged by the abundant rain in the area. The formation therefore appears to constitute a heterogeneous aquiferous lithological sequence up to 450 m depth (Offodile, 2002). Yields of 0.0263m^3/hr, 0.013m^3/hr, 48m^3/hr, 105m^3/hr and 162 m^3/hr were reported for some boreholes drilled into the Ajali Sandstone aquifer.

2.3.5. The Alluvium Aquifer

The alluvium aquifer occurs along river and stream channels which are liable to seasonal flooding. It is the least extensive of all the aquifers. The thickness of the aquifer ranges from 2 to 15 m, the thickest occur along the Benue trough while the least thickness is along the stream channels (Adanu, 1981). It suggested watertable (unconfined) aquifer condition for the alluvium aquifer.

Adanu (1981) also reported porosity and permeability coefficient for this aquifer as 37.5 percent and about 0.26 m/day respectively. The permeability and porosity value favors effective recharge into the aquifer. Recharge into this aquifer is mainly direct from annual precipitation and indirect recharge occurring when the river character is influent thus supplying water to the alluvium aquifer (Adanu, 1981).

2.4. Groundwater Chemistry (Hydrogeochemistry)

The major constituents of groundwater are a complex combination of ions from natural sources such as geology, scavenging from the atmosphere as rain taking these ions (e.g. chloride, carbondioxide, sulphur) into solution. Most dissolved constituents in groundwater are derived from atmospheric precipitation, weathering and dissolution of silicate materials from rocks by the slightly acidic water formed when rain water takes carbondioxide into solution (Judith, 1986).

Other constituents dissolved in precipitation are calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^{+}) (Judith, 1986). Sodium (Na^{+}) and calcium (Ca^{2+}) concentration in groundwater is usually higher than potassium (K^{+}) concentration because plagioclase feldspar which is the source of Sodium (Na^{+}) and calcium (Ca^{2+}) is more soluble than

orthoclase feldspar from which potassium (K^+) is derived. Bicarbonate (HCO_3^-) is a major anion in natural groundwater. Soil permeability also affects the chemistry of groundwater (Judith, 1986).

Groundwater chemistry can be influenced by constituents leached from manure or from areas where animals are confined, constituents leached from cropland where fertilizers are used for agricultural purpose and from septic tanks, street dust, refuse dump sites, etc. Leachates from these sources (natural, geological and man induced sources) could impair the quality of groundwater. Irtwange and Sha'ato (2009) reported 0.22 mg/l TDS, 60 mg/l Cl^-, 28.81 mg/l SO_4^{2-}, 1.36 mg/l Zn^{2+} and 200 mg/l Na^+ for groundwater from a borehole located at a solid waste disposal site in Makurdi. Idoko (2010) reported iron concentration ranging from 0.03mg/l to 2.38 mg/l for groundwater in Benue State during the rainy season and values ranging from 0.01 mg/l to 5.02 mg/l during the dry season. This elevated iron concentration was attributed to the geology and confirmed higher concentration in areas with lateritic soil. Edet *et al.* (2011) reported concentrations of 6136.75 mg/l Na^+, 243.15 mg/l K^+, 390.58 mg/l Ca^{2+}, 70.80 mg/l Mg^{2+}, 10278.75 mg/l Cl^- and 406.05 mg/l HCO_3.

2.5. Groundwater Quality in Benue State

The quality of water may be described in terms of the concentration and state (dissolved or particulate) of some or all of the organic and inorganic material present in the water together with certain physical characteristics of water (Jamie and Richard, 1996). The quality of water should satisfy the requirements or standards set for specific uses, such as drinking, domestic, agricultural, industrial and recreational purposes. Groundwater contamination posses a very serious problem in groundwater resources management and this is basically with the increased level of urbanization, industrialization and large scale

agricultural activities in areas with hydrological contacts with aquifers (Offodile, 2002). Water quality is affected by a wide range of natural and human influences (Jamie and Richard, 1996), the most important of the natural factors being geological, hydrological and climatic factors.

Groundwater quality assessments carried out in some parts of Benue State have shown that there is great influence of urbanization on the quality of ground water. According to the report of Irtwange and Sha'ato (2009), groundwater sampled is of excellent quality for drinking and domestic use with respect to its TDS, Cl^-, SO_4^{2-}, Zn^{2+} and Na^+ concentration. Idoko (2010) reports that 35 percent of the samples analyzed from boreholes in Benue State for iron during the rainy season have elevated iron concentrations above the WHO maximum limit of 0.3 mg/l for drinking water while 7.7 percent of groundwater sampled during the dry season have iron concentration above the WHO allowable limit for drinking and domestic use.

The high iron content in the wells may be traced to the geology of the area and the use of galvanized hand pump and land use activities (Idoko, 2010). The presence of iron in drinking water is objectionable because it enhances the growth of iron bacteria and causes gastrointestinal irritation (Schoeneich and Garba, 2010). Edet *et al.* (2011) confirms that the water samples from the Makurdi Sandstone analyzed had concentration that are unsuitable for domestic use especially because of its elevated Na^+, Mg^{2+} and Cl^- concentrations.

Isikwue *et al.* (2011) reported that all wells sampled in Makurdi metropolis were of poor biological quality and identified sources of pollution as pit latrines, septic tanks and refuse dumps. It confirms that deeper wells in terms of coliform counts yield water of better

quality than shallow wells because the soil profile serves as a natural filter which purifies contaminated water. This shows that wells must be up to 15 m deep so as to be free from pollution. Wells were found to be most polluted in rainy season, when water table was highest. Groundwater in Wadata is the most polluted, this is generally due to lack of adequate drainage facilities and high population density (Isikwue *et al*, 2011).

CHAPTER THREE

3.0. METHODOLOGY

The research was carried out in three stages namely; Desk studies, fieldwork, and laboratory analysis. The fieldwork was carried within one hydrogeological year (2011/2012) and certain hydrogeological data were obtained during this period. These data include static water level in wells at the end of the rainy season and the end of dry season and water sampling from some selected areas.

3.1 Desk Studies

The desk study was in three stages. The first stage involved collection and review of existing literature (publishes and unpublished) on previous work done in the study area, these literature includes: text books, journals, bulletins as well as geological and topographical maps of the study area. The second stage was the evaluation of the field and laboratory data from the analysis of the chemical quality of water accessing its suitability for various uses as well as preparation and evaluation of hydrogeological maps. The third stage involved analysis of pumping test data of four boreholes obtained from BERWASA Makurdi. Evaluation of the dynamic water resources and interpretation of geophysical data were done at this stage as well.

3.2. Field Work

3.2.1. Water level measurement

The positions of the hand-dug wells were first established using a global positioning system (GPS). Rest water levels were measured in the hand-dug wells located during the reconnaissance survey stage. Water level measurements were taken from a reference point

above the ground (the rim of each hand-dug well). The height of these reference points from the ground surface was measured. A calibrated tape with a light metal weight attached to its end was used to measure the rest water level. The metal weight was attached to prevent the tape from sagging. The rest water levels in the wells were obtained by subtracting the height of the reference point from the water level measured from the well. These measurements were done at the end of the rainy season (October 2011) and the peak of dry season (April 2012). Rest water level measurements in 75 wells were taken at the end of rainy season (Appendix 1) and 97 wells at the peak of dry (Appendix 1)

3.2.2. Water Sampling

Groundwater samples were collected from selected hand-dug wells and a few boreholes. Hand-dug wells that are in constant use were selected and boreholes were pumped continuously for about four minute before sampling. These precautions were taken to ensure that the water sampled were directly from the aquifer. In the case of the boreholes, pumping for a while eliminates the possibility of sampling water whose chemistry may have been altered by the galvanized pipes used in borehole construction.

Water samples were taken from 4 boreholes and 20 hand-dug wells and stored in plastic sample bottles. The sample bottles were washed twice with the water to be sampled and filled to overflow, sealed tightly to avoid contamination with atmospheric gases. 500 ml of the sample was acidified to pH of 2 with concentrated nitric acid and another 500 ml non-acidified. A portion of the sampled water was acidified to keep the heavy elements in solution while in storage. Insitu measurement of some physical parameters such as

temperature, pH and total dissolved solids (TDS) was done using a portable 3 in 1 TDS/PH meter.

3.3 Laboratory Work

Chemical analysis of water samples was carried out at the Center for Energy Research and Training (CERT), Department of Water Resources Engineering Laboratory and multipurpose science research laboratory all in Ahmadu Bello University Zaria. Four analytical techniques were employed in determining the concentration of the chemical parameters of interest. These includes; photometric method (Zn^{2+}, Fe^{3+}, Cu^{2+}, Mn^{2+}, Cl^{-}, Zn^{2+}, NH_3^{-} and NO_3^{-}) using a Chemetric V – 2000 model multi – analyte photometer, atomic absorption spectrophotometry (Ca, and Mg) titremetric techniques (HCO_3) and flame photometric method (Na and K).

3.3.1. Zinc

The method employed here is the zincon chemistry. Zinc reacted with zincon (2 – carboxy-2-hydroxy-5-sulfoformazyl benzene) to produce a blue colored complex in direct proportion to the zinc concentration.

3.3.2. Iron

To determine the concentration of ferrous iron, the phenanthroline chemistry was employed. This involved the reaction of ferrous iron with 1, 10 – phenanthroline and an orange colored complex was formed. The colored complex was in direct proportion to the ferrous iron concentration.

3.3.3. Manganese

The periodate chemistry was employed in determining the concentration of manganese. In this method, soluble manganous compounds were oxidized by periodate in a slightly acidic solution and permanganate ion was formed.

3.3.4. Chloride

The ferric thiocyanate chemistry was employed in the determination of chloride concentration in the sample. Chloride reacted with mercuric thiocyanate to liberate thiocyanate ion. Ferric ion reacted with thiocyanate ion to produce an orange brown thiocyanate complex in proportion to the chloride concentration.

3.3.5. Ammonia

Ammonia concentration was determined by nesslerization. Ammonia reacted with Nessler reagent (K_2HgI_4) to produce a yellow colored complex which was in direct proportion to the ammonia concentration of the sample.

3.3.6. Nitrate

Concentration of nitrate was determined using the cadmium reduction method. In this method, nitrate was reduced to nitrite in the presence of cadmium in an acidic solution. The nitrite diazotizes with a primary aromatic amine and couples with another organic molecule and produced a highly colored azo dye with a resulting pink-orange color proportional to the nitrate concentration of the solution.

3.3.7. Bicarbonate

In determining the concentration of bicarbonate, the ethylene diamine tetra acetic (EDTA) titremetric method was employed using the Eriochrome Black indicator. The normalty of the titrant used was 2.5252.

3.4. Field Data Evaluation

3.4.1. Geophysical investigation

Six vertical electrical sounding (VES) data for six locations (Upuu, Youth camp, New GRA, Ankpa ward, High level and North bank) obtained within Makurdi metropolis were interpreted; 3 – 4 lithologies were identified. The data was plotted with IPI2Win software and the error was found to be less than 1.8 %. The layer parameters like depth to weathered zone, thickness of weathered zone and apparent resistivity were derived.

3.4.2. Groundwater elevation maps

Rest water level data and elevations deduced from the topographical map were used to prepare groundwater elevation and thickness of dry zone maps. These maps were prepared manually.

The groundwater elevation maps were prepared by locating the wells on a topographical map to produce base maps for the rainy and dry season, obtaining the elevation of the well location from the topographical map, subtracting the rest water level from the elevation of the wells to obtain the groundwater elevation at these points. Noting points of intersection between streams and topographical contours, drawing contours to join points of equal

groundwater elevation carefully incorporating groundwater elevation at the position of the hand dug wells. This was done for the end of rainy season and the peak of dry season.

3.4.3. Thickness of dry zone (depth to water table) map

Thickness of dry zone map for the peak of dry season was produced by superimposing the groundwater elevation map on a topographical map, noting the intersections of groundwater contour and topographical contours. Values of the groundwater elevation were subtracted from topographical contours to obtain the depth to water table at these points. Contour lines are then drawn to join points of equal values again carefully incorporating the water table depths measured from the hand-dug wells .

3.5 Analysis of pumping test data

Pumping test data of four boreholes were analyzed and values of transmissibility and storage coefficient were determined using the Jacob's method after plotting water level recovery data obtained from these boreholes on a semi – log graph. The expressions employed in determining these aquifer characteristics include;

$$\text{transmissibility } (T) = 2.\frac{30Q}{4\pi\Delta S}$$

$$\text{Storage coefficient (S)} = 2.\frac{25\text{Tto}}{\text{r}^2}$$

where T is transmissibility expressed in m^2/day, Q is the pumping rate expressed in liters/sec or m^3/day, ΔS is the change in drawdown, usually taken on a log cycle. t_0 is the intercept at Zero drawdown and r is the radius of the pumping well.

3.6 Evaluation of Dynamic Water Resource

The dynamic (renewable) water resource of an area consists of surface run – off, base flow and loss to evapotranspiration. The run – off coefficients are obtained from a graph of correlation between depth of rain fall and runoff coefficients for drainage basins. Area of the drainage basin was calculated by delineating the drainage basin on a 1:50,000 scale topographical map of the study area using the least square method.

The parameters estimated were calculated using the following expressions:

Volume of annual rainfall (V) (km^3/year) = A x d

Volume of baseflow (km^3/year) = cRb x V

Volume of total run – off (km^3/year) = cRt x V

where V is volume of annual rainfall (km^3/year), A is the area of drainage basin (km^2), d is the annual rainfall depth (km/year), cRs is coefficient of surface runoff, cRb is coefficient of baseflow and cRt is coefficient of run – off total

Loses to evapotranspiration was estimated by obtaining a coefficient of evapotranspiration (cEt) from the expression below.

$$cEt = 1 - cRt$$

where cEt = coefficient of evapotranspiration and cRt = coefficient of total runoff.

Loses to evapotranspiration is estimated by the expression

Evapotranspiration = cEt x V

V = volume of rain fall (km^3/year)

3.6.1 Utilizable dynamic water resources

This is simply a fraction of the total water resources available for consumption after subtracting loss to evapotranspiration expressed as units of volume divided by time (e.g. km^3/year). It is estimated from the expression

Utilizable dynamic water resource = total vol. of rainfall – loss to Evapotranspiration

3.7 Interpretation of Results From Groundwater Chemical Analysis

3.7.1. Suitability of water for drinking and domestic uses

Results of water quality analysis were collated and concentrations/values of measured parameters were compared with Standard Organization of Nigeria (SON (2007)) maximum permitted/allowable limits of these parameters for drinking water. Graphs of parameter values and SON (2007) maximum permissible limits as well as selected background values were plotted to show samples with concentrations below or above these values (Appendix 2 and 3 respectively).

The facies of the groundwater samples analyzed were determined by plotting the concentration of the major cations and anions on Piper diagram and Durov plot using aquachem V.4.0 software. This software was also used for rock source deductions (Appendix 4), plots of radial diagram (Appendix 5) and some statistical analysis of results such as mean, standard deviation and correlation coefficients.

3.7.2. Suitability of groundwater for irrigation purposes

In determining the suitability of groundwater for irrigation purpose, the percentage sodium (Na %), sodium adsorption ratio (SAR) and bicarbonate hazard of the groundwater samples were calculated using the following expressions:

$$\text{Percentage Sodium (Na \%)} = \left(\frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+}\right) \times 100$$

$$\text{Sodium adsorption ratio (SAR)} = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Bicarbonate hazard (meq/l) = HCO_3^- – (Ca^{2+} + Mg^{2+})

All ionic concentrations are expressed in milliequivalent per liter (meq/l)

CHAPTER 4

4.0. RESULTS AND DISCUSSION

4.1. Geophysical Investigation

Six vertical electrical sounding (VES) data obtained from(Upuu, Youth camp, New GRA, Ankpa ward, High level and North bank within Makurdi metropolis were interpreted; 3 – 4 layers were identified. The data was plotted with IPI2Win software and the error was found to be less than 1.8 %. The layer parameters like depth to weathered zone, thickness of weathered zone and apparent resistivity were derived. Interpreted master curves are the H type (VES 03, VES 04 and VES 09 (Figures 4.1a, 4.1b and 4.1d respectively), Q type (VES 06 and VES 11 (Figures 4.1c and 6f respectively) and K type (VES 10 (Figure 4.1(e))

It is observed that the resistivity in the first layer varied from 72.63 to 1787 Ωm, the thickness of the layer varied from 0.31 to 4.16 m. In the second layer, resistivity varied from 75.02 to 4666 Ωm and the thickness varied from 1.18 to 15.2 m. In the third layer, resistivity varied from 3.414 to 400.3 Ωm and thickness of 5.54 to 29.25 m. Resistivity of the fourth layer varied from 59.04 to 1085 Ωm (Table 4.1), the thickness of this layer however could not be determined due to the quite shallow depth of penetration during the sounding.

Borehole logs presented in Appendix 6 also reveal that the depth to the Sandstone (Makurdi Sandstone aquifer) which is the most important aquifer in Makurdi metropolis ranges from about 4m to 24 m. The first layer identified here is mostly reddish brown (sometimes lateritic) sand. Borehole logs also reveal that the thickness of this layer ranges from about 3.0 m to about 24 m. This however corresponds with the thickness of layers one and two

obtained from the interpretation of the VES data. Layer three and/or four here is the fractured Sandstone and is the most prolific aquifer in this area from which most boreholes tap.

Apparent resistivity within this weathered zone varies from 3.414 to about 400 Ωm. This range of values suggests that the fractured Sandstone is the best aquifer for groundwater exploitation. The integration of resistivity sounding and geochemistry of groundwater was found to be a highly effective method of determining the location of fresh water areas and

Table 4.1: Resistivity and thickness of geoelectrical sections

			Resistivity (Ωm)				Thickness (m)				
VES No.	Co- ordinates	Location	Layer 1	Layer 2	Layer 3	layer 4	Layer 1	Layer 2	Layer 3	layer 4	Curve **type**
VES 03		Upuu	417.4	4667	3.414	1085	0.31	1.19	5.54	∞	H
VES 04	N07°42'49.7", E08°34'23.7"	Youth camp	1787	75.02	197.7	-	4.16	15.2	∞	∞	H
VES 06	N07°41'33.6", E08°32'14"	New GRA	1324	3740	241.4	59.04	2.06	3.14	19.78	∞	Q
VES 09	N07°43'09.5", E08°30'34.2"	Ankpa ward	722.4	101.8	13.3	402.8	0.76	3.33	15.18	∞	H
VES 10	N07°43'31.6", E08°31'28.7"	High level	72.63	209.5	40.79	3951	1.01	2.12	29.25	∞	K
VES 11	N07°46'05.9", E08°33'47.2"	North bank	947.9	2179	400.3	70.71	0.59	1.18	6.52	∞	Q

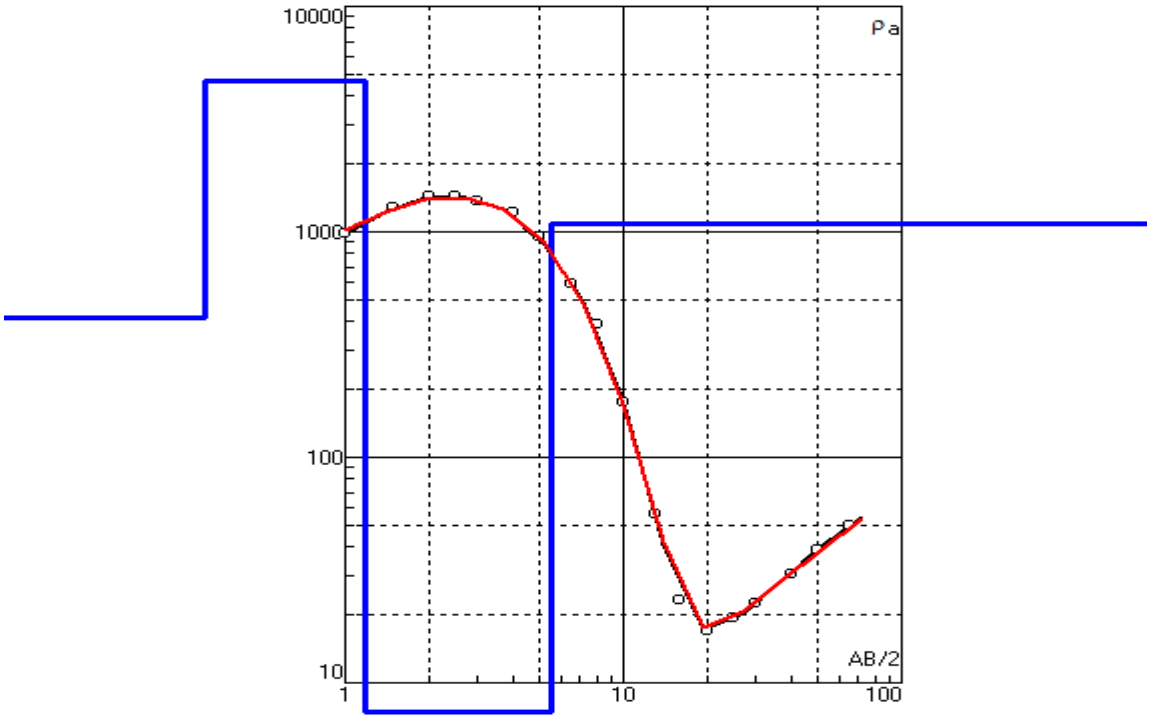


Figure 4.1(a). Interpreted VES curve for Upuu (VES 003) in Makurdi metropolis

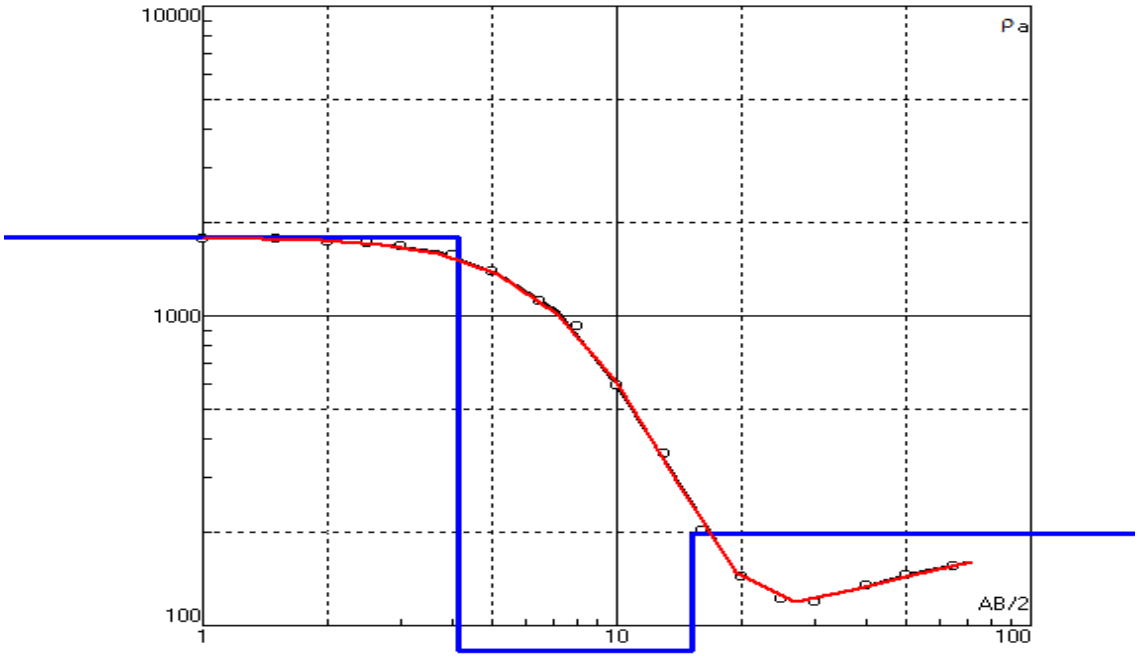


Figure 4.1(b). Interpreted VES curve for Youth camp (VES 04) in Makurdi metropolis

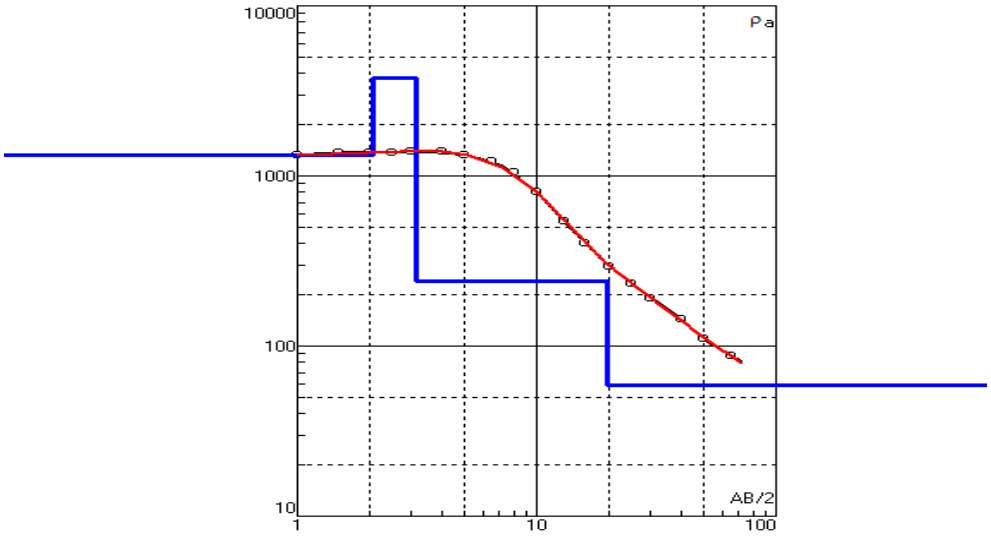


Figure 4.1(c). Interpreted VES curve ECWA Church, New GRA (VES 006) in Makurdi metropolis

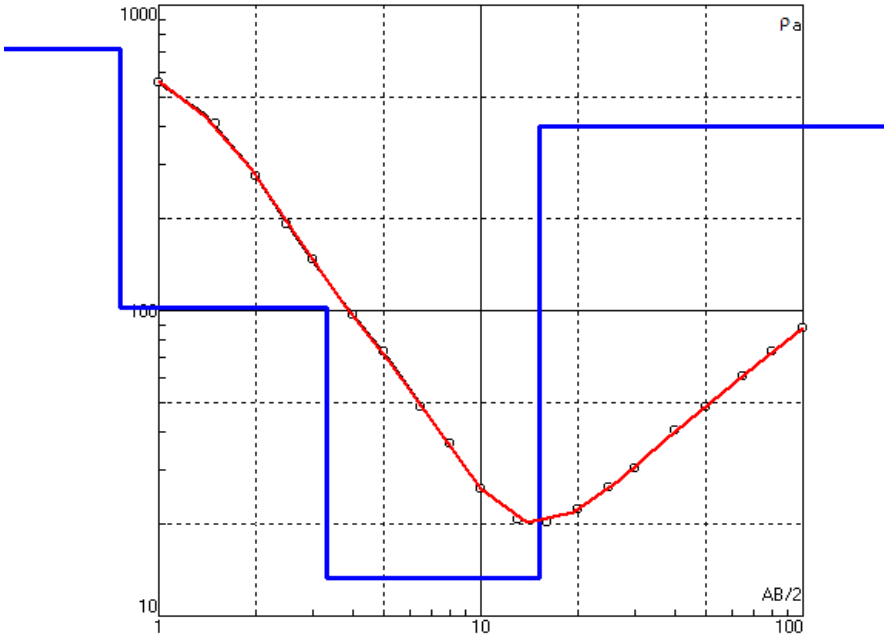


Figure 4.1(d) Interpreted VES curve Nations eye clinic, Ankpa ward (VES 09) in Makurdi metropolis

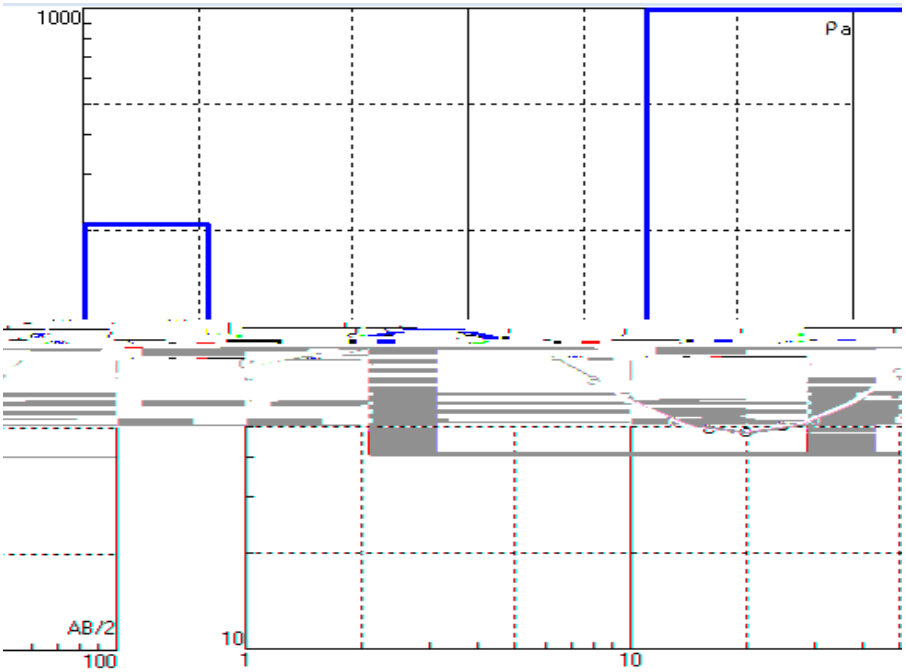


Figure 4.1(e) Interpreted VES curve for Empire suites, High level (VES 10) in Makurdi metropolis

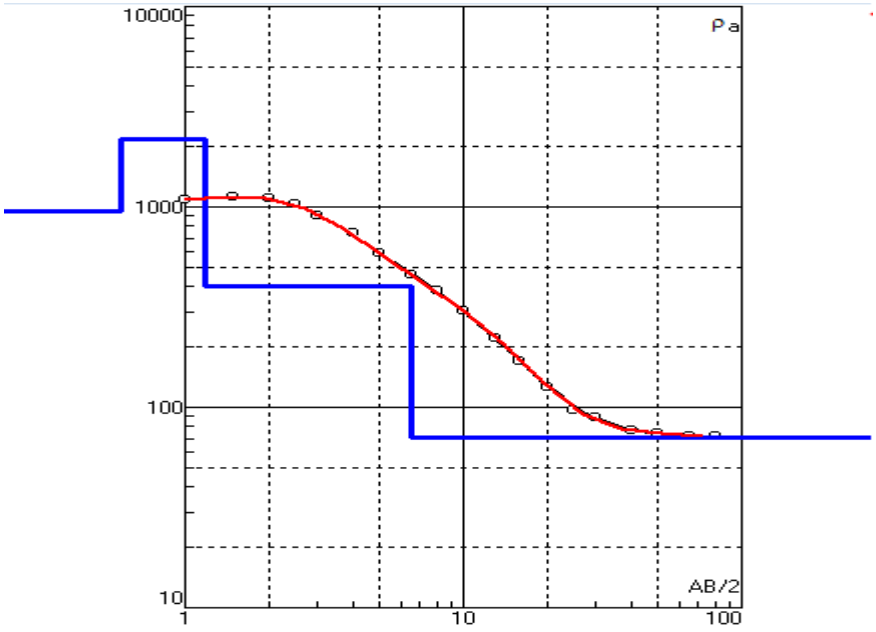


Figure 4.1(f). Interpreted VES curve for Mr. John Unum's residence, North Bank (VES 11) in Makurdi metropolis

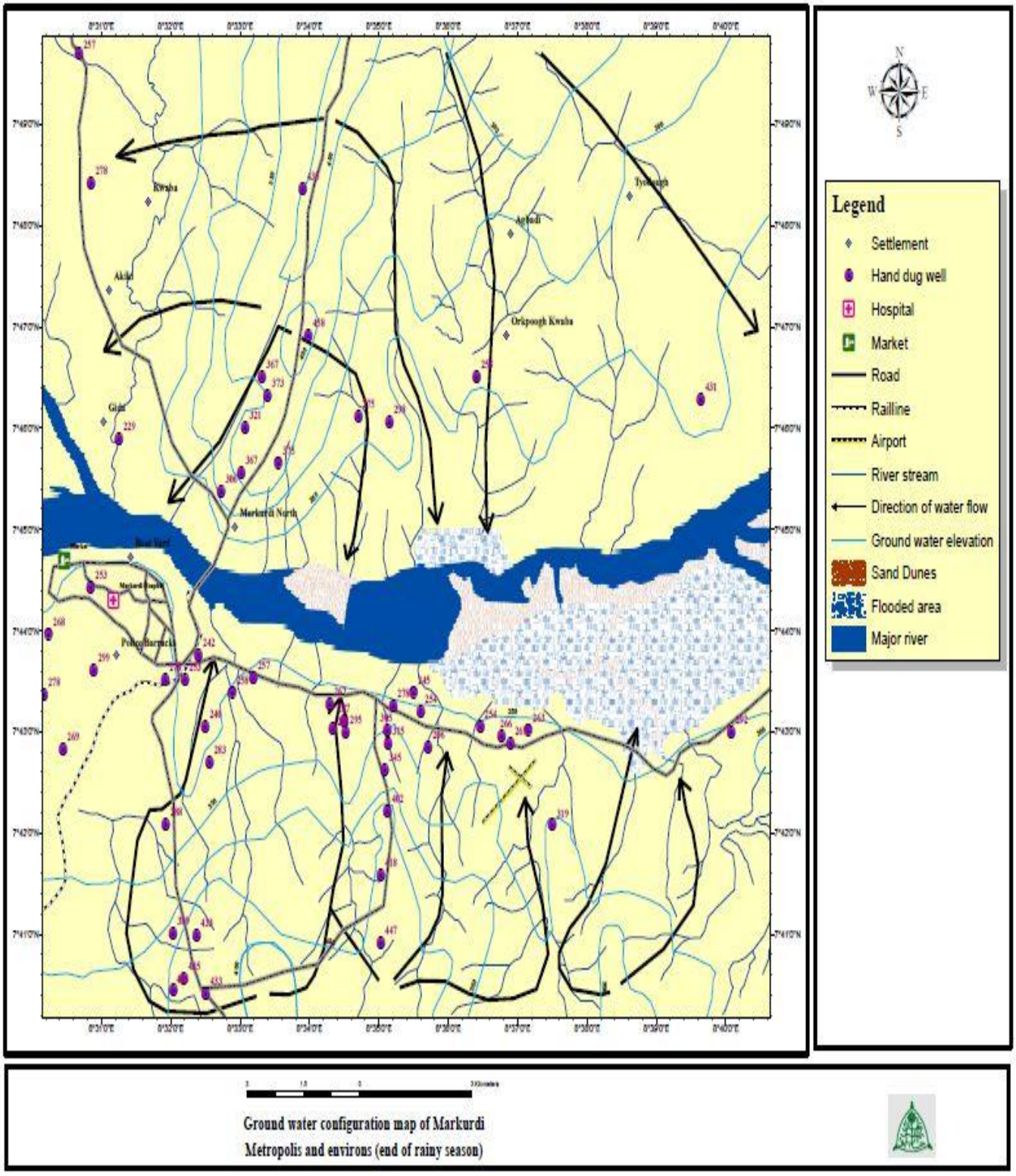
the saline water or industrial effluent contaminated zones (Choudhury and Saha, 2004). It suggests that the low resistivity values at some points may have resulted from the high mineralization of the water in this aquifer (brine also have been reported to issue from the Awe Formation within this area).

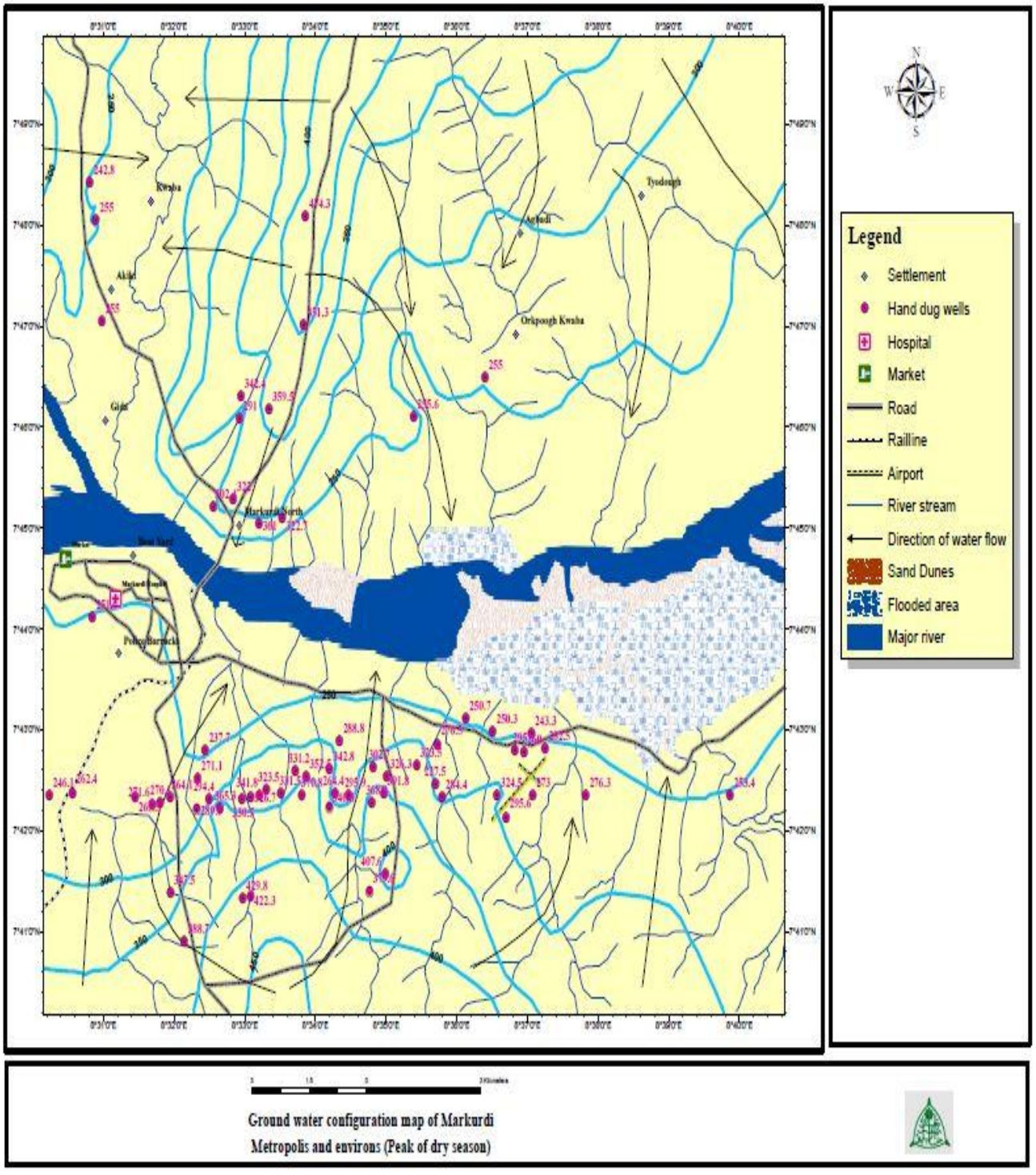
4.2. Evaluation of Hydrogeological Maps

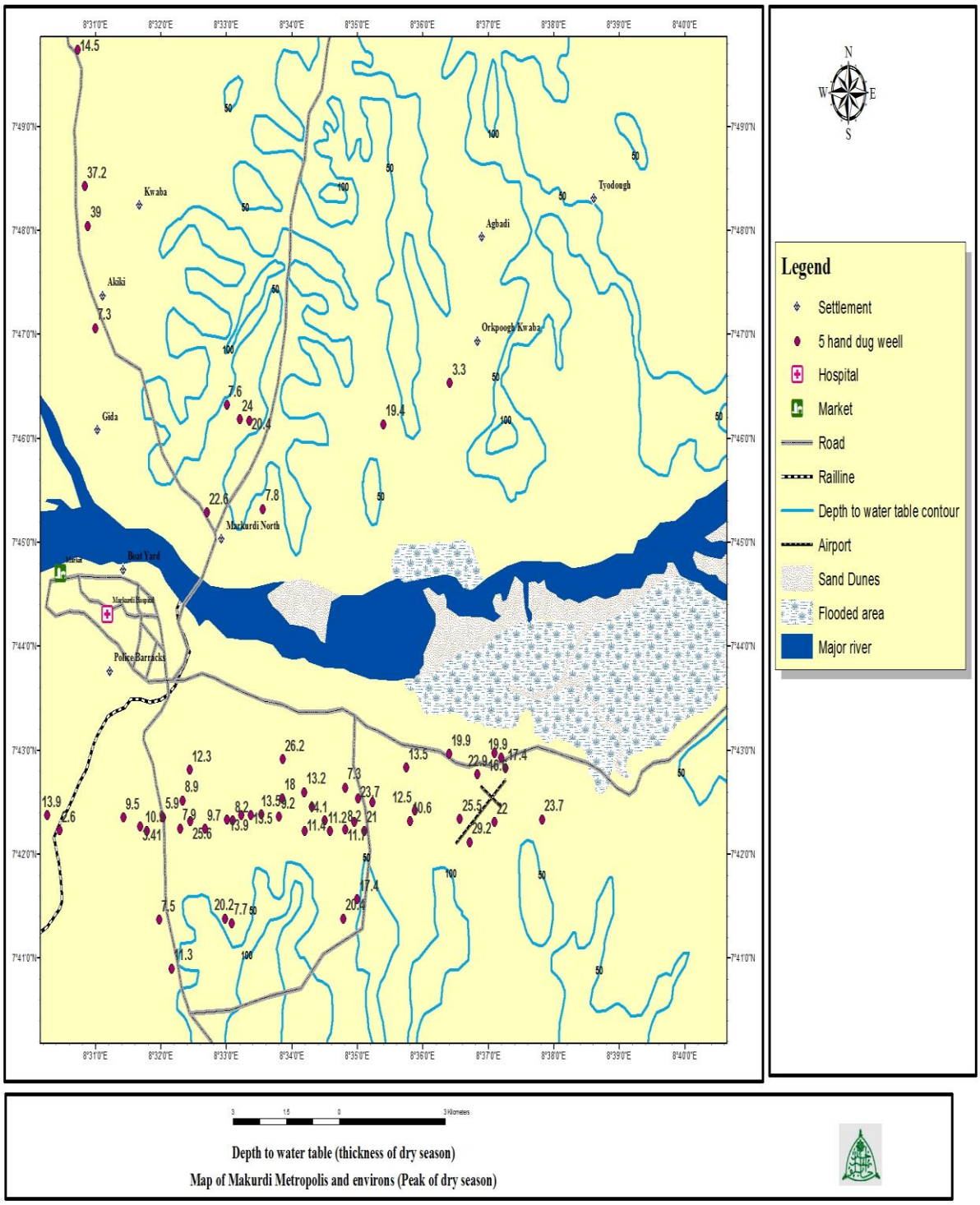
Analysis of the produced hydrogeological maps (watertable maps) reveals important information on the occurrence and behavior of groundwater in this study area. Groundwater data collected at the end of the rainy season and the peak of dry season were used to prepare the map of groundwater configuration for both seasons (Figures 4.2 and 4.3) and map of the thickness of dry zone for the peak of dry season (Figure 4.4).

4.2.1. Map of Groundwater Configuration (Groundwater Elevation Map)

Watertable elevation in wells within the study area ranged from 67.7 m (229 ft) to 97.8 m (497 ft) a.m.s.l (Figures 4.2 and 4.3) in the fractured and weathered Makurdi Sandstone aquifer. The groundwater elevations are higher at the groundwater mounds (recharge areas) which correspond to surface watersheds at the northeastern and southern parts of the study area (Figure 1.2). The spacing of groundwater contours gives an indication of variation in aquifer permeability. Areas where the contours are close indicates aquifers of low permeability. More spaced groundwater contours on the other hand is indicative of areas with aquifers that are likely to be more permeable.


Legend
Settlement
Hand dug well
Hospital
Market
Road
Railline
Airport
River stream
Direction of water flow
Ground water elevation
Sand Dunes
Flooded area
Major river
Markurdi North
Akiki
Orkpoogh Kwaha
Ayiradi
Ground water configuration map of Markurdi
Metropolis and environs (end of rainy season)


Legend
Settlement
Hand dug wells
Hospital
Market
Road
Railline
Airport
River stream
Direction of water flow
Sand Dunes
Flooded area
Major river
Kwaba
Akilo
Gida
Markurdi North
Police Barracks
Tyodzogh
Orkpogh Kwaba
Ground water configuration map of Markurdi
Metropolis and environs (Peak of dry season)



Depth to water table (thickness of dry season)

Map of Makurdi Metropolis and environs (Peak of dry season)

The map of groundwater elevation is useful in the proper sitting of wells at the convergent zones to ensure that the well is productive all year round. It is also important in sitting wells that may not be prone to pollution by effluents from pit latrines by siting these wells upstream of settlements.

4.2.2. Groundwater Movement

Groundwater moves from areas of higher head to areas of lower head in the direction of the steepest hydraulic gradient. The directions of groundwater flow within the study area are indicated by arrows drawn perpendicular to the groundwater contour. These arrows are seen to diverge at groundwater mounds (divergent zones) at the north western, south western and south eastern parts of the study area (Figures 4.2 and 4.3) and corresponds with the surface water sheds marked by a few hills. These divergent zones constitute the major groundwater recharge areas within the study area.

The general flow direction of groundwater within the study area is from the northern and southern part towards the River Benue which is the major groundwater discharge area and corresponds with the groundwater convergent zone within the study area. The map of groundwater configuration for both the end of the rainy season and the peak of the dry season shows that River Benue is effluent all year round and consistently drains the study area.

4.2.3. Thickness of Dry Zone (Depth to Watertable) Map

Figure 4.4 shows the depth to watertable (thickness of dry zone) at the peak of dry season in the study area. Depths to watertable measured in wells within the study area at the end of the rainy season ranged from 0 m (0.0 ft) to about 5.85 m (19.2 ft) below ground surface (Appendix 1). While values measured at the peak of dry season ranged from about 1.2 m

(3.9 ft) to about 11.34 m (37.2 ft) (Figure 4.4). As expected the thickness of dry zone is more during the dry season because the rate of groundwater discharge is higher with no corresponding recharge.

The thickness of dry zone is observed to be shallower along the flood plains of the River Benue (discharge areas) where some flowing wells were also encountered. Greater depths to groundwater table were observed at the groundwater mounds (recharge areas) at North Bank and Yaiko in the northern and southern parts of the study area respectively (Figure 4.4) where it reaches about 30.4 m (100 ft). Groundwater at such depth can only be abstracted through boreholes drilled into favorable aquifer beyond this depth to be productive all year round.

The thickness of dry zone has greatly influenced the concentration of the population to the areas closer to the River Benue where the depth to the groundwater table is minimal. The thickness of dry zone map will be useful to well drillers as it provides information on how deep a well should be sunk to yield water throughout the year.

4.3. Suitability of Groundwater for Drinking and Domestic Use

Results of water quality analysis carried out gives a range of values for the concentration of some chemical and physical parameters. Concentrations of the measured parameters are compared with guideline values of the Standard Organization of Nigeria (SON) (2007) to determine the suitability of groundwater within the study area for drinking and domestic use.

4.3.1 Physical parameters

The physical parameters measured are temperature, pH, and total dissolved solids (TDS).

4.3.1.1. Total Dissolved Solids

Total dissolved solids (TDS) refer to inorganic salt and small amount of organic matter present in solution in water. TDS content in groundwater within the research area ranges from 90 mg/l to 520 mg/l in boreholes and from 90 mg/l to 1250 mg/l in hand dug wells with an average of 489.55 mg/l. Five (20.8%) of the samples analyzed had values below the background value of 180 mg/l and 19 (79.2%) samples with concentrations above the background value. (Appendix 2)

The SON (2007) permissible limit for TDS in water for drinking and domestic use is 500 mg/l. The result shows that 15 (62.5%) of these water samples analyzed have values below the permissible limit while nine (37.5%) of the 24 samples analyzed had elevated concentration above this limit (Table 4.2). It is however important to mention that very high concentration in hand dug wells may have resulted from poor maintenance of these well. Elevated concentrations also pose no direct health danger (SON, 2007). According to the classification of water based on total concentration of dissolved solids (Table 4.3), groundwater in most part of the study area (87.5%) fall within the fresh water class with TDS concentration less than 1000 mg/l. However groundwater from some part of Wadata and North bank fall within the brackish water class. The high TDS in groundwater within Wadata and North bank can be attributed to dissolution from carbonate rock or sourced from salty water. This was confirmed using the rock source deduction function of the aquachem 4.0. softwere. The location of these sample points on the geological map

Table 4.2: Results of water analysis from Makurdi Metropolis and environs

S/N	ID	TDS (mg/l)	PH	Temp (°C)	Fe	Cu	Mn	Zn	NH3	Cl	NO3	Na	K	Ca	Mg	HCO3	SO_4	Designation
1	SL 1	130	5.65	29.5	0.47	0.11	2.43	0.22	0.54	0.97	0.53	11.6	2.5	3.18	22.1	90.9	5	B
2	SL 2	260	7	31.3	0.1	0.18	0.53	0	1.03	1.37	16	13.3	2.1	31.68	12.53	525.2	15	A
3	SL 3	400	3.1	30.3	0	0.11	0.39	0.02	1.39	0	15	12.3	3	42.33	36.49	858.5	40	B
4	SL 4	360	7.26	29.1	0.02	0.15	0.31	0.1	0.76	0.34	0.63	12.8	3	29.58	5.68	401.25	10	B
5	SL 5	320	4	28.6	0.27	0.09	0.36	0.1	0.82	1.75	32	16.7	18.6	8.16	74.2	232.3	25	B
6	SL 6	260	4.41	31.4	0.29	0.18	0.19	0.13	0.61	0	32	14	45.4	9.92	22.66	313.1	15	B
7	SL 7	850	2.24	32.2	0.38	0.01	0.28	0.09	0.86	9.28	107	20.9	51.1	41.5	9.71	700.65	5	C
8	SL 8	1230	4.34	30.4	0.27	1.93	0.26	0.12	3.2	13.11	150	36	2.99	94.5	7.43	1525.5	105	C
9	SL 9	90	4	30.5	0.47	0.11	0.53	0.16	0.53	1.39	16	10.5	4.7	18.45	10.99	171.7	15	B
10	SL 10	1190	5.82	29.4	0.2	0.87	0.49	0.12	2.8	11.29	96	35.5	66.5	49.59	9	550.30	6.5	C
11	SL 11	1250	6.44	29.9	0.25	0.9	0.54	0.09	0.34	10.76	117	36	64	36.25	15.43	450	50	C
12	SL 12	240	7.01	28.3	0	0.2	0.93	0.08	0.49	0	17	11.8	17.4	15.27	9.93	255	30	B
13	SL 13	330	5.8	31.2	0	0.14	1.28	0.06	0.89	0	33	10.7	8.3	4.39	7.09	200	25	C
14	SL 14	450	7.17	32.3	0.11	0.09	0.5	0.03	0.96	0.3	36	17.8	33.2	2.78	24.27	565.6	40	C
15	SL 15	170	4.33	32.3	0.35	0.29	0.66	0.11	1.11	0	26	10.4	7.3	32.86	38.59	181.8	15	B
16	SL 16	810	5.01	32.6	0.18	0.39	0.09	0.13	2.34	5.61	21.3	25.7	53.5	14.12	9.77	757.5	80	C
17	SL 17	180	4.18	29.6	0.86	0.28	0.24	0.16	0.5	0	38	12.1	1.8	25.19	21.86	131.3	5	A
18	SL 18	90	3.33	29.8	0.11	0.1	0	0.07	0.96	0	26	10.5	2.2	144.74	24.21	111.1	5	A
19	SL 19	520	5.91	31.7	0.37	0.27	0	0.11	0.83	0.39	18	20	2.5	119.71	22.98	505	20	A
20	SL 20	630	2.95	29.1	0.22	0.08	0	0.18	0.79	1.91	49	19.4	4.2	169.74	44.5	505	40	A
21	SL 21	520	5.88	30.4	0.58	0.35	0.13	0.07	0.61	0.88	16	13	2.3	10.63	39.54	767.6	10	A
22	SL 22	490	2.9	30.4	0.43	0.23	0	0.15	0.9	4.84	29	19.3	28	110.43	44.08	343.4	15	A
23	SL 23	130	4.18	28.1	0.13	0.13	0	0.06	0.37	1.09	28	11.7	3					A
24	SL 24	520	5.88	30.4	0.66	0.97	1.29	0.14	1.58	0.98	21	13.1	2.8					A
	Background	180			0	0.09	0	0.02	0.5	0		10.7	1.8	2.78	21.86	131.3	40	
	SON MPL	500	6.5 - 8.5		0.3	1	0.2	3		250	50	200			0.2		100	

Units: mg/l except for pH and temperature (Temp): SON MPL : Standard organization of Nigeria Maximum permissible limit. A: meteoric water, B: meteoric + formation water, C: formation + meteoric water

(Figure 2.1) shows that water from these area must have come in contact with the limestone which forms part of the dominant geology of North bank and Wadata.

Table 4.3: Classification of water based on total concentration of dissolved solids (Source: Davis and Dewiest, 1966)

Name	**Concentration of Total Dissolved solids in parts per million (mg/l)**
Fresh water	0 - 1000
Brackish water	1000 – 10,000
Salty water	10,000 – 100,000
Brine	More than 100,000

4.3.1.2. Temperature

Temperature of groundwater ranges from 28.10°C to 32.60°C with an average of 30.57°C (Table 4.2 and Table 4.4). These values are a little above the Stevenson Screen mean annual ground surface temperature of 27.20°C for the area.

4.3.1.3. pH

pH values ranges from 2.90 to 7.26 with an average of 4.94. Only three (12.5%) of the 24 samples have values within the Standard Organization of Nigeria (2007) permissible range of 6.50 to 8.50 (Table 4.2)

Low pH of groundwater could result from free carbon dioxide picked up from atmospheric rain, the presence of acids of peaty origin, decaying vegetation and the presence of sulphates. pH according to SON (2007) has no direct health impact.

4.3.2. Trace Elements

This group of metals is essential at low concentrations (concentrations less than one milligram per liter) acting as micro – nutrients but become toxic at higher concentrations. Trace elements analyzed in this study include; iron, copper and zinc.

4.3.2.1. Iron

Concentration of iron (Fe^{3+}) in groundwater within the study area ranges from 0.00 mg/l to 0.86 mg/l in with an average of 0.27 mg/l (Table 4.2). Only three (12.5%) of the 24 samples analyzed were within the background concentration of 0.00 mg/l while 21(87.5%) samples had values above the background value (Table 4.2 and Appendix 2). Also 15 (62.5%) of the samples analyzed were within the SON (2007) permissible limit of 0.30 mg/l and nine (37.5%) samples had elevated iron concentration above the permissible limit (Appendix 3)

Iron promotes the growth of "iron bacteria", which derive their energy from the oxidation of ferrous iron to ferric iron and in the process deposits a slimy coating on the piping. At concentrations above 0.30 mg/l, iron stains laundry and plumbing fixtures. There is usually no noticeable taste at iron concentrations below 0.30 mg/l, although turbidity and colour may develop (WHO, 2011). Sources of iron in groundwater could be from atmospheric absorption, leaching of the products of rock weathering especially pyrite (Appendix 4), the use of galvanized hand pump (Idoko, 2010). Water from most part of the study area is safe for drinking and other domestic uses. Some parts of the study like Wurukum, Mu village, Kanshio, North bank and Airport village however have iron in concentrations that make them unsafe for drinking and domestic use.

4.3.2.2. Copper

Copper in water supply usually arises from the corrosive action of water leaching copper from copper pipes in buildings (WHO, 2011). This corrosive action of water is often accelerated by high levels of dissolved oxygen in water. The analysis reveals concentration of 0.09 mg/l to 1.93 mg/l with an average of 0.31 mg/l for samples analyzed. At concentration above 5 mg/l copper imparts colour and an undesirable bitter taste to water (WHO, 2011). Maximum permissible limit of copper concentration in water for drinking and domestic uses by SON (2007) is set at 1.00 mg/l; consumption of water with concentration above this value causes gastrointestinal disorder. All except one (SL 8 at North Bank) of the samples analyzed had concentration below the permissible limit (Appendix 3). Groundwater in Makurdi metropolis is considered safe for drinking and domestic uses with an exception of the immediate area around SL 8 at North Bank.

4.3.2.3. Zinc

All samples analyzed had zinc concentration below the SON (2007) permissible limit of 3.00 mg/l (Appendix 3) with concentration ranging from 0.00 mg/l to 0.18 mg/l with an average of 0.09 mg/l. All samples except 2 (8.3%) of the samples analyzed had concentrations above the background value of 0.02 mg/l (Appendix 2).

Zinc in drinking water has no direct health impact (SON, 2007) but imparts an undesirable astringent taste to water at a taste threshold concentration of about 4 mg/l. Water containing zinc at concentrations in excess of 3.00 mg/l to 5.00 mg/l may appear opalescent and develop a greasy film on boiling (WHO, 2011). Zinc in groundwater has resulted from zinc leaks from zinc pipes and rain pipes, Car tires containing zinc and motor oil from zinc tanks which releases zinc compounds on roads, zinc compounds present in fungicides and

insecticides and from chemical waste dumps and landfills. Groundwater in Makurdi metropolis and environs with respect to zinc concentration is safe for all domestic purposes and drinking.

4.3.3. Anions

4.3.3.1. Chloride

Chloride (Cl^-) concentration in groundwater within the studied area ranges from 0.00 mg/l to 13.11 mg/l with an average of 2.92 mg/l. These values are far below the SON (2007) maximum permissible limit of 250.00 mg/l (Appendix 3). No health-based guideline value is proposed for chloride concentration in drinking-water.

4.3.3.2. Bicarbonate

Guideline values have not been established for bicarbonate. Bicarbonate (HCO_3^-) concentration in groundwater within the study area ranges from 90.90 mg/l to 1525.50 mg/l with an average of 555.97 mg/l (Table 4.2). Bicarbonate in groundwater is derived from carbondioxide in the atmosphere, carbondioxide in the soil and dissolution of carbonate rocks. The concentration of bicarbonate is high in groundwater samples from areas with carbonate rocks (limestone). Groundwater from Wadata and North bank areas have high bicarbonate content and this can also be attributed to dissolution from limestone.

4.3.3.3. Sulphate

The presence of sulphate (SO_4^{2-}) in drinking-water can cause noticeable taste and very high concentration might cause laxative effect to unaccustomed consumers (WHO, 2011). Sulphate concentration in groundwater within the study area ranges from 5.00 mg/l to 500.00 mg/l with an average of 28.25 mg/l (Table 4.2). Only two (4.5%) of the samples

analyzed had sulphate concentration above SON (2007) maximum permissible limit of 100 mg/l (Appendix 3). Sulphate in groundwater within the study area as deduced from the aquachem software is from pyrite oxidation. Other sources of sulphate in groundwater includes; atmospheric precipitation and from the solution of sulphate minerals in sedimentary rocks (Davis and Dewiest, 1966). Most part of the study area (95.5 %) contains groundwater considered safe with respect to its sodium concentration. One location however, SL 8 at North Bank has elevated sulphate concentration (150 mg/l) and is therefore unsafe for drinking and domestic use.

4.3.4. Cations

4.3.4.1. Sodium

Sodium (Na^+) concentration ranges from 10.70 mg/l to 36 mg/l with an average of 17.24 mg/l (Table 4.2). All samples analyzed had concentrations below SON (2007) maximum permissible limit of 200 mg/l (Appendix 3)**.** The source of sodium in groundwater in the study area has been traced to weathering of albite in the Sandstone and ion exchange (Appendix 4). Groundwater in the study area is safe for all uses as it concerns its sodium concentration.

4.3.4.2. Potassium and Calcium

Guideline values have not been established for potassium and calcium. Potassium (K^+) concentration in groundwater within the studied area ranges from about 1.80 mg/l to 94.50 mg/l with an average of 23.46 mg/l and calcium (Ca^{2+}) concentration ranges from 2.78 mg/l to 144.74 mg/l with an average of 41.98 mg/l (Table 4.2). Potassium in groundwater results from weathering of orthoclase and microcline. The abundance of potassium and sodium is about the same but potassium is commonly less than one tenth of sodium in natural water

because many potassium minerals have higher resistance to weathering (Davis and Dewiest, 1966).

Calcium in groundwater on the other hand, has resulted from its contact with sedimentary rocks of marine origin such as dolomite. Groundwater derives most of its calcium content from the solution of calcite, aragonite, dolomite and gypsum (Davis and Dewiest, 1966).

4.3.4.3. Magnesium

Magnesium (Mg^{2+}) concentration in groundwater within the studied area ranges from 5.68 mg/l to 74.20 mg/l with an average of 23.32 mg/l. 11 (50%) of the 22 samples analyzed for magnesium had concentrations below the background value of 21.86 mg/l. All the samples analyzed had concentration above SON (2007) permissible limit of 0.20 mg/l (Appendix 3). Concentration of magnesium greater than 125 mg/l negatively affects taste of beverages.

Magnesium in groundwater may have resulted from the dissolution of dolomitic limestone ($CaMg(CO_3)_2$) especially at the North bank and Wadata areas of the study area, fertilizer applied to farmlands, from cattle feed, Magnesium sulphate applied in beer breweries (Benue briweries) and magnesium hydroxide is applied as a flocculant in wastewater treatment plants. Groundwater in most part of the study area has elevated concentrations of magnesium and is considered unsafe for drinking and domestic use.

4.3.5. Heavy Metal

4.3.5.1. Manganese

Manganese (Mn^{2+}) concentration ranges from 0.00 mg/l to 0.16 mg/l in boreholes and 0.00 mg/l to 2.43 mg/l in hand dug wells with an average of 0.48 mg/l (Table 4.2). Only five (20.8%) samples have concentration below the background value of 0.00 mg/l and 18

(79.2%) of the samples above that value (Appendix 2). 18 (75%) of the samples show elevated manganese concentration above the SON (2007) maximum permissible limit of 0.20 mg/l while five (25%) of the samples had values below this limit (Appendix 3). Concentration above 0.1 mg/l causes undesirable taste in beverages, stains sanitary wares and laundry (WHO, 2011) and neurological disorder (SON, 2007). Health - based value for manganese according to the World Health Organization is placed at 0.40 mg/l. Manganese present in groundwater is usually absorbed from the atmosphere or leached from products of rock weathering.

4.3.6. Ammonia

Background value for ammonia (NH_3) in the study area is placed at 0.50 mg/l. Results show a range of 0.34mg/l to 3.20 mg/l with an average of 1.06 mg/l (Table 4.2). Four (16.6%) of the samples had concentration below the background value and 20 (83.4%) of the samples analyzed had values above the background (Appendix 2). The threshold odour concentration of ammonia at alkaline pH is approximately 1.50 mg/l, Ammonia is not of direct relevance to health at this level (WHO, 2011) and no health – based guideline value has been proposed either by the World Health Organization or the Standard Organization of Nigeria; however WHO suggests concentration of 0.20 mg/l in natural groundwater. Considering this value, all samples analyzed have concentration above the natural occurrence. Ammonia in groundwater within the area of study has resulted from decaying organic materials through which this water has percolated.

4.3.7. Nitrate (NO_3^-)

Nitrate concentration in groundwater within the studied area ranges from 0.53 mg/l to 196.00 mg/l with an average of 42.61 mg/l. Three (12.5%) of the samples have nitrate

concentration below the background value of 15.00 mg/l while 21 (87.5%) of the samples analyzed have concentrations above this value (Appendix 2). Four (16.7%) of the samples, SL7 and SL8 from North Bank, SL10 and SL11 from Wadata and Judge's quarters respectively have elevated concentrations of 107 mg/l, 196 mg/l, 96 mg/l and 117 mg/l respectively above the maximum permissible limit of 50 mg/l (Table 4.2, Appendix 3).

Elevated nitrate concentration in groundwater may have resulted from agricultural activities (e.g. excess application of nitrogenous fertilizers and manures), from waste water disposal and oxidation of nitrogenous waste products in human and animal excreta. Wadata and North Bank areas are the most populated areas of Makurdi metropolis and lacks adequate drainage or efficient waste disposal system. These conditions however may be responsible for the high nitrate concentration in groundwater from these areas.

Groundwater in most part of the study area is unsafe for drinking and should not be used for this purpose as it could cause methemoglobinemia. Also infant cyanosis or blue-baby syndrome results from ingestion of water containing high nitrate concentration.

4.4. Indication of Salty Water in Shallow Aquifers

Considering the dominance of some ions over others, the groundwater from the study area has been characterized. According to Schoeneich and Garba (2010), meteoric water has characteristic predominance of HCO_3^- anion over Cl^- and predominance of Ca^{2+} and Mg^{2+} over Na^+. In salty, connate or fossil water, Cl^- predominates over all other anions and predominates over all other cations. Based on these relationships, nine (37.5 %) of the samples analyzed are meteoric, designated A (Table 4.2). Eight (33.3 %) are a mixture of meteoric and formation water (with more of meteoric water), designated B and seven (29.2

%) contains a mixture of formation and meteoric water designated C (with more of formation water) (Table 4.2).

This result shows that intrusion of formation water into near surface aquifers has occurred in a larger part of the study area (62.5%). This has resulted from intensive development of the aquifers to meet the water need of the population especially during the dry season.

4.5. Statistical Analysis

Statistical functions carried out with the results from water quality analysis include mean, standard deviation, deviation coefficient (Table 4.4) and correlation matrix (Table 4.5) for the parameters measured.

The correlation coefficient reveals some relevant hydrochemical relationships, the content of TDS have high positive correlation with Na^+, Cl^-, K^+ and SO_4^{2-} with correlation coefficients of 0.96, 0.90, 0.62 and 0.56 respectively (Table 4.5). This positive correlation indicates that the ions are derived from the same source. In a similar way, there exists positive correlation between $Cl^- – Na^+$ (0.90), $K^+ – Na^+$ (0.63), $K^+ – Cl^-$ (0.63), $NO_3^- – NH_3^-$ (0.5), $NO_3^- – Cl^-$ (0.92) and $Na^+ – Cl^-$ (0.90),

The high positive correlation (0.90) between Na^+ and Cl^- may represent influence from salty water.

On the other hand, there are negative relationships Mg – Na, Mg – K, K – Ca, SO_4 – Mg and HCO_3 - Mg. These relationships could indicate ion exchange process between the groundwater and soil minerals.

Table 4.4: Statistical summary of measured parameters

Parameter	Min	Max	Mean	St. Dev.	Dev. Coef	Sample Num
TDS(mg/l)	90	1250	489.545	362.931	74.136	22
pH	2.24	7.26	4.942	1.538	31.126	22
TEMP(°C)	28.6	32.6	30.571	1.194	3.906	21
Fe^{3+}(mg/l)	0	0.86	0.27	0.213	79.152	22
Mn^{2+}(mg/l)	0	2.43	0.477	0.549	115.096	22
Cu^{2+}(mg/l)	0	1.93	0.307	0.433	140.963	22
Zn^{2+}(mg/l)	0	0.22	0.099	0.057	57.532	22
Ca^{2+}(mg/l)	2.78	169.74	46.136	48.969	106.139	22
K^{+}(mg/l)	1.8	66.5	19.3	22.48	116.481	22
Mg^{2+}(mg/l)	5.68	74.2	23.32	16.98	72.814	22
Na^{+}(mg/l)	10.4	36	17.741	8.424	47.483	22
Cl^{-}(mg/l)	0	13.11	2.918	4.262	146.068	22
$HCO3^{-}$(mg/l)	90.9	858.5	409.973	232.618	56.74	22
SO_4^{2-}(mg/l)	5	105	26.205	25.481	97.24	22
NH_3^{-}(mg/l)	0.34	3.2	1.057	0.751	71.076	22
NO_3^{-}(mg/l)	0.53	150	40.521	39.799	98.218	22

Min: minimum, Max: maximum, St. Dev.: standard deviation, Dev. Coef: deviation coefficient.

Table 4.5: Correlation matrix for measured parameters

	pH	Na^{+}	Mg^{2+}	Ca^{2+}	Cl^{-}	K^{+}	$SO_4$2-	TDS	Temp	Fe(3)	Mn^{2+}	Cu^{2+}	Zn^{2+}	NO_3^{-}	HCO_3^{-}	NH_3^{-}
pH	1.00	0.05	-0.41	-0.45	-0.26	0.04	0.02	0.02	0.30	-0.33	0.27	0.09	-0.16	-0.19	-0.02	-0.07
Na^{+}		1.00	-0.22	0.22	0.90	0.63	0.58	0.96	-0.16	-0.24	-0.19	0.78	0.10	0.83	0.45	0.63
Mg^{2+}			1.00	0.17	-0.37	-0.20	-0.14	-0.25	-0.18	0.18	-0.10	-0.27	0.02	-0.25	-0.05	-0.25
Ca^{2+}				1.00	0.15	-0.20	0.11	0.19	-0.15	-0.17	-0.31	0.17	0.25	0.21	0.14	0.17
Cl^{-}					1.00	0.63	0.46	0.90	0.02	-0.05	-0.17	0.77	-0.07	0.92	0.42	0.63
K^{+}						1.00	0.13	0.62	-0.01	-0.23	-0.18	0.17	-0.20	0.49	0.13	0.24
$SO_4$2-							1.00	0.56	0.04	-0.28	-0.21	0.67	-0.05	0.46	0.39	0.60
TDS								1.00	0.15	-0.21	-0.25	0.74	0.01	0.84	0.61	0.61
Temp									1.00	-0.08	0.15	-0.06	-0.11	-0.13	-0.15	-0.17
Fe(3)										1.00	0.09	-0.03	0.37	-0.06	-0.20	-0.31
Mn^{2+}											1.00	-0.12	0.43	-0.19	-0.47	-0.29
Cu^{2+}												1.00	0.12	0.76	0.38	0.71
Zn^{2+}													1.00	-0.01	-0.35	0.03
NO_3^{-}														1.00	0.43	0.50
HCO_3^{-}															1.00	0.42
NH_3^{-}																1.00

4.6. Hydrochemical Facies

From the Piper plot, Durov plot (Figure 4.5 and Figure 4.6 respectively) and radial plots (Appendix 5) an evaluation of the hydrochemistry of groundwater in Makurdi metropolis was done. The groundwater samples fall in the fields of Mg – Na – HCO_3, Mg-K-HCO_3, K – HCO_3 – SO_4, Mg-Ca-HCO3, Mg-HCO3 and Ca - Mg - HCO_3 in order of increasing dominance (Table 4.6).

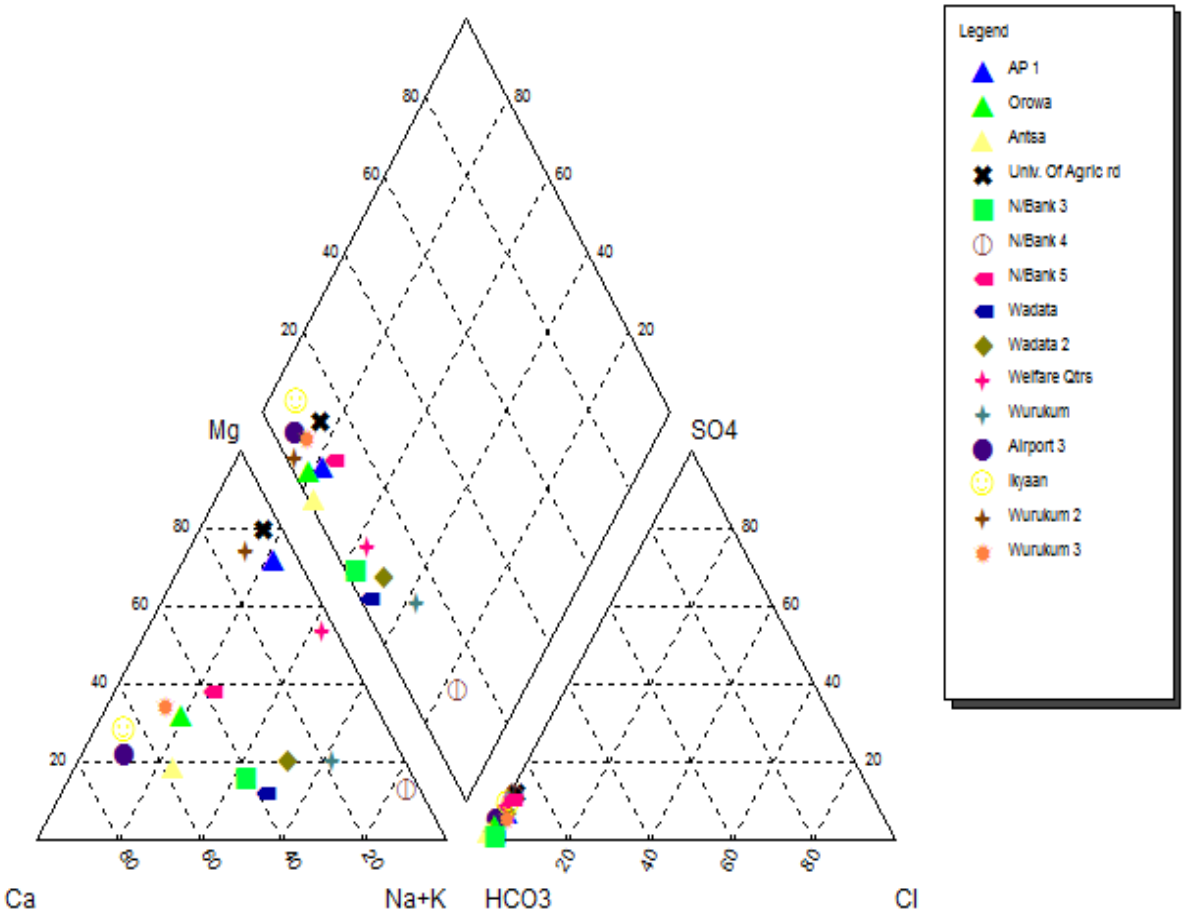


Figure 4.5: Piper diagram of groundwater in Makurdi metropolis and environs

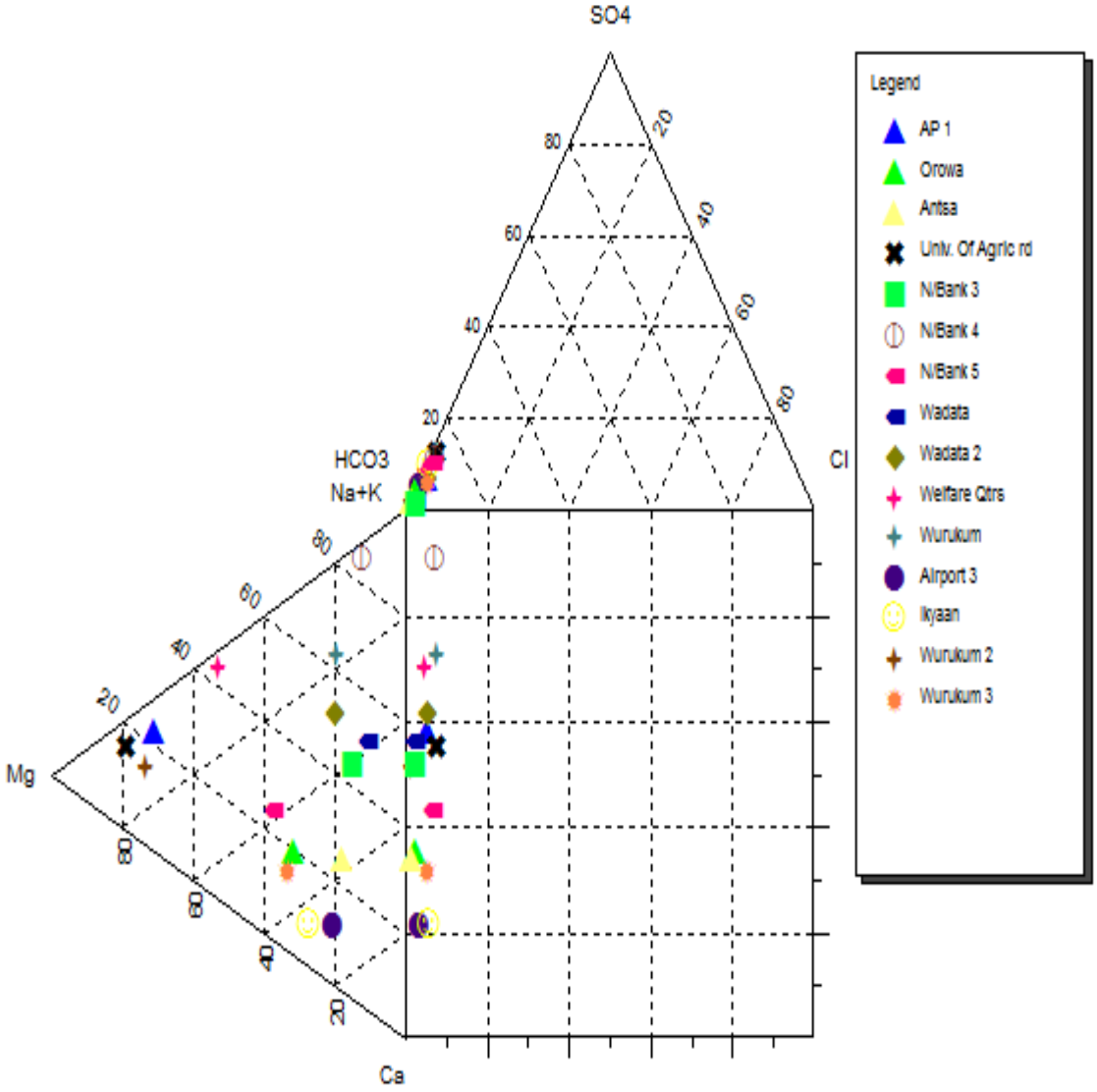


Figure 4.6: Durov plot of groundwater in Makurdi metropolis and environs

Table 4.6: Water classification based on percentage of equivalents per million

Sample ID	Sampling Date	Date of Analysis	Water Type	Station ID	Designation
SL1	4/9/2012	4/16/2012	Mg-Na-HCO3	Airport village 1	B
SL2	4/9/2012	4/16/2012	Ca-HCO3	Orowa	A
SL3	4/9/2012	4/16/2012	Mg-Ca-HCO3	Akpu	B
SL 4	4/9/2012	4/16/2012	Ca-HCO3	Antsa	B
SL 5	4/9/2012	4/16/2012	Mg-HCO3	Univ. of Agric.	B
SL 6	4/9/2012	4/16/2012	Mg-K-HCO3	N/Bank 2	B
SL 7	4/9/2012	4/16/2012	Ca-HCO3	N/Bank 3	C
SL 8	4/9/2012	4/16/2012	Ca-HCO3	N/Bank 4	C
SL 9	4/9/2012	4/16/2012	Ca-Mg-HCO3	N/Bank 5	B
SL 10	4/9/2012	4/16/2012	Ca-HCO3	Wadata	C
SL 11	4/9/2012	4/16/2012	Ca-HCO3	Wadata 2	C
SL 12	4/9/2012	4/16/2012	Mg-HCO3	Judge's' Qtrs	B
SL 13	4/9/2012	4/16/2012	Mg-HCO3	Nyor Village	C
SL 14	4/9/2012	4/16/2012	Mg-HCO3	Welfare Qtrs	C
SL 15	4/9/2012	4/16/2012	Mg-Ca-HCO3	Kanshio	B
SL 16	4/9/2012	4/16/2012	K-HCO3-SO4	Wurukum	C
SL 17	4/9/2012	4/16/2012	Mg-Ca-HCO3	Mu Village	A
SL 18	4/9/2012	4/16/2012	Ca-Mg-HCO3	Airport village 2	A
SL 19	4/9/2012	4/16/2012	Ca-Mg-HCO3	Airport village 3	A
SL 20	4/9/2012	4/16/2012	Ca-Mg-HCO3	Ikyaan	A
SL 21	4/9/2012	4/16/2012	Mg-HCO3	Wurukum 2	A
SL 22	4/9/2012	4/16/2012	Ca-Mg-HCO3	Wurukum 3	A

A: meteoric water, B: meteoric + formation water, C: formation + meteoric water

4.7. Suitability of Groundwater for Irrigation Purpose

The quality of water used for irrigation purpose is of great importance for crop productivity, soil maintenance and environmental protection (Tabue *et. al.*, 2012). In this research, bicarbonate hazard, sodium adsorption ratio (SAR) and percentage sodium (Na %) are used to determine the suitability of groundwater within Makurdi metropolis for irrigation purposes. Table 4.7 shows the classification of water for irrigation purpose based on bicarbonate hazard, Na% and SAR.

Table 4.7: Classification of groundwater based on Na %, SAR and bicarbonate hazard (source: Tabue *et. al.*, 2012)

Parameters	**Range (meq/l)**	**Class**
Na %	>200	Above max permissible limit
	20 – 40	Good
	<20	Excellent
SAR	20 - 40	Good
	40 - 60	Permissible
	60 - 80	Doubtful
	>80	Unsuitable
Bicarbonate hazard	0.00 – 1.25	Safe
	1.25 – 2.50	Marginal
	>2.50	Unsuitable

4.7.1. Percentage Sodium (Na %)

The value of percentage sodium within Makurdi metropolis and environs varies from 3.44 % to 104.50 % and are less than the maximum allowable limit of 200 % (Table 4.8). Three (14 %) of the samples fall within the class of 20 to 40 Na % and are considered good for irrigation. Nine samples (41 %) have percentage sodium values above the 20 to 40 % class but are still below the maximum permissible limit of 200. Ten (45 %) have Na % less than 20 % and are considered excellent for irrigation (Table 4.7).

Higher Na % observed in groundwater from nine locations which constitutes 41 % of the study area indicates the dominance of ion exchange and weathering from lithological units of the study area (Tabue, 2012). Groundwater with relatively high Na % values above 40 occurs around North bank, Wadata, Judge's quarters, Nyon, welfare quarters and Wurukum. When the concentration of sodium is high in water, sodium tends to be absorbed by clay particles displacing magnesium and calcium. This exchange of sodium for calcium and magnesium reduces soil permeability and results in soil with poor internal drainage. A larger proportion (59 %) of groundwater within the study area is considered safe for irrigation.

4.7.2. Sodium adsorption ratio (SAR)

SAR for samples within the study area varies from 0.21 to 2.54. The groundwater according to the classification in table 4.7 is of excellent quality with respect to sodium adsorption ratio. If water used for irrigation has high Na and low Ca, the ion exchange complex may become saturated with Na which destroys the soil structure due to dispersion

Table 4.8: Calculated values of bicarbonate hazard, percentage sodium and sodium adsorption ratio for groundwater in Makurdi metropolis and environs

Location Description	**Sample ID**	**Bicarbonate Hazard (meq/l)**	**SAR**	**Na%**
Air Port 1	SL 1	0	0.50757	22.4544
Orowa Village	SL 2	5.99648	0.5063	17.2636
Miande Akpu Village	SL 3	8.95688	0.3346	7.18366
Antsa Village	SL 4	10.3066	0.56487	24.8983
University Of Agriculture Road	SL 5	0	0.40263	11.3864
North Bank 2	SL 6	2.77269	0.56075	41.697
North Bank 3	SL 7	12.5255	0.759	40.6189
North Bank 4	SL 8	24.2426	2.53973	104.498
North Bank 5	SL 9	0.98947	0.47819	24.9151
Wadata	SL 10	17.9758	1.21801	45.1799
Wadata 2	SL 11	11.8204	1.2623	46.1543
Judge's Qtrs	SL 12	3.38736	0.57772	40.3086
Nyon Village	SL 13	6.64697	0.73489	63.9963
Welfare Qtrs	SL 14	7.13501	0.74939	42.5265
Kanshio	SL 15	0	0.29159	8.77019
Wurukum	SL 16	10.9072	1.28735	66.4799
Mu Village	SL 17	0	0.42586	13.0085
Airport village 2	SL 18	0	0.2128	2.76602
Airport village 3	SL 19	0.41309	0.43875	5.71364
Ikyaan Village	SL 20	0	0.34266	3.44029
Wurukum 2	SL 21	8.79797	0.41118	10.6638
Wurukum 3	SL 22	0	0.3928	10.37

of clay particles and reduces plant growth (Tabue *et. al.*, 2012). High Na^+ and low Ca^{2+} in water used for irrigation results in ion exchange complex which becomes saturated with Na^+ as a result of clay particle dispersion. This causes the destruction of the soil structure and consequently reduces plant growth.

4.7.3. Bicarbonate Hazard

Bicarbonate hazard means excess of bicarbonate over calcium and magnesium, all expressed in milliequivalent per liter Water with bicarbonate hazard greater than 1.25 meq/l should not be used for irrigation except on very sandy, highly permeable soils or with some soil chemical amendments such as the application of gypsum. Only nine (41%) of the samples analyzed (SL 1, SL 5, SL 9, SL 15, SL 18, SL 19 and SL 20) fall within the class of samples considered safe (0.00 to 1.25 meq/l) for irrigation in terms of bicarbonate hazard. Groundwater from other locations should not be used for irrigation purpose except on soils that are sandy, permeable or with some chemical amendments as they are considered unsuitable (Table 4.8)

4.8. Evaluation of Dynamic Water Resources of the Makurdi Metropolis and Environs

Dynamic water resources of Makurdi metropolis and environs is estimated to be about 0.4124 km^3/year from which 17 percent (0.0701 km^3) constitutes baseflow (dynamic groundwater resources), 32 percent (0.1219 km^3) constitutes surface runoff while evapotranspiration accounts for 51 percent (0.2103 km^3) (Figure 4.7).

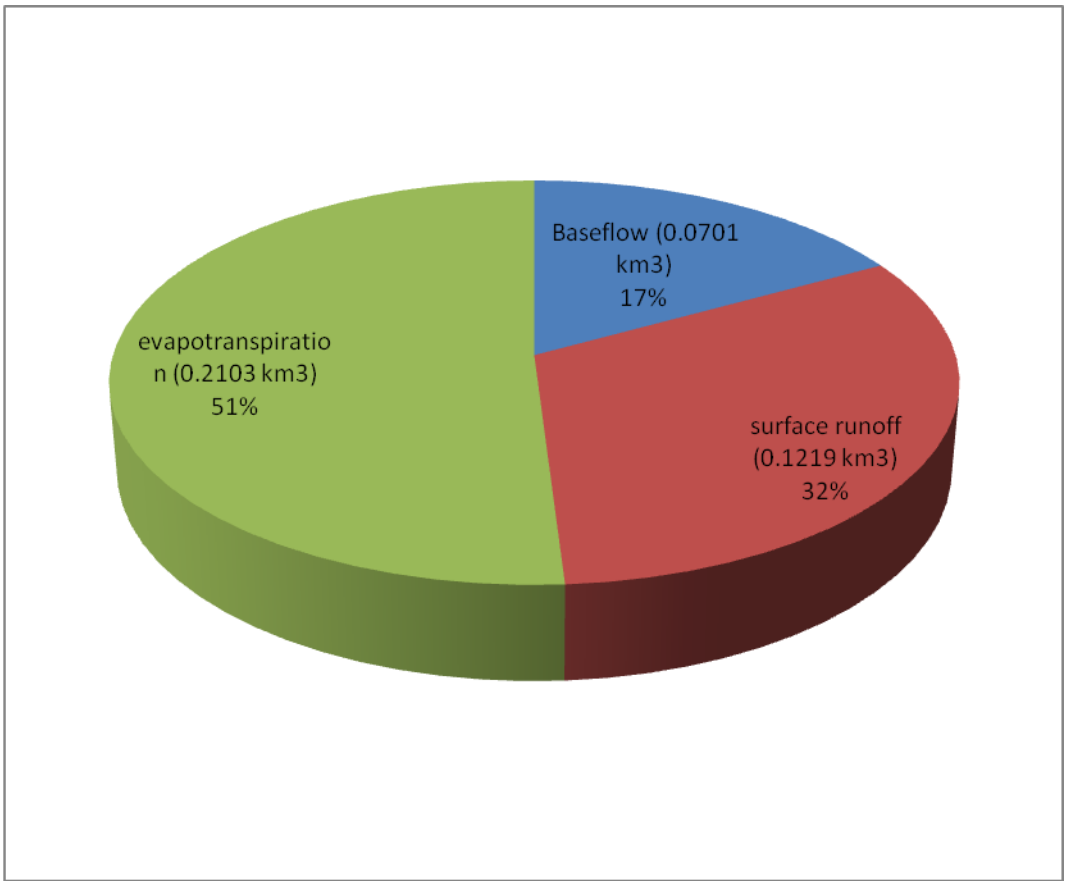


Figure 4.7: Distribution of dynamic water resources of the Makurdi metropolis and environs

The various coefficients are derived from a graph of correlation between depth of rainfall and runoff coefficient in drainage basins (Figure 4.8) Utilizable dynamic water resources (total runoff volume) of the drainage basin, obtained from the difference between volume of rainfall in table 4.9 and loss to evapotranspiration is estimated at 0.2021 km^3.

Table 4.9: Estimated values of renewable water resources for the Makurdi metropolis and environs

Parameter	Value
Area of drainage basin (Km^2)	305.5
Annual rainfall depth (mm)	1350
Total run – off coefficient (cRt)	0.49
Base flow coefficient (cRb)	0.17
Surface run – off coefficient (cRs)	0.32
Coefficient of Evapotranspiration (cEt)	0.51
Volume of rainfall (Km^3/year)	0.4124
Base flow (Km^3/year)	0.0701
Surface run – off (Km^3/year)	0.1319
Total run – off volume (Km^3/year)	0.2021
Loss to Evapotranspiration (Km^3/year)	0.2103

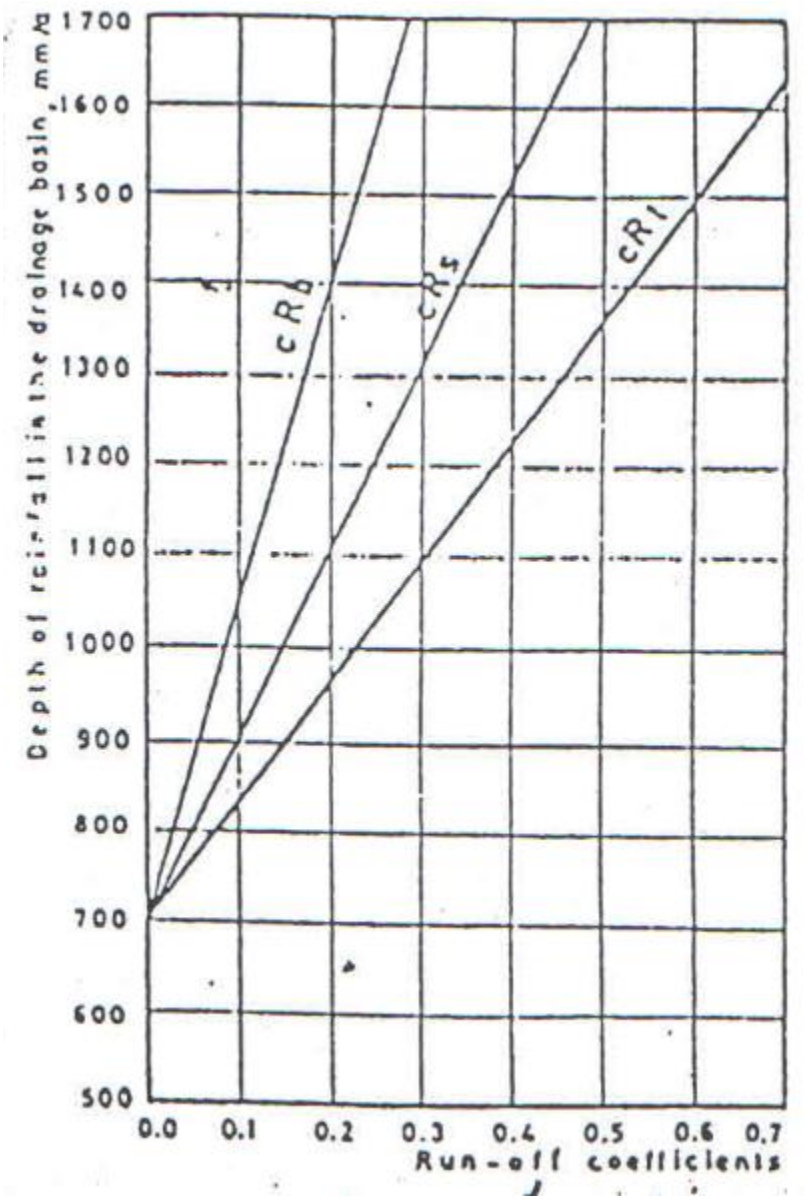


Figure 4.8: Correlation between depth of rainfall and runoff coefficient in drainage basins (Source: Schoeneich and Garba, 2010)

4.9. Aquifer Characteristics

The aquifer characteristics studied here are transmissivity (T) and storage coefficient (S). Transmissivity is the discharge through a unit width of an aquifer for the fully saturated depth under a unit hydraulic gradient (Raghunath, 2007). It is the rate at which water will flow through a vertical strip of an aquifer of a unit width and extending through the full saturated thickness under unit hydraulic gradient. Storage coefficient, on the other hand, is the volume of water that an aquifer releases or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Values of transmissibility and storage coefficient from four boreholes in Makurdi metropolis tapping the Makurdi Sandstone aquifer are presented in Table 4.10.

Table 4.10: Aquifer characteristics of some boreholes in Makurdi metropolis tapping the Makurdi Sandstone

BOREHOLE NO.	LOCATION	Co-ORDINATES	YIELD (m^3/day)	TRANSMISSIBILITY (m^2/day)	STORAGE COEFFICIENT	HYDRAULIC CONDUCTIVITY (m/day)
1	YAJI	N7°42'24'' E8°31'8.8''	84.40	1.144×10^{-2}	1.950×10^{-2}	5.20×10^{-4}
2	NEW GRA	N7°41'33.6'' E8°32'14.1''	49.25	2.730×10^{-1}	1.27×10^{-2}	9.4×10^{-3}
3	UPUU		151.20	5.27×10^{-2}	6.180×10^{-3}	1.60×10^{-1}
4	YOUTH CAMP	N7°42'49.7'' E8°34'23.7''	129.60	0.138×10^{1}	2.495×10^{-1}	3.20×10^{-2}

Transmissivity values calculated for this aquifer ranges from 1.144 $x10^{-2}$ m^2/day to 5.27 x 10^{-2} m^2/day while storage coefficient and hydraulic conductivity ranges from 6.18 $x10^{-3}$ to 1.27 x 10^{-2} and 5.20 × 10^{-4} to 3.20 × 10^{-2} respectively. According to Gheorghe standards for transmissivity (Table 4.11) the aquifers at borehole location No. 1 and No. 2 are of negligible yield while at locations No. 4 and No. 3 are of very low and low potentials respectively.

Table 4.11: Gheorghe standards for transmissivity

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

Petrological studies show that the Makurdi Sandstone consists of quartz, feldspars and minor muscovite in order of dominance. The quartz grains are mostly monocrystalline with few polycrystalline grains and undergo uniform to slightly undulose extinction. The grains have stretched crystals and long sutured contacts. The proportion of quartz in the rock is between 70 and 75 %. (plate 1a and 1b)

Feldspars identified in the Makurdi sandstone are untwined feldspars, microcline and plagioclase feldspars. The proportion of feldspars falls between 20 and 25 %. The

feldspars are fresh and unaltered. The presence of these labile (unstable grains) is an indication that the rock is chemically immature. Diagenetic processes affecting this rock are formation of minor clay rim cement then mechanical and chemical compaction. The sandstone is generally a well sorted, medium to coarse grained, grain supported, texturally immature rock with 3 – 4 % porosity.

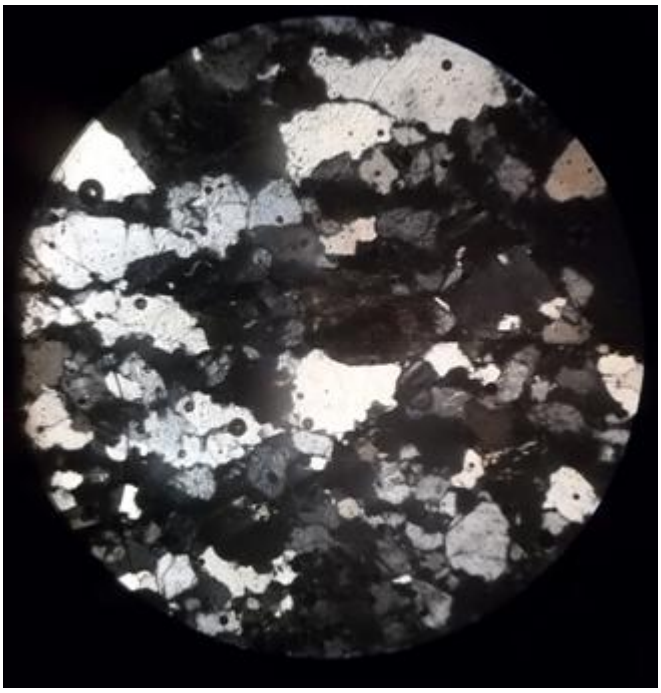


Plate 1(a): A view of the Makurdi Sandstone under XPL

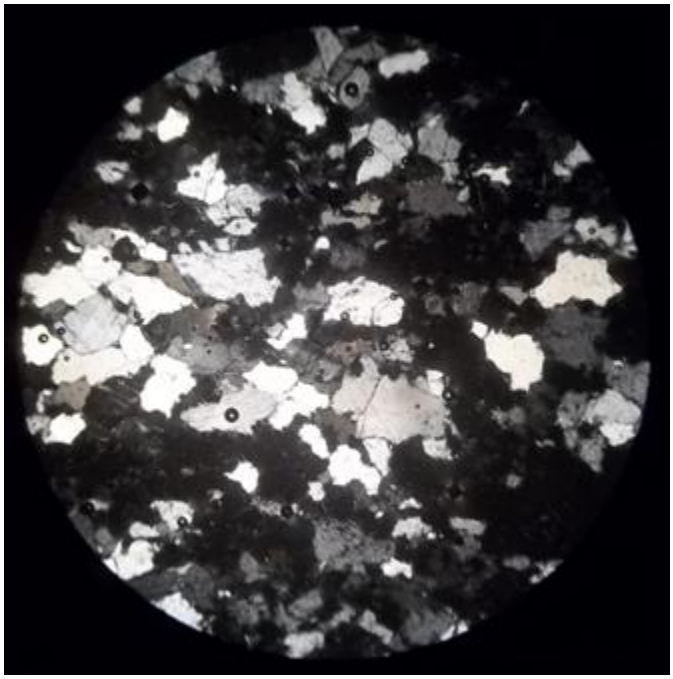


Plate 1(b): A view of the Makurdi Sandstone under XPL

Based on classification of sandstones proposed by Pettijohn *et. al.* (1987) the Makurdi sandstone falls within the category ‘‘subarkose’’. The compact and indurated nature of this sandstone makes it a poor aquifer as it has little or no primary (interstitial) porosity except where fracturing/weathering has resulted in the some form of secondary porosity. This explains the reason for the poor yields of some boreholes drilled within Makurdi metropolis as reported in section 4.9

CHAPTER 5

5.0. CONCLUSION AND RECOMENDATION

5.1. Conclusion

Geophysical investigations reveal two major aquifers within Makurdi metropolis; these are the weathered and fractured Sandstone aquifer described as the Makurdi Sandstone. The reddish - brown (sometimes lateritic) sand which overlies the weathered Sandstone also serves as an aquifer but only yields water during the rainy season. This sandy aquifer is recharged directly by precipitation and the weathered/ fractured Sandstone aquifer in turn is recharged by water percolating through the reddish - brown sand which is in hydraulic connection with it. The thickness of weathered Makurdi Sandstone aquifer within the study area varies from 1.19 m to about 15.2 m with resistivity ranging from 3.414 Ώm to about 400 Ώm. The low resistivity at depths of the Sandstone aquifer observed at some VES points have resulted from water with high mineralization (Salty or formation water from the stagnant belt).

Watertable elevation in wells within the study area ranged from 67.7 m (229 ft) to 97.8 m (497 ft) a.m.s.l (Figures 4.2 and 4.3) in the fractured and weathered Makurdi Sandstone aquifer. Major Groundwater recharge areas within the study area indicated by the groundwater moulds which extends from Agana to North Bank at the north western part of the study area and at southern part of the study area. The general flow direction of groundwater within the study area is from the northern and southern part towards the River Benue which is the major groundwater discharge area and corresponds with the groundwater convergent zone within the study area. The uni-directions in the flow of

groundwater at the end of the rainy season and the peak of dry season confirms that the River Benue is consistently effluent.

Petrological analysis carried out during the course of this research reveals that the Sandstone aquifer a well sorted, medium to coarse grained, texturally mature subarkose with about three to four percent porosity and minor clay rim cement which reduces its permeability. These characteristics also account for the low yield and high number of abandoned boreholes in Makurdi metropolis.

Water quality analysis of samples revealed that groundwater in some parts of the study area have elevated concentration of TDS as indicated by high concentration of iron, magnesium, copper, manganese and nitrate and are considered unsafe for drinking and some domestic uses. Some of these pollutioncould be traced to anthropogenic sources. Groundwater in Wadata and North bank areas of the study area is the most polluted especially with respect to nitrate and manganese concentrations. Concentrations of zinc, chloride and sodium for all samples analyzed are below the SON (2007) permissible limits and are considered safe for drinking with respect to these parameters. Groundwater within the area is safe for irrigation with respect to sodium adsorption ratio but a good number of the samples had high values of bicarbonate hazard and percentage sodium and are unsuitable for irrigation except when used on very porous and permeable soils or with some chemical soil amendments.

Analysis of pumping test data of four boreholes within the study area tapping the Makurdi Sandstone aquifer reveals storage coefficient ranging from 6.18×10^{-3} to 1.27×10^{-2} and transmissivity ranging from $1.144\ 10^{-2}$ m^2/day to $5.27\ 10^{-2}$ m^2/day. These values fall within

the range for aquifers with negligible to very low yields and accounts for the high number of abandoned boreholes within the study area.

Dynamic water resources of the Makurdi metropolis and environs is estimated at 0.4124 km^3/year. 17 percent (0.0701 km^3/year of this constitute baseflow, 32 percent (0.1219 km^3/year) occur as surface runoff and 51 percent is lost to evapotranspiration. Utilizable dynamic water resource available in this basin is thus estimated at 0.2021 km^3/year (49 percent of the total dynamic water resource).

5.2 Recommendations

Based on the findings from the investigations described in chapter four, the following recommendations are hereby made;

Some areas with poor groundwater quality have been identified and should not be used for drinking as this could endanger the population. An adequate groundwater quality monitoring program should therefore be put in place to monitor and limit further pollution of groundwater within the study area. This monitoring program should also include detailed delineation and monitoring of water used for irrigation so as to avoid further damage to the soil caused by the use of water with high sodium percentage and bicarbonate hazards.

More detailed hydrogeological research should be carried out to determine the concentration of other ions and trace and heavy metals that were not determined during the course of this research so as to delineate areas with elevated concentration that could pose health problems to its users.

The characteristics of the aquifers within the study area could not be adequately determined due to lack of borehole data. Borehole data like pumping test data for boreholes drilled should be properly collected kept safe for further research as this will enhance more understanding of the groundwater situation in the area.

Proper evaluation of the available water resources and water demand should be done and adequate planning made to meet the water demand of the inhabitants of Makurdi metropolis. The location of boreholes is no longer determined by geology or availability of prolific aquifers but by the choice of individuals who can afford them; detailed geophysical investigations should be carried out to locate suitable points for boreholes so as to reduce the incidence of drilling abortive boreholes or boreholes that cannot yield sufficient water to sustain its users. Laws guiding borehole drilling should be enforced as this will prevent well (borehole) interference and ensure standard drilling practices.

REFERENCES

Adanu, E.A. (1981). Hydrogeology of Makurdi and the environ with the General Geology of the Agana sheet (250) and Makurdi sheet (251). Unpublished M.Sc. thesis, Ahmadu Bello University Zaria.

Ajibade, A. C. and Woakes, M. (1989). Proterozioc Crustal Development in the Pan African Regime of Nigeria in: Kogbe, C. A. (Ed) Geology of Nigeria. Elizabethan publishing Company Lagos, pp. 57 – 69.

Choudhury, K. and Saha, D. K. (2004). Integrated geophysical and chemical study of saline Water intrusion; *Groundwater* 42(5): pp. 671 – 677.

Dada, S. S. (1998). Crust – forming ages and Proterozoic crustal evolution in Nigeria a repraisal of current interpretations. *Precambrian research*. 87: pp. 65 – 74.

Davis, S. N. and De Wiest, J.M. (1966). Hydrogeology, John Wiley and Sons, Inc. Newyork London, Sydney.

Edet, A. Nganje, T. N. Ukpong, A. J. and Ekwere, A. S. (2011). Groundwater chemistry and quality of Nigeria: A status review, *African Journal of Environmental Science and Technology* 5(13) : pp. 1152-1169.

Freeze, R. A. and Cherry, J.A. (1979). Groundwater, Prentise – Hall, Inc. Pub; Englewood Cliffs, N. J.

Idoko, O. M. (2010). Seasonal Variation in Iron in Rural Groundwater of Benue State, Middle Belt, Nigeria. *Pakistan Journal of Nutrition* 9 (9): pp. 892-895.

Irtwange, S. V. and Sha' Ato, R. (2009). Environmental Baseline Characteristics for a Pilot Project Site for Integrated Solid Waste Management in Makurdi, Nigeria. *Research Journal of Environmental and Earth Sciences* 1(2): pp. 81-98.

Isikwue, M. O. Iorver, D. and Onoja, S. B. (2011). Effect of Depth on Microbial Pollution of Shallow Wells in Makurdi Metropolis, Benue State, Nigeria. *British Journal of Environment & Climate Change* 1(3): pp. 66-73.

Jamie, B. and Richard, B. (1996). Water quality monitoring. A practical guide on the design and implementation of freshwater quality studies and Monitoring.

Judith, M. D. (1986). Hydrogeology and geochemistry of the unconfined aquifer, west – central and southwestern Delaware, university of Delaware, Delaware geological survey report of investigations no. 41

Najime T., (2010). Cretaceous stratigraphy, sequence stratigraphy and tectono – sedimentary evolution of Gboko area, lowar Benue Trough, Nigeria. Unpublished Ph.D dissertation, Geology department, Ahmadu Bello University Zaria.

Obaje, N.G., Ligouis, B., and Abaa, S.I. 1994. Petrographic composition and depositional environment of Cretaceous coals and coal measures in the Middle Benue Trough of Nigeria. *Int. Journ. Coal Geol,* (2) : pp. 233 – 260

Obaje N. G., (1994). Coal petrography, microfossils and paleoenvironment of calcareous coal measures in the middle Benue Trough of Nigeria. Tubinger Mikropalaontolgische Mitteilugen 11, 165 pp

Offodile, M.E. (1976). The Geology of the Middle Benue Nigeria. *Special volume Palaeontological Institution University Uppsala***4**, pp.1-166.

Offodile M. E. (1989). A review of the geology of the Cretaceous of the Benue Trough. In: C.A. Kogbe, (ed), Geology of Nigeria (2^{nd} edition) 265 – 376. Rock view Nigeria Ltd, Jos

Offodile, M. E. (2002). Groundwater study and development in Nigeria. Mecon Geology and Eng. Services Ltd. Jos, Nigeria.

Pettijohn, F. J., Potter, P. E. and Siever, R. (1987). Sand and Sandstones. Springer – Verlag New York.

Raghunath, H. M. (2007).Groundwater; Hydrogeology, groundwater survey and pumping tests, rural water supply and irrigation systems, third edition.

Schoeneich, K. (2010). Water quality, unpublished material on Hydrogeology Ahmadu Bello University Zaria.

Schoeneich, K. and Garba, M. L. (2010). Hydrogeology (Geol. 405), unpublished material on hydrogeology, Ahmadu Bello University Zaria.

Standard Organization of Nigeria, (2007). Nigerian standard for drinking water quality. NIS 554: pp 1-30.

Todd, D.K. (1980). Groundwater hydrology, John Wiley. United Nations, 2000. Millennium Development Goals on water.

Tabue, Y. G., Feumba, R., Wethe, J., Ekodeck, G. E. and De Marsily, G. (2012). Evaluation of the groundwater suitability for domestic and irrigational purposes: A case study from Mingoa River Basin, Yaounde, Cameroon. *Journal of water resources and protection,* 4: pp. 285 – 293.

World Health organization (WHO), (2011). Guidelines for Drinking-water Quality, fourth ed.

Wright, E. P. (1992). The hydrogeology of crystalline basement aquifers in Africa. In Wright, E. P. and Burgess, W. G. (Ed) The hydrogeology of crystalline Basement aquifers in Africa. Geological Society special publication. 66: pp. 1 – 27.

Zaborski, P.M. (1998). A review of the Cretaceous system in Nigeria.*Africa Geoscience Review*, **5:** pp. 385-483.

.

Appendix 1: Co – ordinates, Depth to water table and elevation of hand dud wells measured at the peak of rainy season

S/N	Location	Location ID	Co - ordinates		Well elevation (ft) a.m.s.l	SWL (m)	SWL (ft) Below Ground surface	G/W elv. a.m.s.l	Date Of Measurement	HDW/BH
			Longitude	Latitude						
1	MWO Akuh J (rtd) residence,AirPort Village	L1	N07°42'53.6"	E08°37'17.5"	260	1.18	3.871344	256	14/10/2011	HDW
2	Mrs. Rose Achi's residence Opp RCM Pri Sch Agbaikyor	L2	N07°42'57.3"	E08°37'17.1"	260	1.18	3.871344	256	14/10/2011	HDW
3	Aya's residence, AirPort Village	L3	N07°42'57.7"	E08°37'19.0"	265	1.08	3.543264	261	14/10/2011	HDW
4	Zule Zoo residence, AirPort Village	L4	N07°42'57.7"	E08°37'19.8"	280	0.78	2.559024	277	14/10/2011	HDW
5	276 I KM 9 Makurdi Gboko Road	L5	N07°42'59.0"	E08°37'17.6"	273	0.6	1.96848	271	14/10/2011	HDW
6	Tyor Azande residence, AirPort Village	L6	N07°42'57.5"	E08°37'15.8"	270	0.92	3.018336	267	14/10/2011	HDW
7	Mallam Isyaka's residence, AirPort	L7	N07°42'54.0"	E08°37'14.3"	274	1.44	4.724352	269	14/10/2011	HDW

	Village									
8	Airport village Market, KM 9 Makurdi - Gboko Road	L8	N07°42'48.0"	E08°37'15.0"	275		0	275	14/10/2011	HPBH
9	Audu's residence Airport village	L9	N07°42'50.1"	E08°37'18.3"	265	2.2	7.21776	258	14/10/2011	HDW
10	Fiidi Chief' s house	L10	N07°42'49.2"	E08°37'21.9"	270	2.09	6.856872	263	14/10/2011	HDW
11	Primary Health Clinic Airport village	L11	N07°42'52.7"	E08°37'30.8"	260		0	260	14/10/2011	HPBH
12	Abanga Joseph's residence Fiidi	L12	N07°42'53.2"	E08°37'27.9"	260	1.67	5.478936	255	14/10/2011	HDW
13	Terlunmu Nyiekaa's residence Fiidi	L13	N07°42'57.2"	E08°37'30.3"		1.33	4.363464	4	14/10/2011	HDW
14	Christ Apostolic Church Fiidi	L14	N07°42'56.9"	E08°37'00.2"	260	0	0	260	14/10/2011	HDW
15	Ogah's residence, Behind Fiidi Police Station	L15	N07°42'48.1"	E08°37'04.5"	275	1.76	5.774208	269	14/10/2011	HDW
16	MWO Sule (rtd) residence	L16	N07°42'50.7"	E08°37'06.6"	276	1.05	3.44484	273	14/10/2011	HDW
17	Mrs. Okpe's residence, Behind	L17	N07°42'51.9"	E08°36'54.2"	270	1.13	3.707304	266	14/10/2011	HDW

	RCCG Fiidi									
18	Mr. Chia residence, Off Adasu Road	L18	N07°42'54.5"	E08°36'37.0"	255	0.42	1.377936	254	15/10/2011	HDW
19	House 221 Coca cola	L19	N07°43'01.6"	E08°35'42.4"	255	0.3	0.98424	254	15/10/2011	HDW
20	Mr. Paul Egbe's residence, Behind NKST Church Coca cola	L20	N07°43'18.6"	E08°35'35.7"	245	0	0	245	15/10/2011	HDW
21	KM 5 Makurdi - Gboko Road, Opp Benue Breweries	L21	N07°43'06.2"	E08°35'18.9"	280	0.52	1.706016	278	15/10/2011	HDW
22	Dajo Pottery, KM 5 Makirdi Gboko Road	L22	N07°42'53.2"	E08°35'12.2"	305		0	305	15/10/2011	HPBH
23	Mr. Adum Jerimiah's residence, Opp Benue Breweries	L23	N07°42'49.2"	E08°35'12.5"	315	0	0	315	15/10/2011	HDW
24	At tsenyon Village	L24	N07°42'26.1"	E08°35'08.7"	360	1.4	4.59312	355	15/10/2011	HDW
25	Nyon Tsewase	L25	N07°42'07.5"	E08°35'12.6"	410	2.5	8.202	402	15/10/2011	HDW
26	KM 4 Nyon Tsewase Street	L26	N07°42'07.3"	E08°35'11.2"	407	2.91	9.547128	397	15/10/2011	HDW
27	Behind Judge's	L27	N07°42'55.2"	E08°34'37.3"	295	-0.12	0.393696	295	15/10/2011	HDW

	Qtrs, KM 3 Makurdi									
28	Hotel Fidys, KM 3 Gboko Road	L28	N07°42'59"	E08°34'34.7"	290	0.9	2.95272	287	15/10/2011	HDW
29	153 E Tilley Gyado Villa Makurdi	L29	N07°43'09.7"	E08°34'19"	275	2.54	8.333232	267	15/10/2011	HDW
30	Corner Stone Accademy, Gboko Road Makurdi	L30	N07°42'56.1"	E08°34'23"	295	0.36	1.181088	294	15/10/2011	HDW
31	James Ujah's residence, OPP B. S. U. First gate	L31	N07°43'26.9"	E08°33'13"	260	0.77	2.526216	257	16/10/2011	HDW
32	No. 13 Idyege Street, Logo 2 Wurukum	L32	N07°43'18.2"	E08°32'57.7"	260	0.67	2.198136	258	16/10/2011	HDW
33	Nigerian Prison Services, Oturkpo Road	L33	N07°40'12.5"	E08°32'34.3"	475		0	475	16/10/2011	HPBH
34	Opp Prisons Qtrs, Yaiko	L34	N07°40'13.6"	E08°32'37.3"	500	1.03	3.379224	497	16/10/2011	HDW
35	First Avenue Welfare Qtrs	L35	N07°40'23.8"	E08°32'17.7"	440	1.47	4.822776	435	16/10/2011	HDW
36	GP 771/1 Welfare Qtrs	L36	N07°40'15.6"	E08°32'04"	405	0.6	1.96848	403	16/10/2011	HDW
37	Pope John Paul Pastoral Centre	L37	N07°40'50.1"	E08°32'22.1"	450	5.28	17.32262	433	16/10/2011	HDW

	Yaiko									
38	Hemko Hospital Kansio	L38	N07°40'51.3"	E08°32'06.1"	390	0.45	1.47636	389	16/10/2011	HDW
39	NEPA Qtrs Otukpo road	L39	N07°42'36.3"	E08°32'37.8"	290	2.08	6.824064	283	16/10/2011	HDW
40		L40	N07°42'56.9"	E08°32'33.2"	235		0	235	16/10/2011	HPBH
41	Antsa Village, University of Agriculture Makurdi	L41	N07°46'07.1"	E08°35'16.1"	300	0.62	2.034096	298	17/10/2011	HDW
42	Pillar Village, University of Agriculture Makurdi	L42	N07°46'36.1"	E08°36'30.7"	260	0.65	2.13252	258	17/10/2011	HDW
43	LGEA Primary School Iorawa	L43	N07°46'21.8"	E08°39'47.5"	345		0	345	17/10/2011	HPBH
44	Federal Locust North Bank	L44	N07°47'00.1"	E08°34'06.2"	460	0.5	1.6404	458	17/10/2011	HDW
45	Atookyaa	L45	N07°46'11.0"	E08°34'48.7"	280	1.48	4.855584	275	17/10/2011	HDW
46	Agan, KM 10 Lafia road	L46	N07°48'28.3"	E08°33'59.3"	435	0.01	0.032808	435	17/10/2011	HDW
47	Agagbe Village, KM 14 Lafia road	L47	N07°50'16.6"	E08°34'40.2"		2.4	7.87392	8	17/10/2011	HDW
48	ECWA Sec. Sch. North Bank	L48	N07°46'06.1"	E08°33'07.1"	340	5.85	19.19268	321	17/10/2011	HDW

49	Gever Village	L49	N07°48'36.2"	E08°30'46.1"	280	0.7	2.29656	278	17/10/2011	HDW
50	Youngu Village	L50	N07°49'54.7"	E08°30'44.6"	270	4	13.1232	257	17/10/2011	HDW
51	Akiki Village						0	0		
52	Uga Village	L52	N07°45'58.1"	E08°31'16.0"	230	0.3	0.98424	229	17/10/2011	HDW
53	No. 31 Onisha street Wurukum	L53	N07°43'40.3"	E08°32'25.9"	250	2.55	8.36604	242	19/10/2011	HDW
54	Niger crecent Wadata	L54	N07°44'24.7"	E08°30'53.5"	260	2.18	7.152144	253	19/10/2011	HDW
55	No. 13 Demekpe Street, Wadata	L55	N07°43'52.1"	E08°30'15.0"	270	0.55	1.80444	268	19/10/2011	HDW
56	No. 19 Iorvihi Ikpamkpam street, Modern Market gate	L56	N07°43'38.9"	E08°30'02.5"	275	1	3.2808	272	19/10/2011	HDW
57	Living Spring Accademy, Modern Market Road	L57	N07°43'32.1"	E08°30'03.4"	275	1	3.2808	272	19/10/2011	HDW
58	No. 25 Sefano Tosabo Street	L58	N07°43'19.3"	E08°30'08.8"	280	0.6	1.96848	278	19/10/2011	HDW
59	Federal Locust Qtrs, Naka road	L59	N07°42'43.4"	E08°30'04.4"	270	2.16	7.086528	263	19/10/2011	HDW
60	Glory Of The Majesty Ministries, Naka road	L60	N07°41'44.1"	E08°29'16.6"		0	0	0	19/10/2011	HDW

61	No. 25 Jerome Hwande street Ankpa Qtrs Extension	L61	N07°42'42.0"	E08°30'26.0"	270	0.25	0.8202	269	19/10/2011	HDW
62	Methodist High School, High Level	L62	N07°43'30.9"	E08°30'54.2"	300	0.2	0.65616	299	19/10/2011	HDW
63	No. 13 Otukpa Close High Level	L63	N07°43'28.6"	E08°31'59.1"	280	1.3	4.26504	276	19/10/2011	HDW
64	No. 30 KonshishStreet Low Level	L64	N07°43'23.2"	E08°32'15.2"	255	0.5	1.6404	253	19/10/2011	HDW
65	BANADA Office High Level	L65	N07°41'55"	E08°31'59.0"	290	0.66	2.165328	288	19/10/2011	HDW
66	Tse Poor Village	L66	N07°41'26.3"	E08°35'07.3"	425	2.65	8.69412	416	20/10/2011	HDW
67	Kyabashi residence Tse Poor	L67	N07°40'45.5"	E08°35'06.73"	455	2.5	8.202	447	20/10/2011	HDW
68	No. 27 Mission Ward North Bank	L68	N07°45'23.3"	E08°32'45.7"	325	5.77	18.93022	306	20/10/2011	HDW
69	No. 70 Mission Ward North Bank	L69	N07°45'36.8"	E08°33'03.0"	375	2.32	7.611456	367	20/10/2011	HDW
70	SRS Junction North Bank	L70	N07°45'42.2"	E08°33'38.1"	375	0	0	375	20/10/2011	HDW
71	Ochonu Village Behind Cattle	L71	N07°46'24.6"	E08°33'26.4"	380	2.15	7.05372	373	20/10/2011	HDW

	Market									
72	Intl Cattle Market North Bank	L72	N07°46'37.3"	E08°33'21.7"	370	0.95	3.11676	367	20/10/2011	HDW
73	Tse Adi Village	L73	N07°42'44.5"	E08°35'46.1"	340	1.1	3.60888	336	20/10/2011	HDW
74	Mu Village	L74	N07°42'51.8"	E08°40'17.7"	300	2.45	8.03796	292	20/10/2011	HDW
75	Mami Market NAF Base	L75	N07°41'57.7"	E08°37'39.5"	325	1.85	6.06948	319	20/10/2011	HDW

Co – ordinates, Depth to water table and elevation of hand dud wells measured at the peak of dry season

S/N	Location	Location ID	Co - ordinates		Well elevation (ft) above mean sea level	SWL (m) Below ground level	SWL (ft) Below ground level	GWE elv (ft) above mean sea level	Date of measurement	HDW/ BH
			Longitude	Latitude						
1	MWO Akuh J (rtd) Compound, Air Port Village	L1	N07°42'53.6"	E08°37'17.5"	260	6.07	19.9	240.1	4/4/2012	HDW
2	Mrs. Rose Achi's CopoundOpp RCM Pri Sch Agbaikyor	L2	N07°42'57.3"	E08°37'17.1"	260	5.07	16.6	243.4	4/4/2012	HDW
3	Tor Kyange Compound, Airport Village	L3	N07°42'52.1"	E08°37'19.1"		5.15	16.9	16.9	4/4/2012	HDW
4	Mallam Ishaka compound	L4	N07°42'52"	E08°37'15.7"	260		0.0	260.0	4/4/2012	HDW
5	MWO Igah's compound Airport Village	L5	N07°42'42.2"	E08°37'07"	287	4.44	14.6	272.4	4/4/2012	HDW
6	MWO Abah's compound Airport Village	L6	N07°42'42.2"	E08°37'07.06''		6.7	22.0	22.0	4/4/2012	HDW
7	MWO Sule compound Airport Village	L7	N07°42'50.7"	E08°37'06.6"	276	6.34	20.8	255.2	4/4/2012	HDW

8	Airport village market	L8	N07°42'00"	E08°36'54.5"	325	8.9	29.2	295.8	4/4/2012	HDW
9	Nicodemus Adi's compound, Adasu road	L9	N07°42'51.1"	E08°36'40.2"	270	6	19.7	250.3	4/4/2012	HDW
10	Airways Junction 1	L10	N07°42'50.2"	E08°36'37.3"	270	6.06	19.9	250.1	4/4/2012	HDW
11	Airways Junction 11	L11	N07°42'42.5"	E08°36'38.9"	295		0.0	295.0	4/4/2012	HPBH
12	Mrs. Agbadu's compound, Airport Village	L12	N07°42'40.2"	E08°37'00.1"	295		22.9	272.1	4/4/2012	HDW
13	Igah James' compound, Airport Village	L13	N07°42'40.0"	E08°37'02.7"	290	7.3	24.0	266.0	4/4/2012	HDW
14	Alh. Idris compound, Airport Village	L14	N07°42'42.1"	E08°37'14.7"	300	5.3	17.4	282.6	4/4/2012	HDW
15	RCM Pri. Sch. Agbaikyor	L15	N07°42'42.2"	E08°37'22.1"	295	11.25	36.9	258.1	4/4/2012	HDW
16	Tyough Godwin compound, KM 6 Gboko road	L16	N07°42'13.32''	E08°37'14.34''	295	6.71	22.0	273.0	5/4/2012	HPBH
17	Opp NAF Guest house Fiidi	L17	N07°42'12.7"	E08°36'42.6"	350	7.76	25.5	324.5	5/4/2012	HDW
18	James' compound KM 6 Gboko road	L18	N07°42'13.4"	E08°35'57.4"	295	3.23	10.6	284.4	5/4/2012	HDW
19	Behind NAF Guest house Fiidi	L19	N07°42'14.5"	E08°35'59.6"	290	3.8	12.5	277.5	5/4/2012	HDW

20	Emmanuel Iever's compound, Adi village, KM 6 Gboko rd	L73	N07°42'44.5"	E08°35'46.1"	340	3.2	10.5	329.5	5/4/2012	HDW
21	Adi village, KM 6 Gboko road	L21	N07°42'46.6"	E08°35'51.4"	290	4.12	13.5	276.5	5/4/2012	HPBH
22	opposite BBL, Gboko road	L22	N07°42'13.3"	E08°35'15.4"	395	3.56	11.7	383.3	5/4/2012	HDW
23	Agolo Village, Agbadu road	L23	N07°42'13.3"	E08°35'15.6"		3.75	12.3	12.3	5/4/2012	HDW
24	Agbadu Village 1	L24	N07°42'12.7"	E08°35'06.9"	400	2.5	8.2	391.8	5/4/2012	HDW
25	Agbadu Village 2	L25	N07°42'13.3"	E08°35'02.8"	402	6.3	20.7	381.3	5/4/2012	HDW
26	St. Domnic cath. Church Agbadu	L26	N07°42'12.7"	E08°35'02.0"		5.5	18.0	18.0	5/4/2012	HPBH
27	Terwase Agbadu 3	L27	N07°42'7.32"	E08°34'57.8"	380	3.4	11.2	368.8	5/4/2012	HDW
28	Joseph Mwarga compound, Judge's Qtrs extension	L28	N07°42'30.7"	E08°34'55.3"	310	2.22	7.3	302.7	5/4/2012	HDW
29	Judge's Qtrs Extension	L29	N07°42'6.73"	E08°34'42.7"	330	1.88	6.2	323.8	5/4/2012	HDW
30	MWO Ogenyi's compound, Judge's Qtrs extension	L30	N07°42'12.7"	E08°34'37.2"	310	4.3	14.1	295.9	5/4/2012	HDW
31	Onorgu Agbecha Street, Judge's Qtrs Extension	L31	N07°42'13.6"	E08°34'34.2"	275	3.23	10.6	264.4	5/4/2012	HPBH

32	Gyado Villa, KM 5 Gboko road	L32	N07°42'07.3"	E08°34'18.8"	360	6	19.7	340.3	5/4/2012	HDW
33	Corner Stone Sec. Sch. Gyado Villa	L33	N07°42'13.3"	E08°34'23.5"	355	3.46	11.4	343.6	5/4/2012	HDW
34	Nato Foundation Nur. And Pri. Sch. Gyado Villa	L34	N07°42'46.3"	E08°34'27.8"	300	4.03	13.2	286.8	5/4/2012	HDW
35	Gyado Villa	L35	N07°42'31.4"	E08°34'18.1"	370	7.99	26.2	343.8	5/4/2012	HDW
36	Dunamis Church, KM 2 Gboko road	L36	N07°42'14.7"	E08°33'52.9"	380	2.8	9.2	370.8	5/4/2012	HPBH
37	No. 7 Austine Ezekwesili street, Ankpa Ward	L37	N07°42'07.5"	E08°30'26.7"	265	0.8	2.6	262.4	7/4/2012	HDW
38	Rapturing faith terbanacle Terguma Street, North Bank	L38	N07°45'07.3"	E08°32'54.4"	325	7.33	24.0	301.0	7/4/2012	HDW
39	Gyado Villa	L39	N07°42'13.3"	E08°33'36.2"	345	4.1	13.5	331.5	5/4/2012	HDW
40	Uncle Tims Estate Agent , Opp Sch. Of Health. Sci. BSU	L40	N07°42'15.4"	E08°33'38.9"	345	3.8	12.5	332.5	5/4/2012	HDW
41	No. 10 Pever Aganga Street Wurukum	L41	N07°42'13.6"	E08°33'19.3"	350	2.5	8.2	341.8	5/4/2012	HPBH
42	Lady Victoria College, Logo 2 Wurukum	L42	N07°42'14.8"	E08°33'28.2"	345	6.55	21.5	323.5	5/4/2012	HDW
43	Wurukum Market	L43	N07°42'25.3"	E08°33'58.9"	370	5.5	18.0	352.0	6/4/2012	HDW

44	No. 32 Abukinsolowa road, Wurukum	L44	N07°42'10.62''	E08°33'05.7"	340	2.89	9.5	330.5	6/4/2012	HDW
45	Dose Clinic, Logo 1 Wurukum	L45	N07°42'13.6"	E08°33'54.8"	403	2.55	8.4	394.6	6/4/2012	HDW
46	Opposite Owners occupiers Qtrs	L46	N07°42'15.7"	E08°33'55.7"		3.23	10.6	10.6	6/4/2012	HPBH
47	No. J 06 Owners Occupier Housing estate, Abu kinshuluwa rd	L47	N07°41'13.0"	E08°33'04.1"	450	6.15	20.2	429.8	6/4/2012	HDW
48	Opp Owners occupiers Qtrs	L48	N07°41'10.6"	E08°33'09.4"	430	2.34	7.7	422.3	6/4/2012	HDW
49	Akpehe Village	L96	N07°42'13.3"	E08°33'10.2"	340	4.23	13.9	326.1	6/4/2012	HDW
50	Avu Kwem Compound, Terwase Agbadu	L73	N07°42'25.6"	E08°35'08.9"	350	7.22	23.7	326.3	6/4/2012	HDW
51	Nyon Village	L51	N07°42'07.3"	E08°35'13.2"	410	6.4	21.0	389.0	6/4/2012	HPBH
52	NKST Church, Tse Poor	L52	N07°41'25.3"	E08°35'07.2"	425	5.3	17.4	407.6	6/4/2012	HDW
53	Asen Toor Compound, Tse Poor	L53	N07°41'14.52''	E08°34'52.9"	400	6.22	20.4	379.6	6/4/2012	HDW
54	Tse Kwembe Village	L54	N07°42'31.3"	E08°33'49.6"	345	4.22	13.8	331.2	6/4/2012	HDW
55	Shuwas's compound, behind Oando Filling station Yaiko	L55	N07°42'25.4"	E08°32'30.7"	320	7.8	25.6	294.4	6/4/2012	HDW

56	Anguwan Shege, Lower Benue	L56	N07°40'48.0"	E08°32'15.0"	400	3.44	11.3	388.7	6/4/2012	HPBH
57	GP 771/1 Welfare Qtrs	L57	N07°42'13.3"	E08°32'03.8"	275	3.33	10.9	264.1	6/4/2012	HDW
58	Hemko Hospital Kanshio	L58	N07°42'12.7"	E08°32'03.8"		1.33	4.4	4.4	6/4/2012	HDW
59	BANADA Office	L59	N07°41'13.3"	E08°32'01.2"	355	2.3	7.5	347.5	6/4/2012	HDW
60	Pan African Guest house, Opp radio Benue	L60	N07°41'13.3"	E08°32'02.1"	370	3.5	11.5	358.5	7/4/2012	HDW
61	Benue Britain Department	L61	N07°42'07.3"	E08°31'45.7"	275	1.04	3.4	271.6	7/4/2012	HPBH
62	Federal Pay Office, Amushe Street Idye	L62	N07°42'14.5"	E08°31'29.8"	275	2.9	9.5	265.5	7/4/2012	HDW
63	C. Y Frozen foods, High Level round about	L63	N07°42'07.3"	E08°31'47.4"	275	1.5	4.9	270.1	7/4/2012	HDW
64	NKST Church Conrad Wergba Street Idye	L64	N07°42'13.02''	E08°32'05.9"	290	1.8	5.9	284.1	7/4/2012	HDW
65	No. 13 Konshisha Street Wurukum	L65	N07°42'06.7"	E08°32'23.3"	295	1.8	5.9	289.1	7/4/2012	HDW
66	Opp ICMG Securities, Oturkpo road	L66	N07°42'06.7"	E08°32'44.6"	375	2.97	9.7	365.3	7/4/2012	HPBH
67	No. 15 Market Street	L67	N07°42'13.3"	E08°32'33.9"	345	1.63	5.3	339.7	7/4/2012	HDW
68	No. 7 Awe Street	L68	N07°42'43.3"	E08°32'30.8"	250	3.76	12.3	237.7	7/4/2012	HDW

69	Benue Post Office	L69	N07°44'12.8"	E08°31'32.00''	255		0.0	255.0	7/4/2012	HDW
70	Behind FMC Wadata	L70	N07°44'08.4"	E08°30'53.1"	270	5.6	18.4	251.6	7/4/2012	HDW
71	No. 12 Amodu Kumasi road Wadata	L82	N07°42'16.32''	E08°30'17.0"	260	4.23	13.9	246.1	7/4/2012	HPBH
72	Extension 25 Zakibiam Street Wadata	L72	N07°42'16.32''	E08°30'16.9"		4.12	13.5	13.5	7/4/2012	HDW
73	Youngu Village	L50	N07°49'54.7"	E08°30'44.6"	270	4.43	14.5	255.5	7/4/2012	HDW
74	Elite Intl. College Youngu	L74	N07°49'13.3"	E08°30'04.0"	360	1.95	6.4	353.6	7/4/2012	HDW
75	No. 24 Abgwer Street Wadata	L75	N07°44'13.3"	E08°30'03.9"	255	2.5	8.2	246.8	9/4/2012	HDW
76	Spring Intl. School, Modern Market road	L76	N07°42'13.0"	E08°30'02.4"	273	7.05	23.1	249.9	9/4/2012	HPBH
77	Behind Modern Market	L77	N07°40'00.0"	E08°29'47.0"		5.7	18.7	18.7	9/4/2012	HDW
78	Naka Road	L78	N07°42'13.3"	E08°30'12.5"	265	4.52	14.8	250.2	9/4/2012	HDW
79	No. 27 Mission Ward North Bank	L79	N07°45'13.3"	E08°32'45.6"	325	6.9	22.6	302.4	9/4/2012	HDW
80	Day spring street North Bank	L80	N07°45'13.3"	E08°32'58.1"	340	5.5	18.0	322.0	9/4/2012	HDW
81	ECWA Sec. Sch. North Bank	L81	N07°46'07.3"	E08°33'06.9"	315	7.3	24.0	291.0	9/4/2012	HPBH

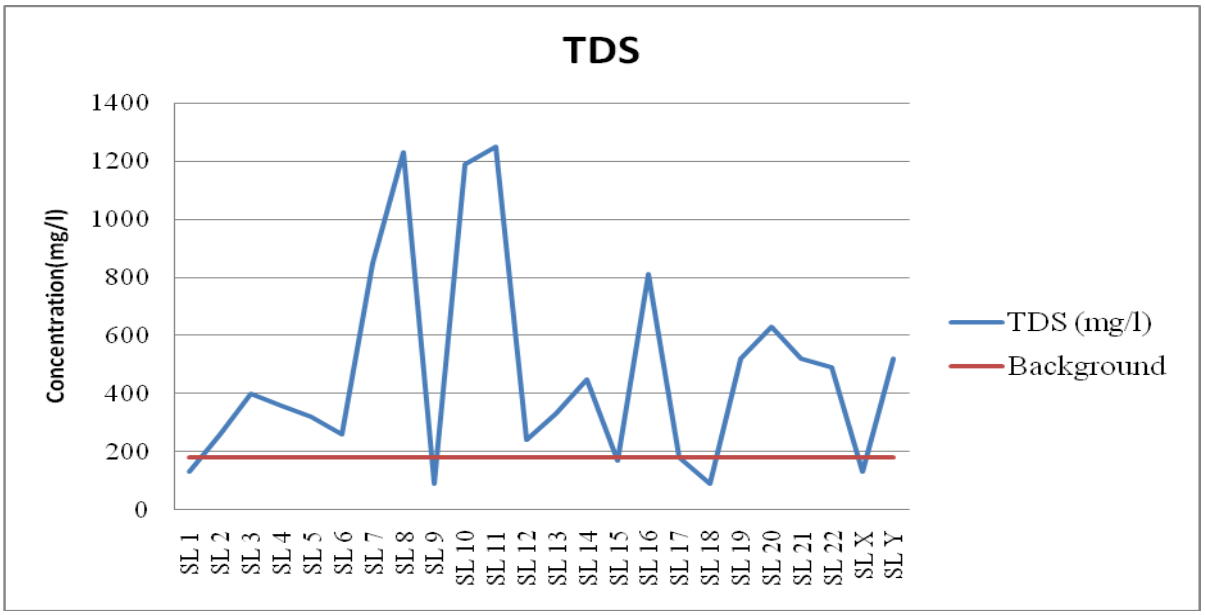
82	Cattle Market	L71	N07°46'37.3"	E08°33'21.7"	370	6.22	20.4	349.6	9/4/2012	HDW
83	72 Barracks road, 4th avenue North Bank	L83	N07°46'01.3"	E08°33'20.8"	350	2.33	7.6	342.4	9/4/2012	HDW
84	Chagu Street North Bank	L84	N07°47'09.1"	E08°33'58.3"	470	5.7	18.7	451.3	9/4/2012	HDW
85	Agan compound, Agan	L85	N07°48'10.32''	E08°33'59.0"	490	4.8	15.7	474.3	9/4/2012	HDW
86	Ujam Village Pilla	L86	N07°46'31.3"	E08°36'30.5"	255		0.0	255.0	9/4/2012	HPBH
87	Antsa Village	L87	N07°46'07.0"	E08°35'30.5"	275	5.9	19.4	255.6	9/4/2012	HDW
88	Dolphin Hotel North Bank	L88	N07°45'13.3"	E08°33'38.2"	330	2.23	7.3	322.7	9/4/2012	HDW
89	No. 13 Amadu Kumase road	L89	N07°42'16.9"	E08°30'15.1"	260	5.05	16.6	243.4	9/4/2012	HDW
90	No. 27 Konshisha Street Wurukum	L90	N07°42'26.6"	E08°32'26.2"	275	1.2	3.9	271.1	9/4/2012	HDW
91	Mu Village KM 14 Gboko road	L91	N07°42'14.5"	E08°40'02.0"	280	8.1	26.6	253.4	9/4/2012	HPBH
92	Christ Apostolic Church Fiidi	L92	N07°42'15.2"	E08°37'59.9"	300	7.22	23.7	276.3	9/4/2012	HDW
93	Primary Health Centre Fiidi	L93	N07°42'15.1"	E08°37'59.8"			0.0	0.0	9/4/2012	HDW
94	NKST Church Coca-cola,	L94	N07°42'19.6"	E08°35'35.0"	350	3.94	12.9	337.1	9/4/2012	HDW

	Gaadi									
95	Zango Akiki Village	L95	N07°47'06.3"	E08°31'02.8"	255		0.0	255.0	9/4/2012	HDW
96	Gever Village	L49	N07°48'36.2"	E08°30'46.1"	280	11.34	37.2	242.8	9/4/2012	HPBH
97	Agever Village	L97	N07°48'07.3"	E08°30'54.0"	255		39.0	216.0	9/4/2012	HDW

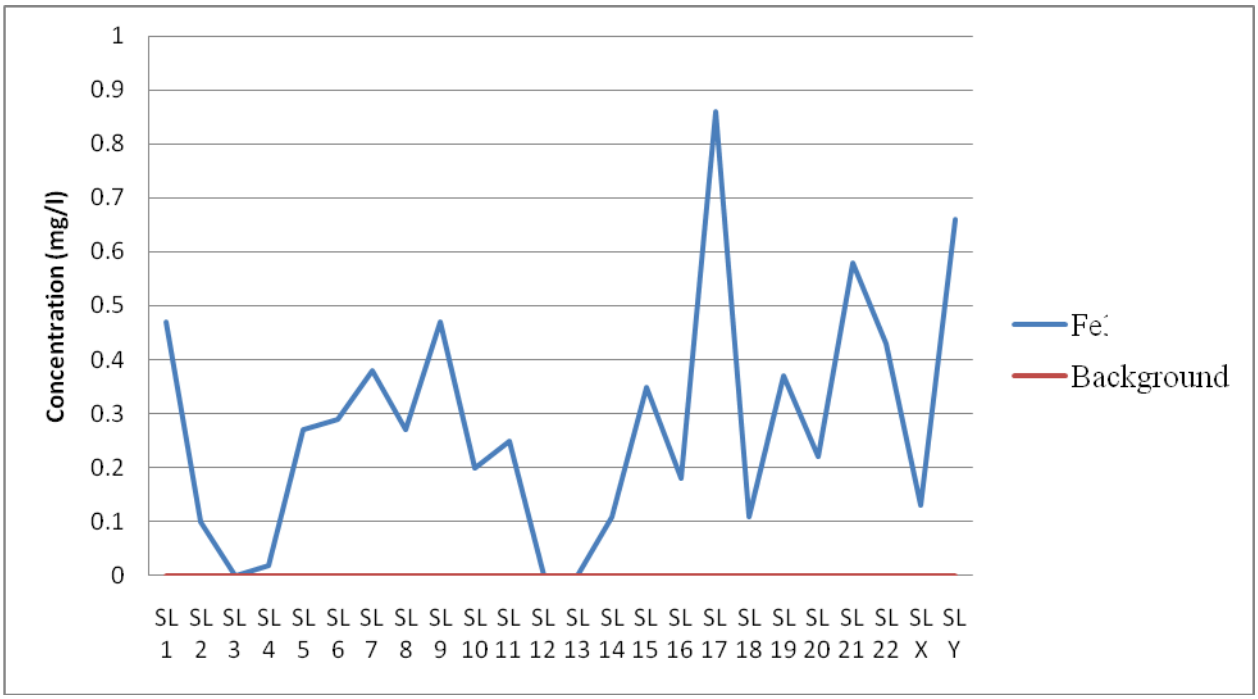
Appendix 2

Plots of concentrations of measured parameters and background values

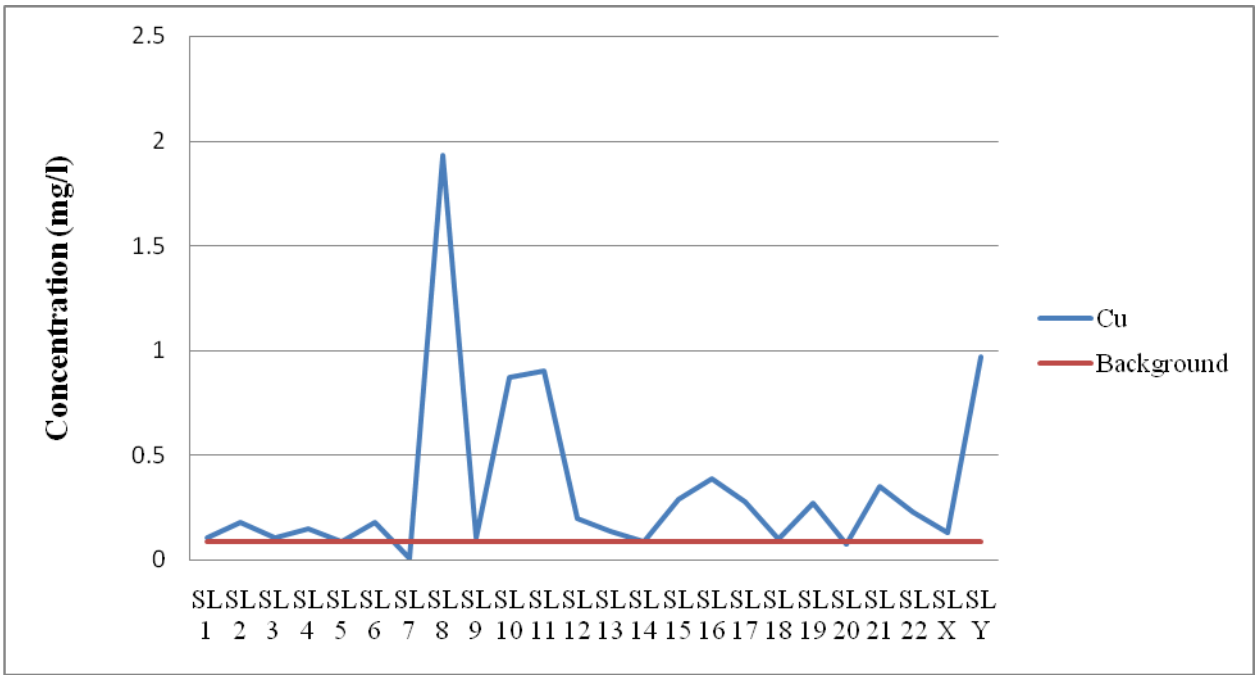
Appendix 2a



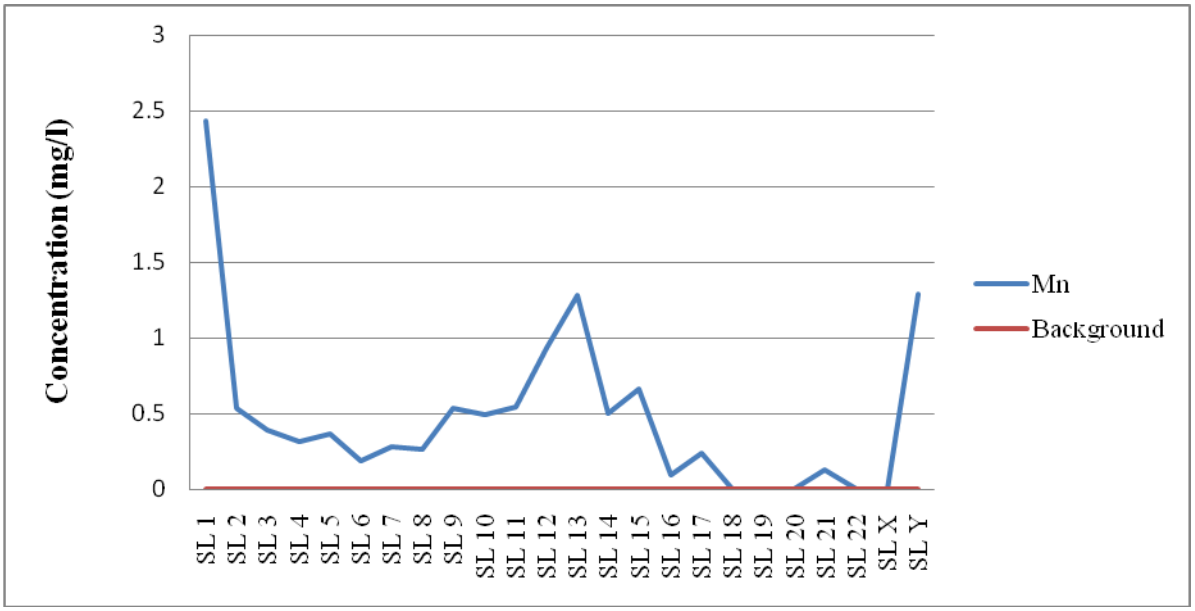
Appendix 2b



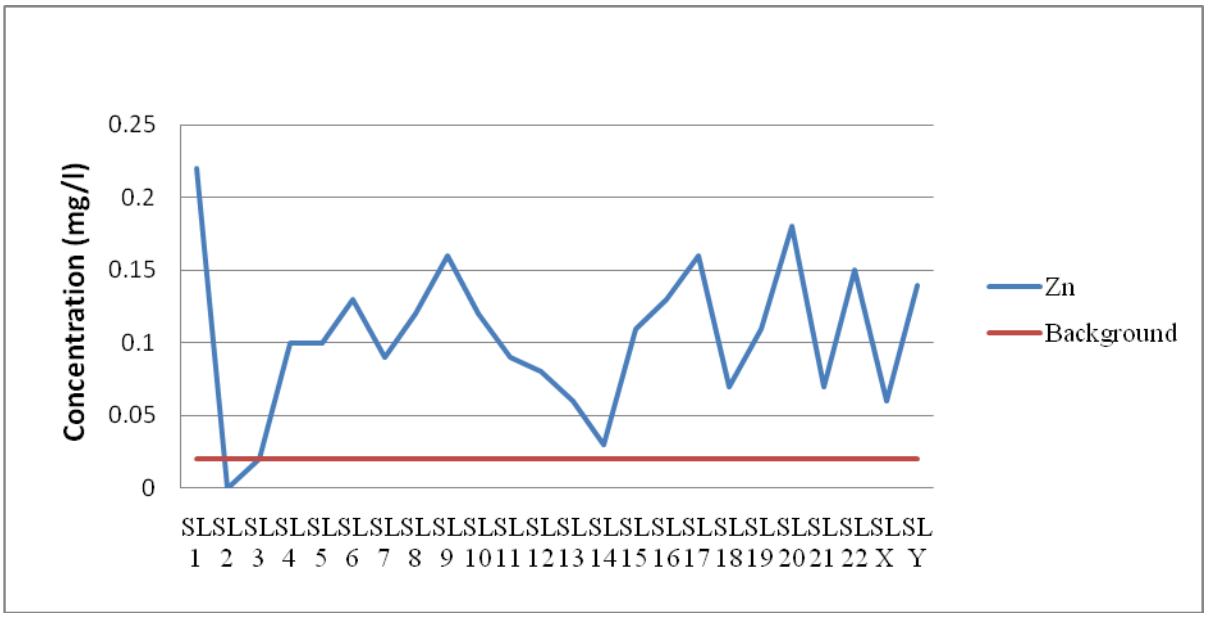
Appendix 2c



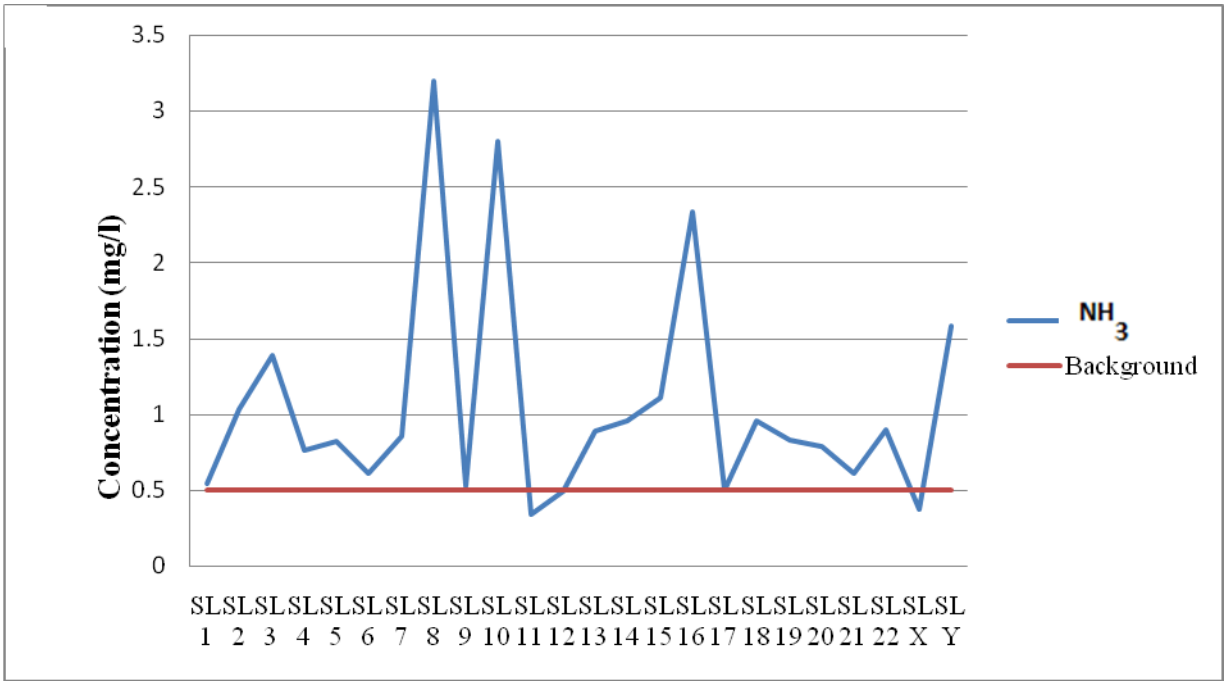
Appendix 2d



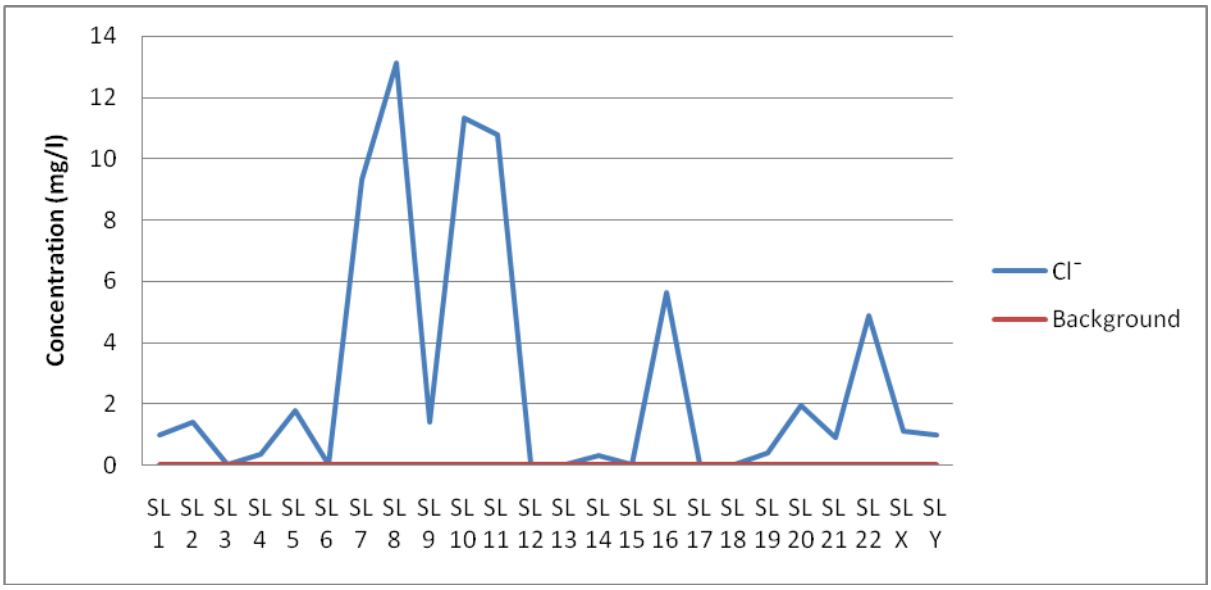
Appendix 2e



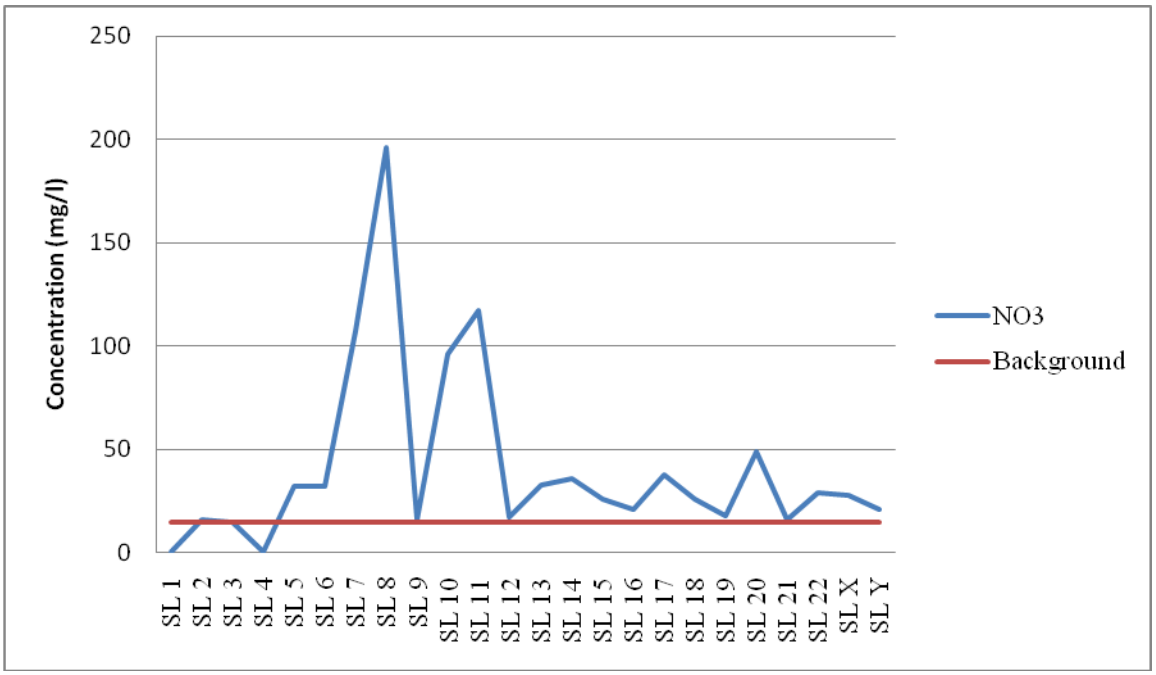
Appendix 2f



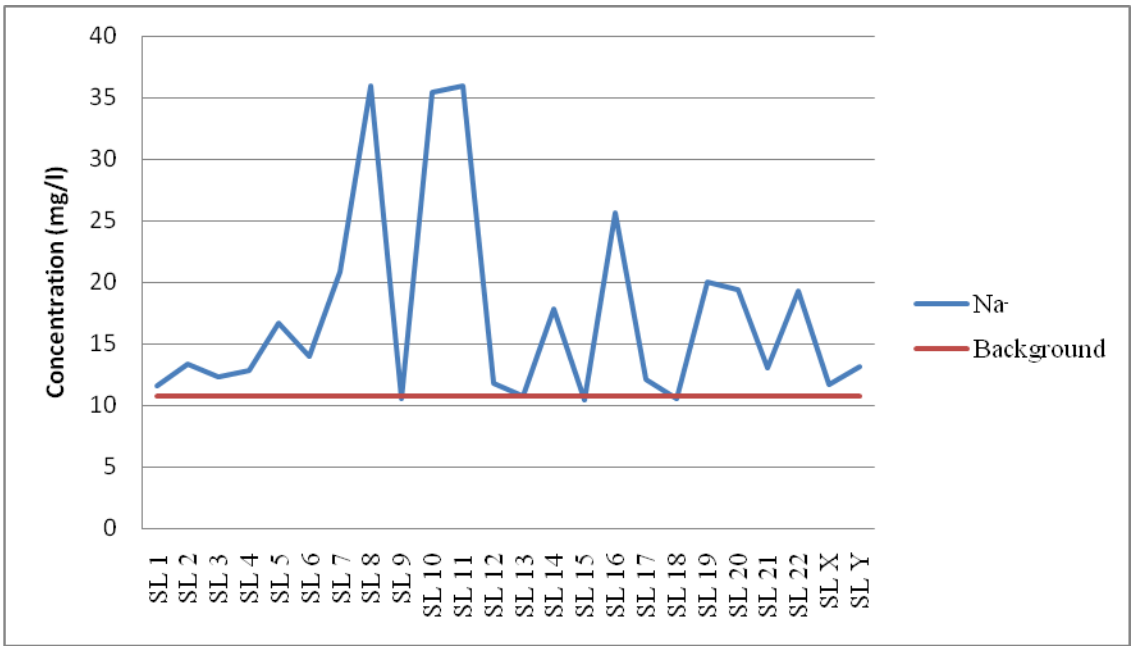
Appendix 2g



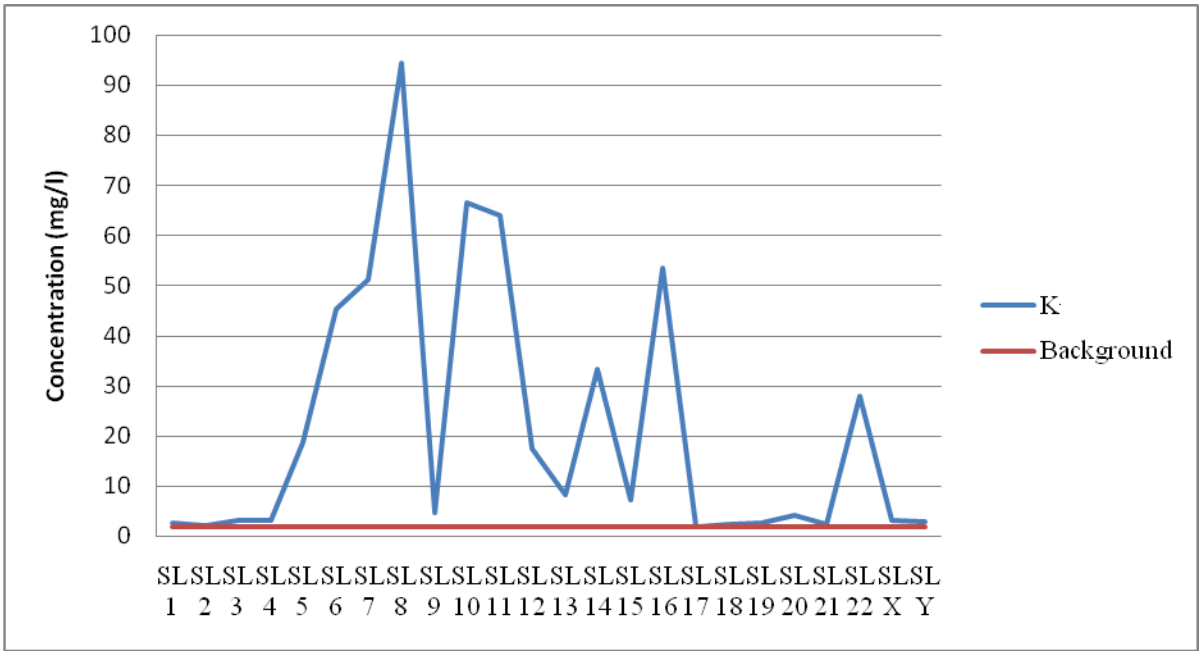
Appendix 2h



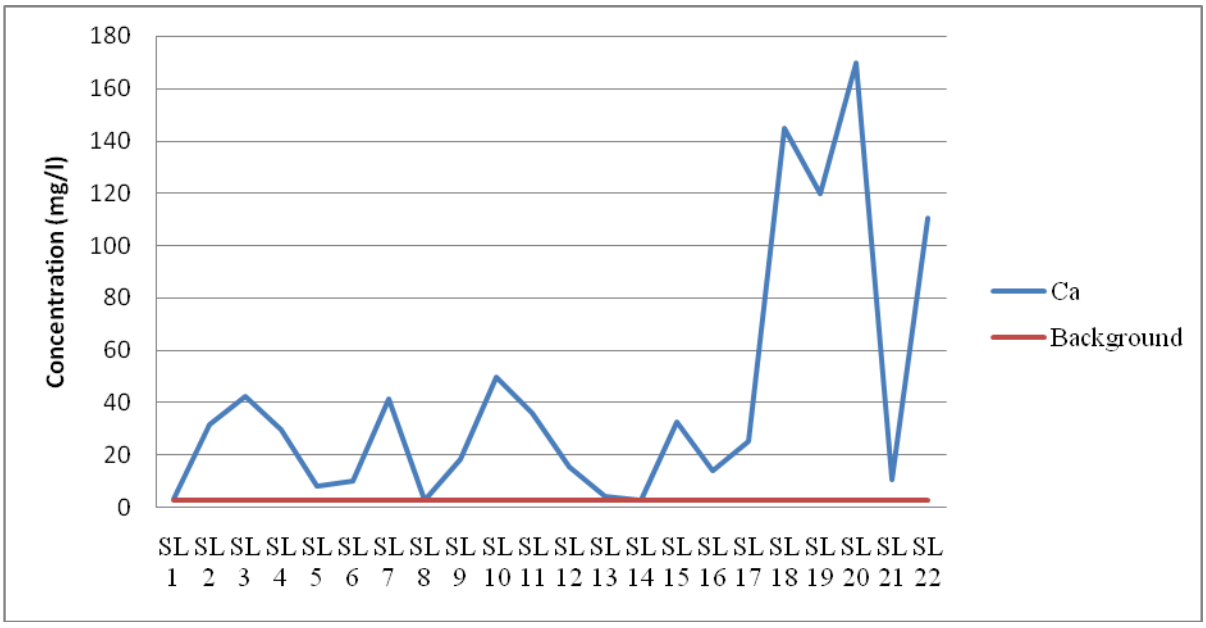
Appendix 2i



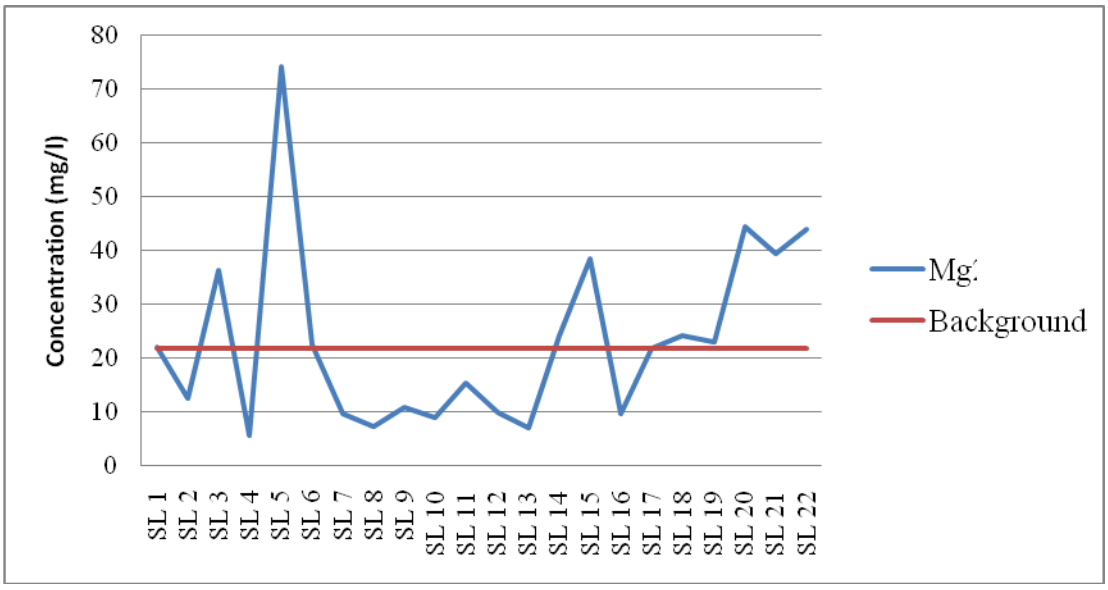
Appendix 2j



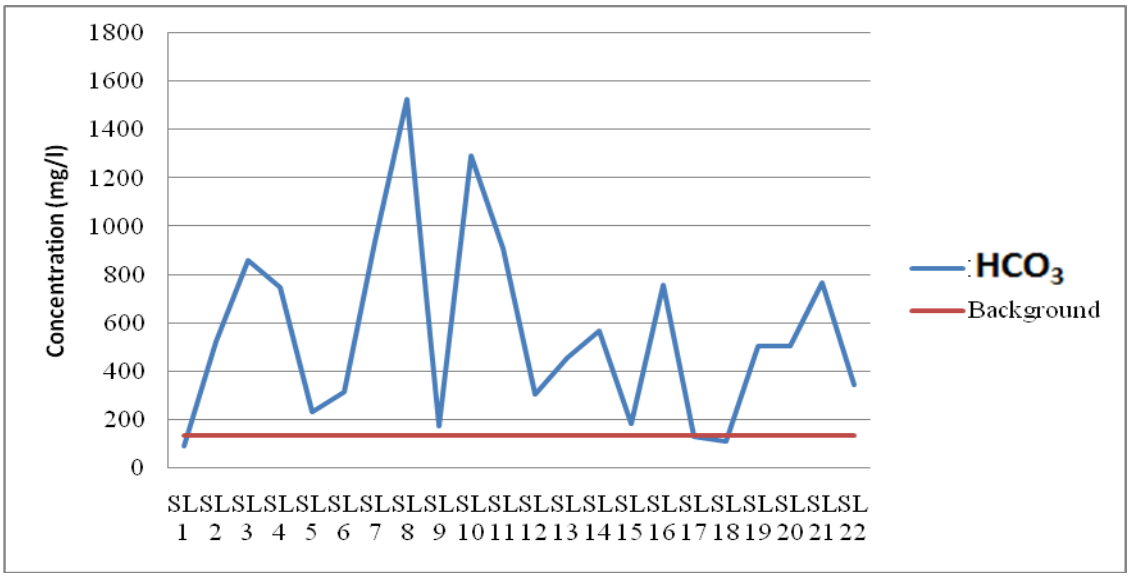
Appendix 2k



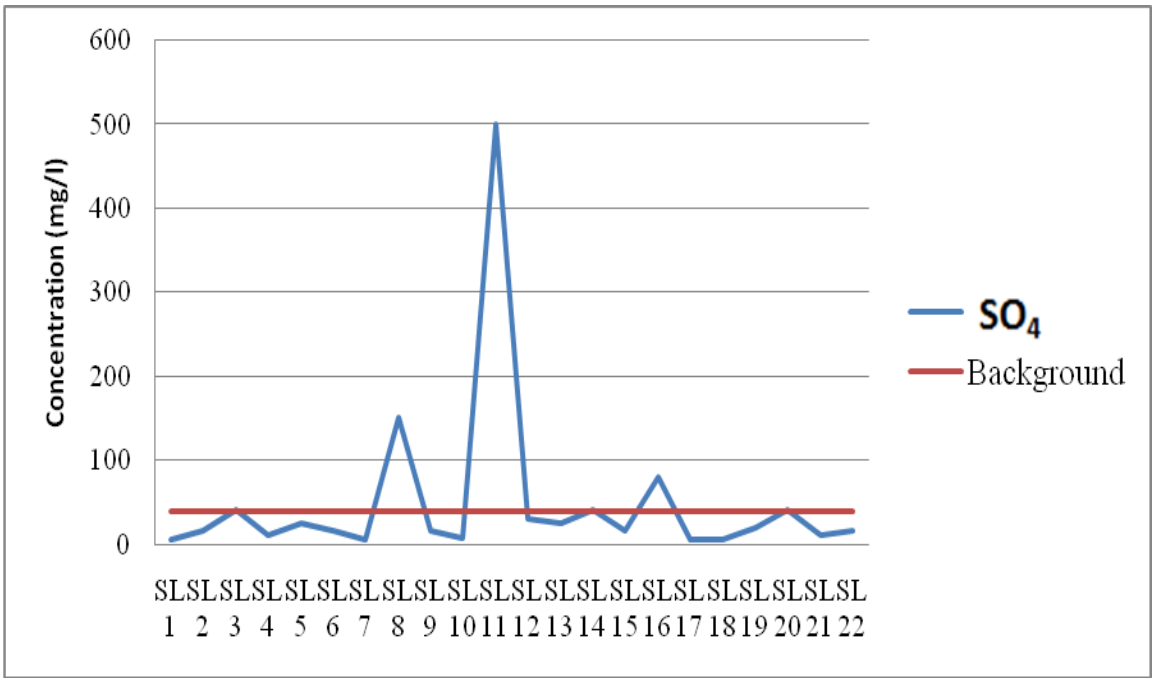
Appendix 2l



Appendix 2m



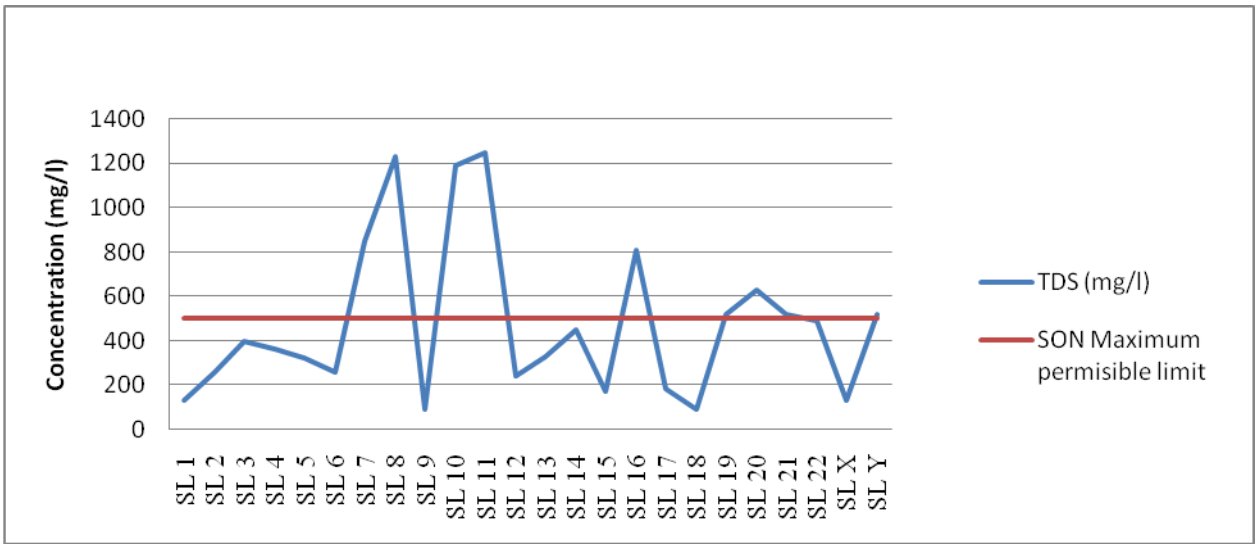
Appendix 2n



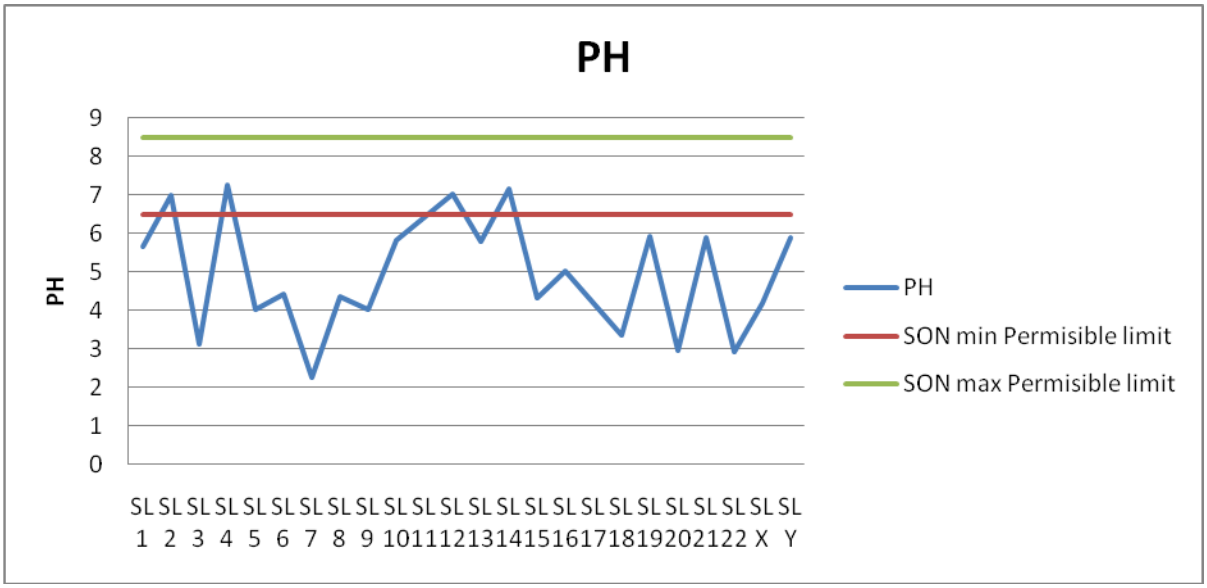
Appendix 3

Plots of concentrations of measured parameters and standard organization of Nigeria's (SON (2007)) permissible limit

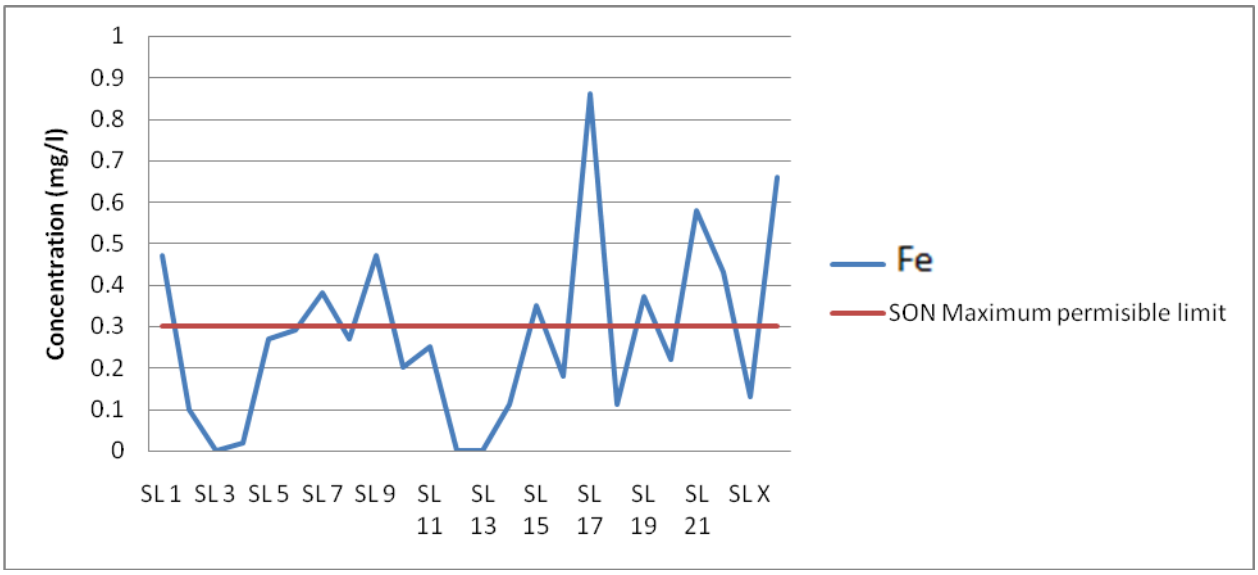
Appendix 3a



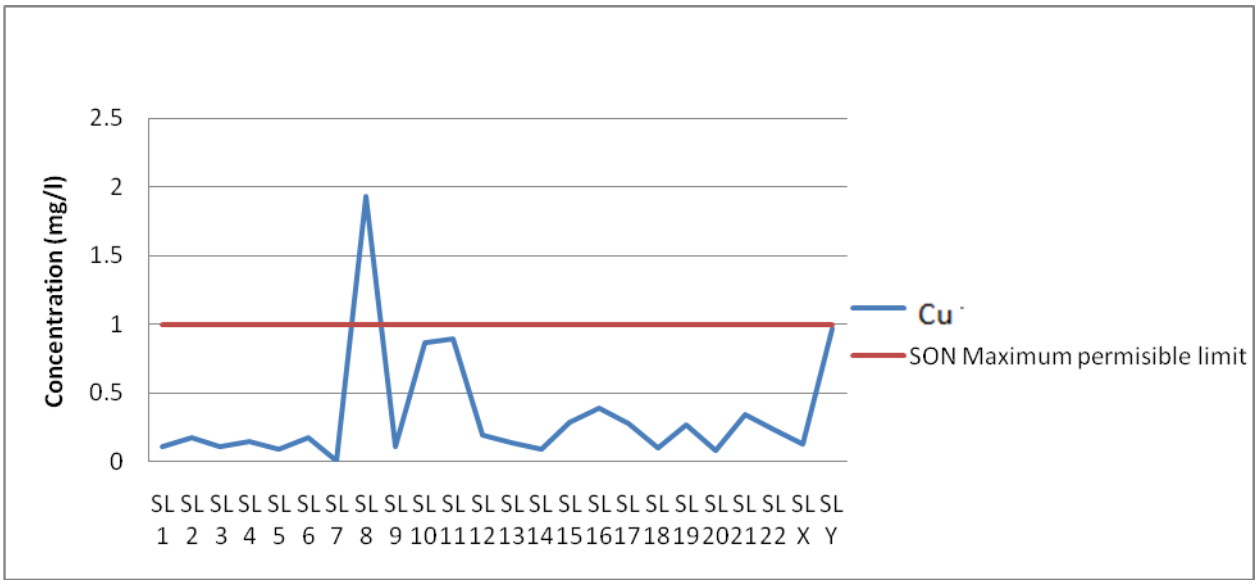
Appendix 3b



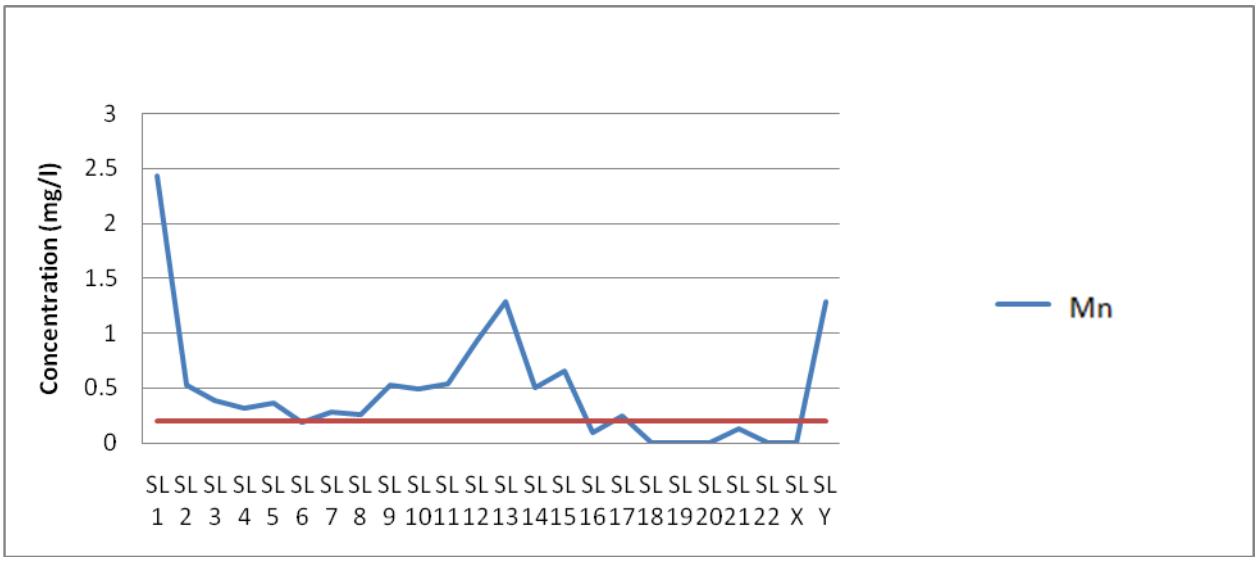
Appendix 3c



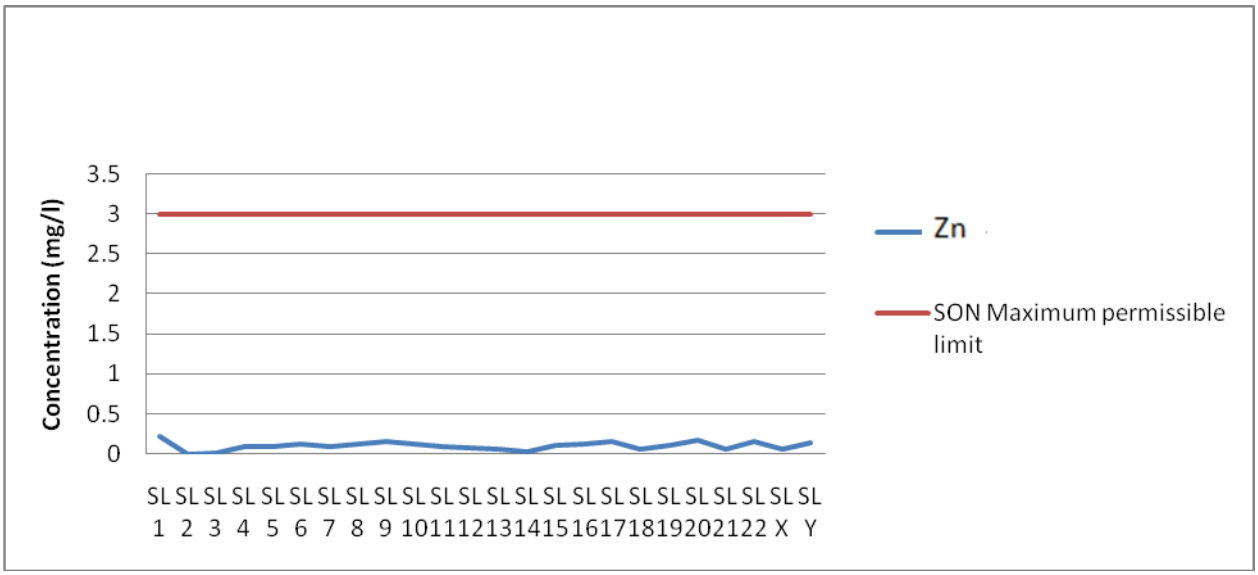
Appendix 3d



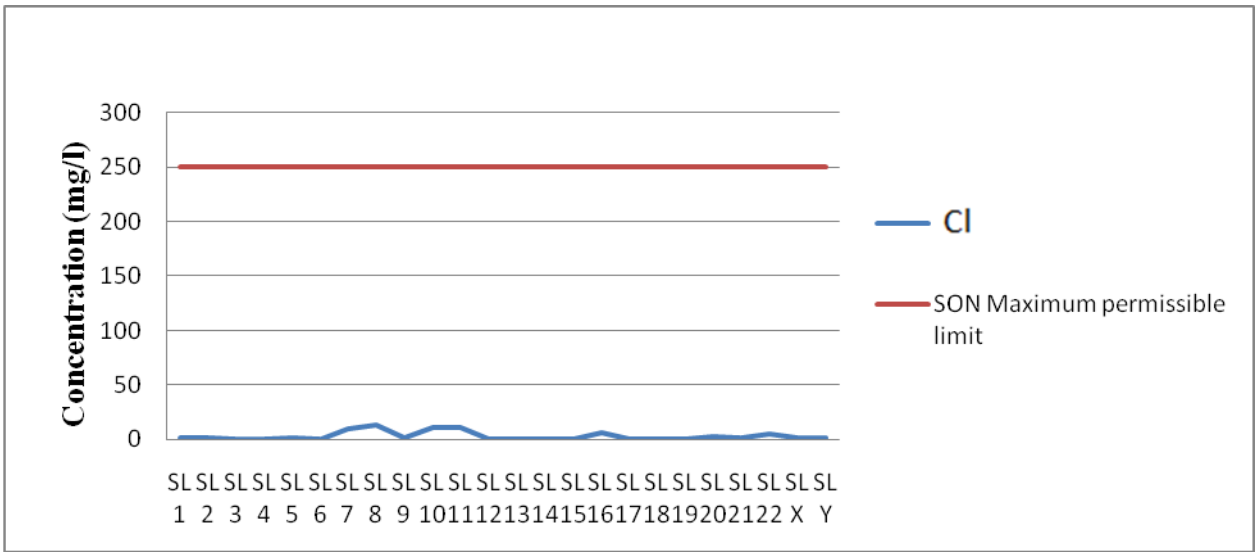
Appendix 3e



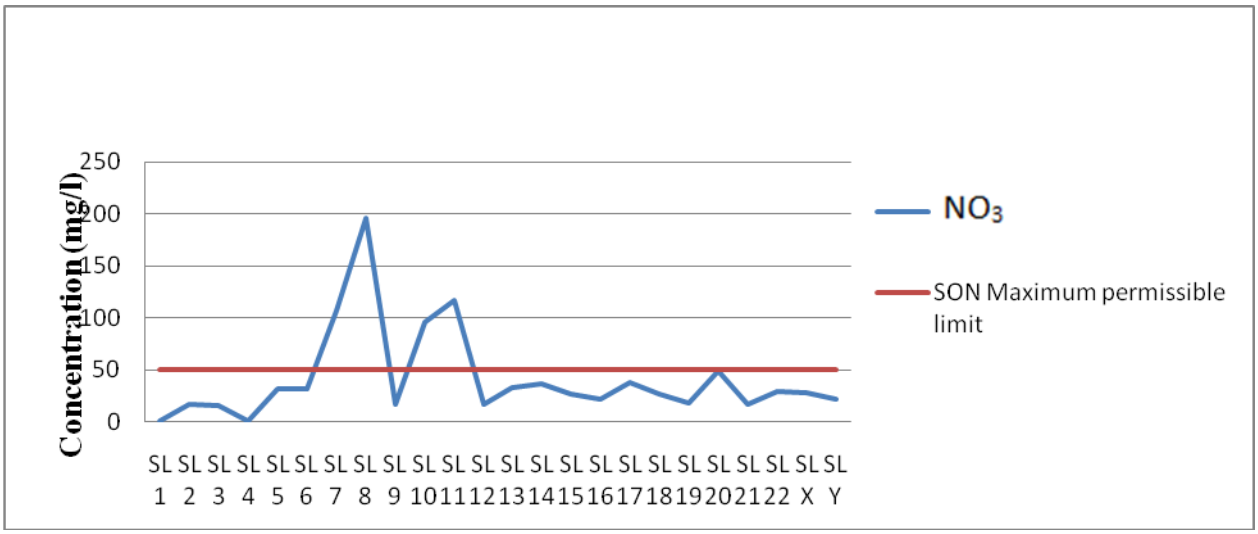
Appendix 3f



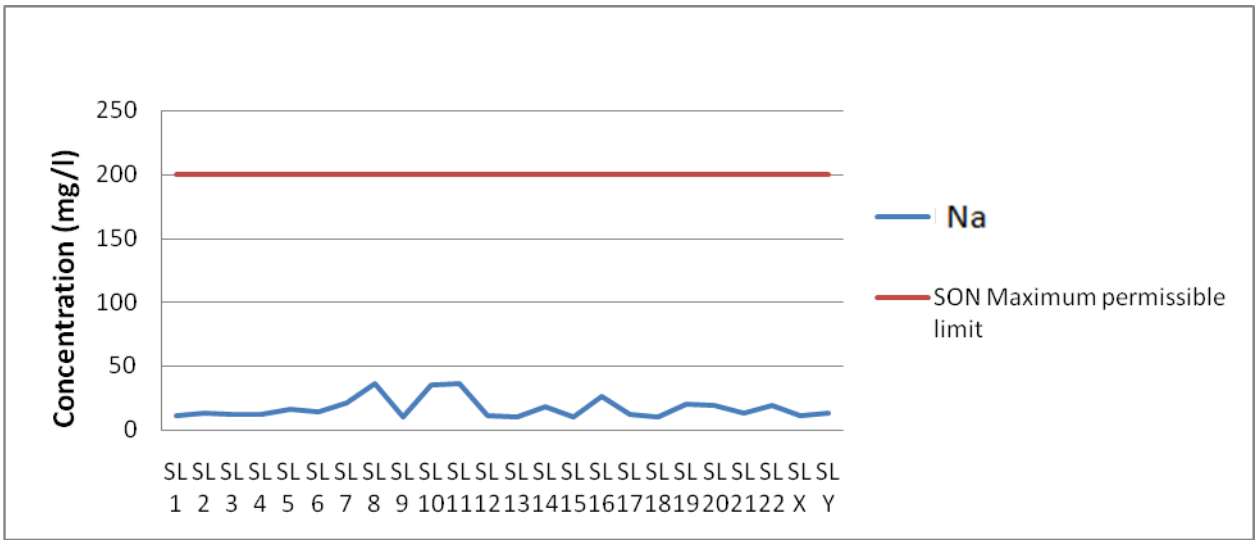
Appendix 3g



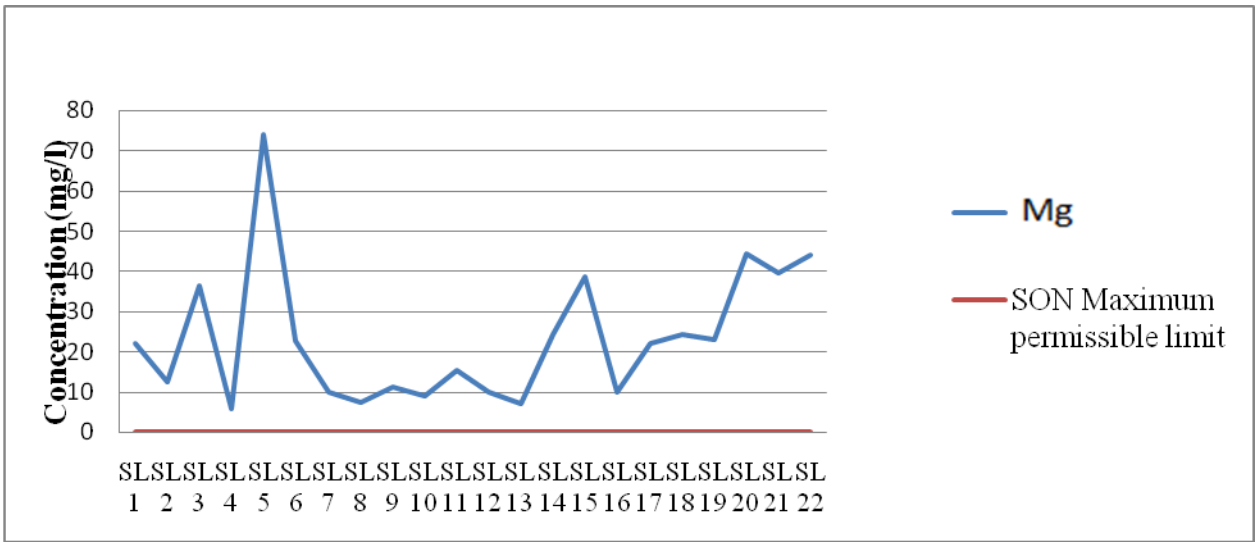
Appendix 3h



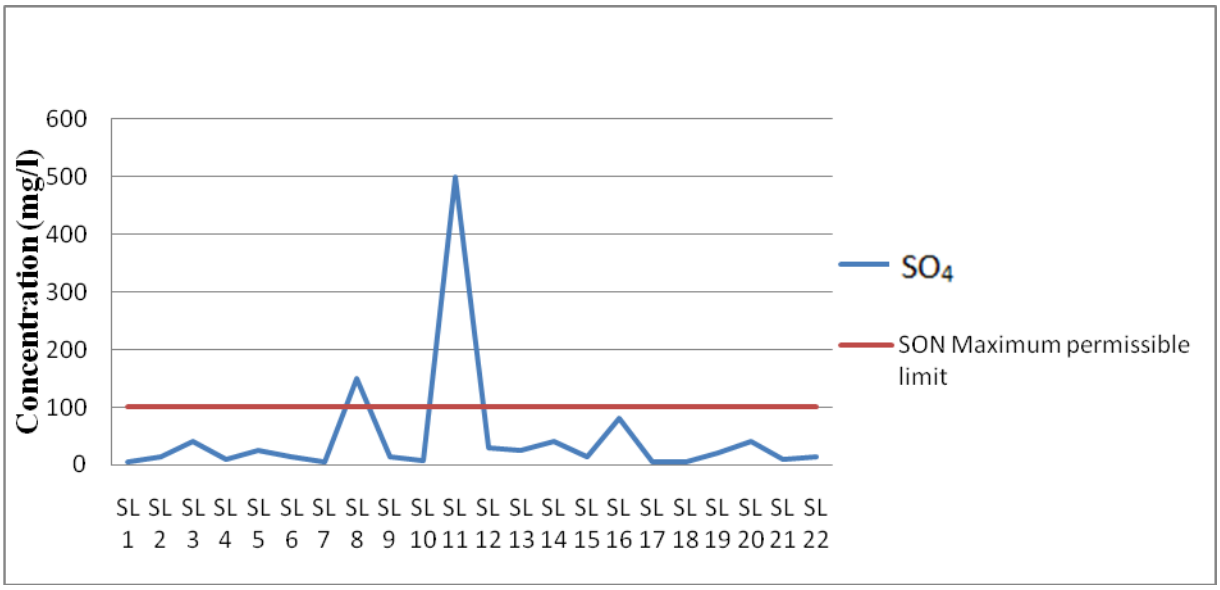
Appendix 3i



Appendix 3j



Appendix 3k


600
500
400
300
200
100
0
Concentration (mg/l)
SL 1
SL 2
SL 3
SL 4
SL 5
SL 6
SL 7
SL 8
SL 9
SL 10
SL 11
SL 12
SL 13
SL 14
SL 15
SL 16
SL 17
SL 18
SL 19
SL 20
SL 21
SL 22
SO4
SON Maximum permissible limit

Appendix 4

Rock source deduction for some groundwater chemical parameters

Sample Designation: AP 1, 4/9/2012	**SL 1**			
Parameter	**Attention Value**	**Conclusion**	**Value**	**Result**
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.949	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
	>0.5	Granitic weathering		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.604	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	130	Silicate weathering
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.017	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.945	Silicate or carbonate weathering

	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Orowa, 4/9/2012	**SL 2**			
Parameter	**Attention Value**	**Conclusion**	**Value**	**Result**
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.937	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.835	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	260	Silicate weathering
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.004	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.956	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		

	<0.8 sulfate low	Seawater or brine		

Sample Designation: Akpu, 4/9/2012	**SL 3**			
Parameter	**Attention Value**	**Conclusion**	**Value**	**Result**
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.717	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	400	Silicate weathering
	<500	Silicate weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.959	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Antsa, 4/9/2012	**SL 4**			
Parameter	**Attention Value**	**Conclusion**	**Value**	**Result**
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.983	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.876	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	360	Silicate weathering
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.001	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.99	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		

Sample Designation: Univ. Of Agric rd, 4/9/2012		**SL 5**		
Parameter	**Attention Value**	**Conclusion**	**Value**	**Result**
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.936	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.439	Pyrite oxidation
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	320	Silicate weathering
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.011	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.841	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: N/Bank 2, 4/9/2012		**SL 6**		
Parameter	**Attention Value**	**Conclusion**	**Value**	**Result**
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.613	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		

	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	260	Silicate weathering
	<500	Silicate weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.901	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: N/Bank 3, 4/9/2012		**SL 7**		
Parameter	**Attention Value**	**Conclusion**	**Value**	**Result**
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.776	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.952	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	850	Carbonate weathering or brine or seawater
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.015	Rock weathering

	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.901	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: N/Bank 4, 4/9/2012		**SL 8**		
Parameter	**Attention Value**	**Conclusion**	**Value**	**Result**
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.809	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.046	Pyrite oxidation
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	1230	Carbonate weathering or brine or seawater
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.013	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.849	Silicate or carbonate weathering

	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: N/Bank 5, 4/9/2012		SL 9		
Parameter	Attention Value	Conclusion	Value	Result
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.921	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	90	Silicate weathering
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.012	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.875	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Wadata , 4/9/2012		**SL 10**		
Parameter	**Attention Value**	**Conclusion**	**Value**	**Result**
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.829	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.948	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	1190	Carbonate weathering or brine or seawater
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.014	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.929	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Wadata 2, 4/9/2012		**SL 11**		
Parameter	**Attention Value**	**Conclusion**	**Value**	**Result**
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.838	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.635	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	1250	Carbonate weathering or brine or seawater
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.018	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.865	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Judge's Quaters, 4/9/2012		**SL 12**		
Parameter	**Attention Value**	**Conclusion**	**Value**	**Result**
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.549	Gypsum dissolution
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	240	Silicate weathering
	<500	Silicate weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.903	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Nyor Village, 4/9/2012		SL 13		
Parameter	Attention Value	Conclusion	Value	Result
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.296	
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	330	Silicate weathering
	<500	Silicate weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.916	Silicate or carbonate weathering
	>0.8 sulfate	Gypsum dissolution		

	high			
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Welfare Qtrs, 4/9/2012		SL 14		
Parameter	Attention Value	Conclusion	Value	Result
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.989	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.143	Calcium removal - ion exchange or calcite precipitation
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	450	Silicate weathering

Sample Designation: Kanshio, 4/9/2012	SL 15			
Parameter	Attention Value	Conclusion	Value	Result
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.84	Calcium source other than gypsum -

				carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	170	Silicate weathering
	<500	Silicate weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.859	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Wurukum, 4/9/2012		SL 16		
Parameter	Attention Value	Conclusion	Value	Result
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.876	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.297	Pyrite oxidation
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	810	Carbonate weathering or brine or seawater

	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.012	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.908	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Mu Village, 4/9/2012		SL 17		
Parameter	Attention Value	Conclusion	Value	Result
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.923	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	180	Silicate weathering
	<500	Silicate weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.8	Seawater or brine
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Airport village 2, 4/9/2012		SL 18		
Parameter	Attention Value	Conclusion	Value	Result
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.986	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	90	Silicate weathering
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	n.d.	
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.825	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Airport village 3, 4/9/2012		SL 19		
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.988	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS	Analysis Error		

	<500 and >50			
	<0.5 TDS <50	Rainwater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.935	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	520	Carbonate weathering or brine or seawater
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.001	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.948	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Ikyaan, 4/9/2012	**SL 20**			
Parameter	**Attention Value**	**Conclusion**	**Value**	**Result**
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.94	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		

	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.91	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	630	Carbonate weathering or brine or seawater
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.006	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.883	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

Sample Designation: Wurukum 2, 4/9/2012		**SL 21**		
(Na/(Na+Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.958	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.718	Calcium source other than gypsum

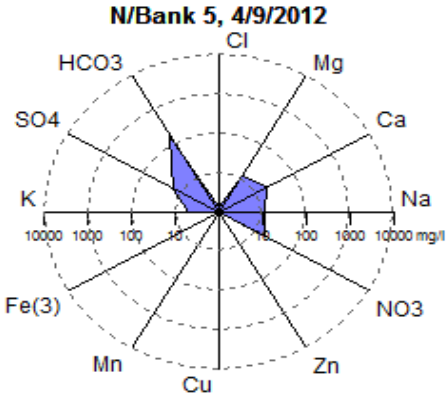
				- carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	520	Carbonate weathering or brine or seawater
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.002	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.974	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

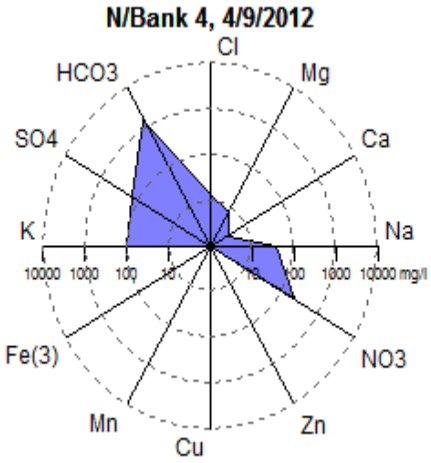
Sample Designation: Wurukum 3, SL 22 DOA 4/9/2012 – 14/09/2012				
Parameter	Attention Value	Conclusion	Value	Result
(Na/(Na + Cl)	>0.5	Sodium source other than halite - albite, ion exchange	0.86	Sodium source other than halite - albite, ion exchange
	0.5	Halite solution		
	<0.5 TDS >500	Reverse Softening, seawater		
	<0.5 TDS <500 and >50	Analysis Error		
	<0.5 TDS <50	Rainwater		
Ca/(Ca+SO4)	0.5	Gypsum dissolution	0.946	Calcium source other than gypsum - carbonate or silicates
	<0.5 and pH <5.5	Pyrite oxidation		

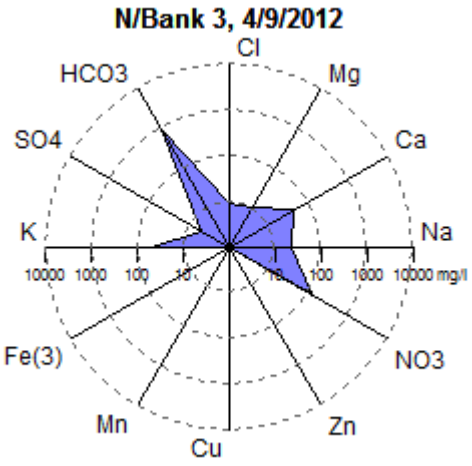
	<0.5 and pH neutral	Calcium removal - ion exchange or calcite precipitation		
	>0.5	Calcium source other than gypsum - carbonate or silicates		
TDS	>500	Carbonate weathering or brine or seawater	490	Silicate weathering
	<500	Silicate weathering		
Cl-/Sum Anions	>0.8 and TDS>500	Seawater or brine or evaporites	0.022	Rock weathering
	>0.8 and TDS<100	Rainwater		
	<0.8	Rock weathering		
HCO3-/Sum Anions	>0.8	Silicate or carbonate weathering	0.894	Silicate or carbonate weathering
	>0.8 sulfate high	Gypsum dissolution		
	<0.8 sulfate low	Seawater or brine		

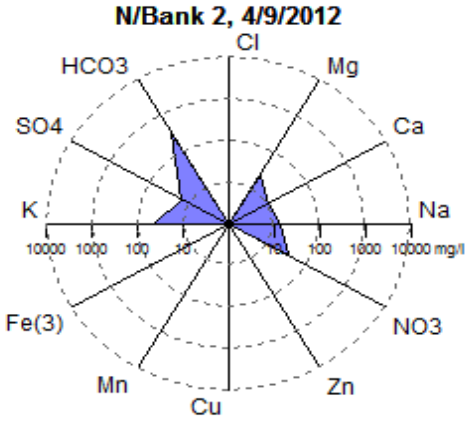
APPENDIX 5

Radial plots of groundwater in Makurdi metropolis and environs

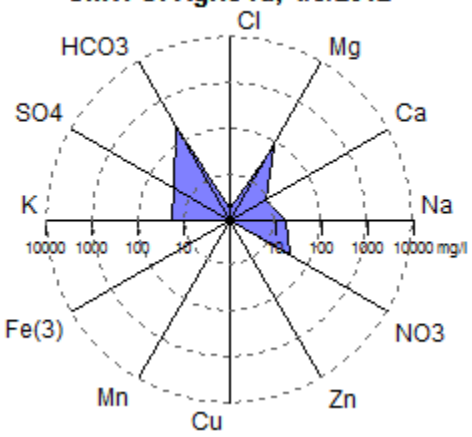




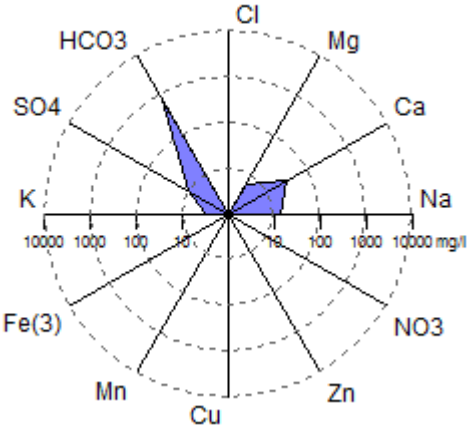




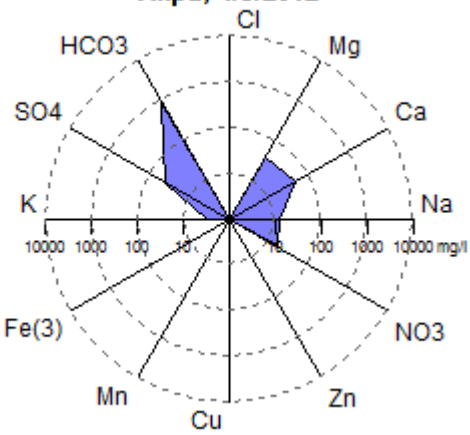
Univ. Of Agric rd, 4/9/2012



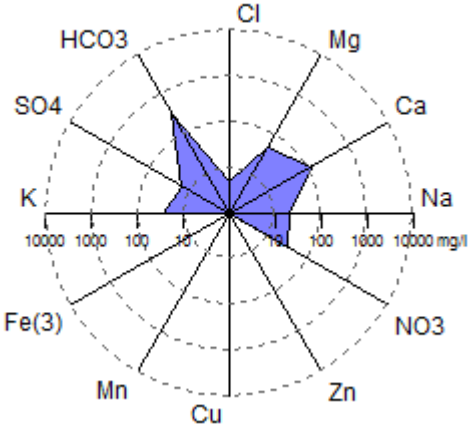
Antsa, 4/9/2012



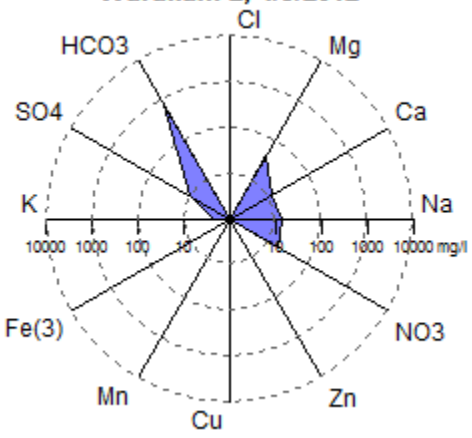
Akpu, 4/9/2012



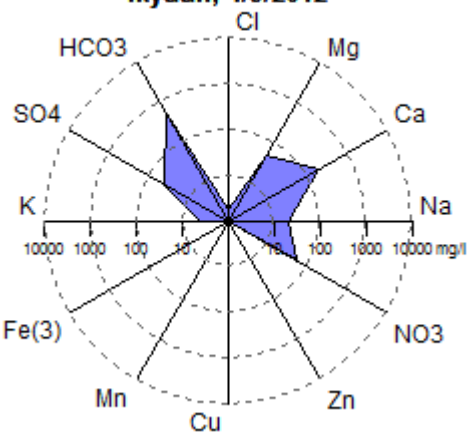
Wurukum 3, 4/9/2012



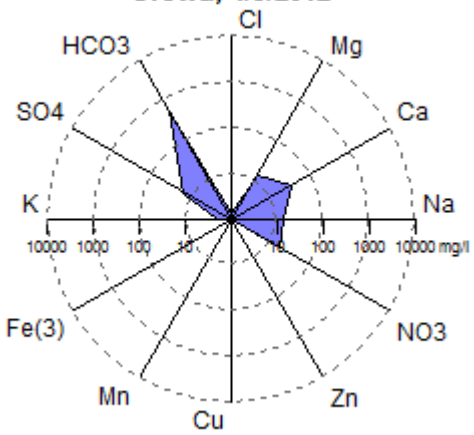
Wurukum 2, 4/9/2012



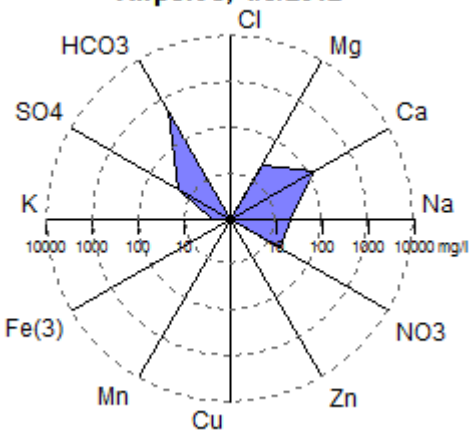
Ikyaan, 4/9/2012



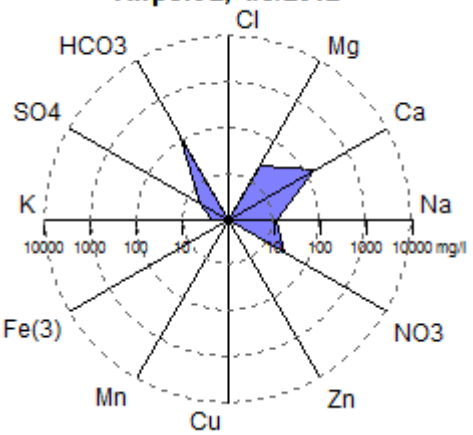
Orowa, 4/9/2012



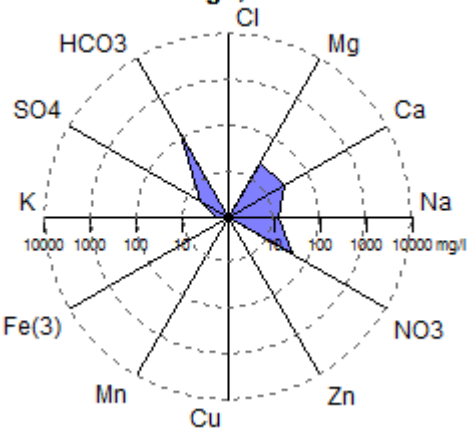
Airport 3, 4/9/2012



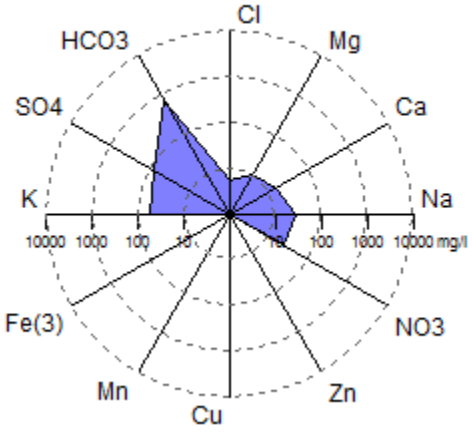
Airport 2, 4/9/2012



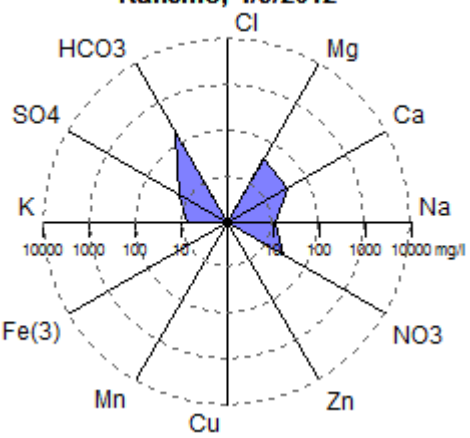
Mu Village, 4/9/2012



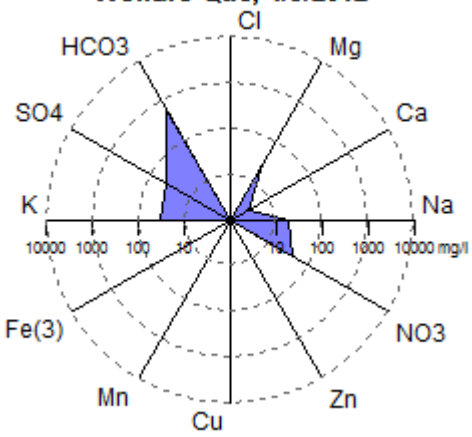
Wurukum, 4/9/2012



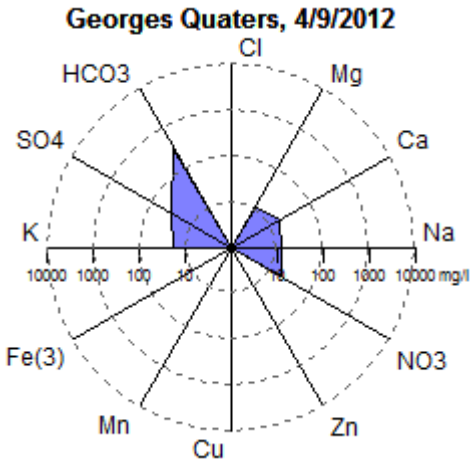
Kanshio, 4/9/2012



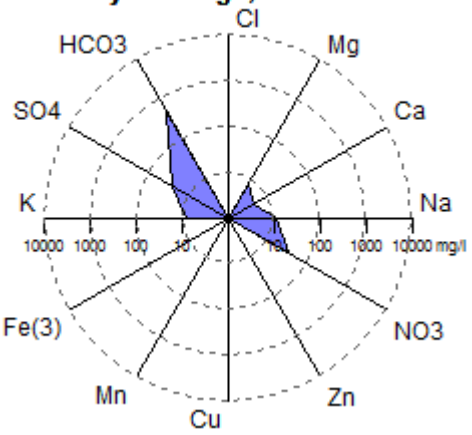
Welfare Qtrs, 4/9/2012



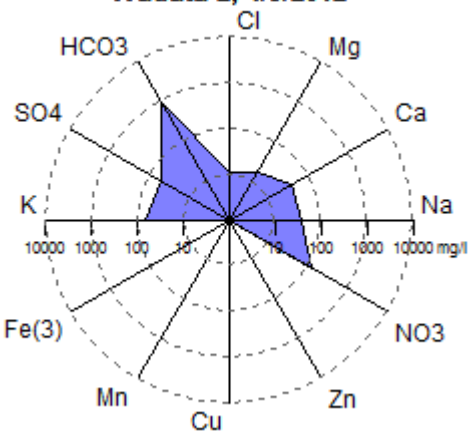
Georges Quaters, 4/9/2012



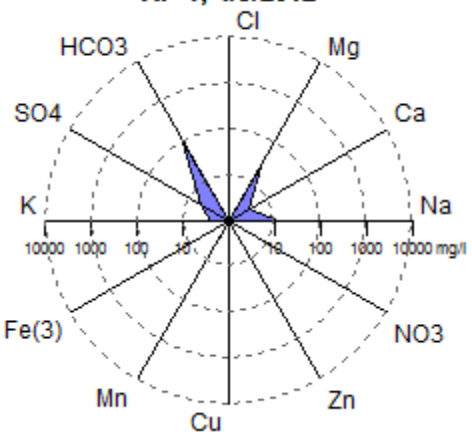
Nyor Village, 4/9/2012



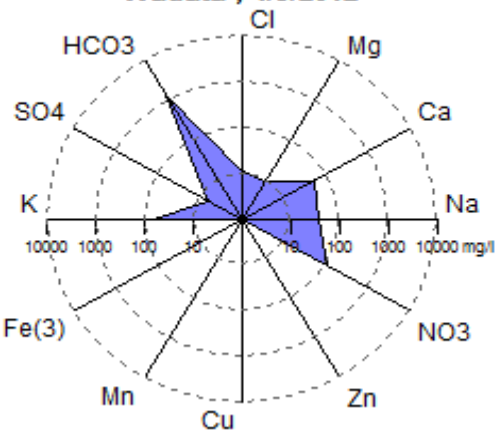
Wadata 2, 4/9/2012



AP 1, 4/9/2012



Wadata , 4/9/2012



APPENDIX 6

BOREHOLE
LOGS

FATIGEN DRILLING (NIG) LTD.

UNICEF ASSISTED RURAL
WATER SUPPLY PROGRAMME
PROJECT:
RIG NR
Latitude N:
Longitude E:

LGA: Makurdi
COMMUNITY: Yaji
BOREHOLE NO.
DATE: 13/12/09

DRILLING OPERATIONS

Depth (m)		Clock Time		Elapsed Time	Formation/Sample Description	Remarks e.g Water Strike, loss circulation
From	To	From	To			
0	1				Brownish sandy clay (moist)	8" drag bit
1	2				"	
2	3				Weathered brownish siltstone	
3	4					
4	5				"	
5	6					
6	7				"	
7	8				"	
8	9					
9	10				"	
10	11				"	
11	12				"	
12	13				"	
13	14				"	
14	15					
15	16				"	
16	17				Hard light greyish siltstone	5½" DTH @ 16m
17	18					
18	19				"	
19	20					Water strike
20	21				"	
21	22				"	
22	23				"	
23	24				Fractured light brownish sandstone	Water strike
24	25				"	
25	26				Fairly hard dark greyish shale	
26	27				"	
27	28				Fairly hard greyish fine grained sandstone	
28	29					
29	30				"	
30	31				"	
31	32				"	

FATIGEN DRILLING (NIG) LTD.

UNICEF ASSISTED RURAL

WATER SUPPLY PROGRAMME

PROJECT:

RIG NR

Latitude N:

Longitude E:

LGA: Makurdi

COMMUNITY: YAGU

BOREHOLE NO:

DATE: 13/12/09

DRILLING OPERATIONS

Depth (m)		Clock Time		Elapsed Time	Formation/Sample Description Fractured dark grey shale	Remarks e.g Water Strike, loss circulation
From	To	From	To			
32	33				Fairly hard greyish fine grained sandstone	
33	34				"	
34	35				"	
35	36				"	
36	37				Hard greyish sandstone	
37	38				"	
38	39				"	
39	40				"	
40	41				"	
41	42				"	
42	43				"	
43	44				"	
44	45				"	
45	46					
46	47					
47	48					
48	49					
49	50					
50	51					
51	52					
52	53					
53	54					
54	55					
55	56					
56	57					
57	58					
58	59					
59	60					
60	61					
61	62					
62	63					
63	64					
64	65					
65	66					
66	67					
67	68					

FATIGEN DRILLING (NIG) LTD.

UNICEF ASSISTED RURAL

WATER SUPPLY PROGRAMME

PROJECT:

RIG NR

Latitude N07.63501^0

Longitude E008.54368^0

LGA: Makurdi

COMMUNITY: Ecwa Church

BOREHOLE NO.

DATE: 21/11/09

DRILLING OPERATIONS:

Depth (m)		Clock Time		Elapsed Time	Formation/Sample Description	Remarks e.g Water Strike, loss circulation
From	To	From	To			
0	1				Brownish fine grained sand	8" drag bit
1	2				Hard light greyish siltstone	$5^1/_2$"DTH@2m
2	3				"	
3	4				Hard pinkish fine grained sandstone	
4	5				"	
5	6				"	
6	7				Hard light greyish fine grained sandstone	
7	8				"	
8	9				"	
9	10				Fractured pinkish sandstone	Wet
10	11				Fairly hard greyish siltstone	
11	12				"	
12	13				"	
13	14				"	
14	15				"	
15	16				"	
16	17				"	
17	18				"	
18	19				"	
19	20				"	
20	21				Minor fractured greyish siltstone	Water strike
21	22				"	
22	23				Hard greyish siltstone	
23	24				"	
24	25				"	
25	26				"	
26	27				"	
27	28				"	
28	29				"	
29	30				"	
30	31				"	
31	32				Hard greyish fine grained sandstone	

A = 60 - 31 =

FATIGEN DRILLING (NIG) LTD.

UNICEF ASSISTED RURAL

WATER SUPPLY PROGRAMME

PROJECT:

RIG NR

Latitude N07.63501^0

Longitude E003.54368^0

LGA: Makurdi

COMMUNITY: Ewa Church

BOREHOLE NO.

DATE: 21/11/09

DRILLING OPERATIONS

Depth (m)		Clock Time		Elapsed Time	Formation/Sample Description Fractured dark grey shale	Remarks e.g Water Strike, loss circulation
From	To	From	To			
32	33				Hard greyish fine grained sandstone	
33	34				"	
34	35				"	
35	36				"	
36	37				"	
37	38				"	
38	39				"	
39	40				"	
40	41				Hard greyish siltstone	
41	42				"	
42	43				"	
43	44				"	
44	45				"	
45	46				"	
46	47				"	
47	48				"	
48	49				"	
49	50				Greyish fine grained sandstone	
50	51				Hard greyish siltstone	
51	52				"	
52	53				"	
53	54				"	
54	55				"	
55	56				"	
56	57				"	
57	58				"	
58	59				"	
59	60				"	
60	61					
61	62					
62	63					
63	64					
64	65					
65	66					
66	67					
67	68					
68	69					
69	70					

FATIGEN DRILLING (NIG) LTD.

UNICEF ASSISTED RURAL WATER SUPPLY PROGRAMME

PROJECT:

RIG NR

Latitude N

Longitude E

LGA: Makurdi

COMMUNITY: Angllican Church Upuu

BOREHOLE NO.

DATE: 20/11/09

DRILLING OPERATIONS

Depth (m)		Clock Time		Elapsed Time	Formation/Sample Description	Remarks e.g Water Strike, loss circulation
From	To	From	To			
0	1				Reddish brown lateritic sand	8'' drag bit
1	2				''	
2	3				Light brownish highly weathered sandstone	
3	4				''	
4	5				''	$5^{1}/_{2}$"DTH@2m
5	6				Brownish clayey sand	
6	7				Light brownish weathered fine grained sandstone	
7	8				''	
8	9				''	
9	10				''	
10	11				''	
11	12				Greyish sandstone/shale intercalation	
12	13				''	
13	14				''	
14	15				''	
15	16				''	
16	17				''	
17	18				''	
18	19				''	
19	20				Greyish shale	
20	21				Dark greyish fine grained sandstone	
21	22				''	
22	23				''	
23	24				Greyish shale	
24	25				''	
25	26				''	
26	27				Brownish fine-medium grain fractured sandstone	Water strike
27	28				''	
28	29				''	
29	30				''	
30	31				Greyish shale	
31	32				''	

A= ~~33~~ A= 59-26 = 33

FATIGEN DRILLING (NIG) LTD.

UNICEF ASSISTED RURAL WATER SUPPLY PROGRAMME

PROJECT:

RIG NR

Latitude N

Longitude E

LGA: Makurdi

COMMUNITY: Angllican Church Upuu

BOREHOLE NO.

DATE: 20/11/09

DRILLING OPERATIONS

Depth (m)		Clock Time		Elapsed Time	Formation/Sample Description Fractured dark grey shale	Remarks e.g Water Strike, loss circulation
From	To	From	To			
32	33				Greyish shale	
33	34				"	
34	35				"	
35	36				"	
36	37				"	
37	38				Milkish fine-medium grain sandstone	Water strike
38	39				Dark greyish shale	
39	40				"	
40	41				"	
41	42				"	
42	43				"	
43	44				Milkish fine-medium grain sandstone	
44	45				"	
45	46				"	
46	47				"	
47	48				Dark greyish shale intercalated with sandstone	
48	49				"	
49	50				"	
50	51				"	
51	52				"	
52	53				"	
53	54				"	
54	55				"	
55	56				"	
56	57				"	
57	58				"	
58	59					
59	60					
60	61					
61	62					
62	63					
63	64					
64	65					
65	66					
66	67					
67	68					
68	69					
69	70					

FATIGEN DRILLING (NIG) LTD.

UNICEF ASSISTED RURAL

WATER SUPPLY PROGRAMME

PROJECT:

RIG NR

Latitude N

Longitude E

LGA: Makurdi

COMMUNITY: Youth Camp

BOREHOLE NO.

DATE: 13/11/09

DRILLING OPERATIONS

Depth (m)		Clock Time		Elapsed Time	Formation/Sample Description	Remarks e.g Water Strike, loss circulation
From	To	From	To			
0	1				Top soil, reddish brown laterite	8'' drag bit
1	2				''	
2	3				Dark brownish highly weathered sandstone	
3	4				''	
4	5				''	$5^{1}/_{2}$"DTH@5m
5	6				Brownish highly weathered sandstone	
6	7				''	
7	8				''	
8	9				''	
9	10				''	
10	11				''	
11	12				Greyish shale/sandstone intercalation	
12	13				''	
13	14				''	
14	15				Greyish fine grained sandstone	
15	16				''	
16	17				''	
17	18				''	Water strike
18	19				''	
19	20				''	
20	21				''	
21	22				''	
22	23				''	
23	24				''	
24	25				''	
25	26				Greyish shale/sandstone intercalation	
26	27				''	
27	28				''	
28	29				''	
29	30				''	
30	31				''	
31	32				''	

FATIGEN DRILLING (NIG) LTD.

UNICEF ASSISTED RURAL
WATER SUPPLY PROGRAMME
PROJECT:
RIG NR
Latitude N
Longitude E

LGA: Makurdi
COMMUNITY: Youth Camp
BOREHOLE NO.
DATE: 13/11/09

DRILLING OPERATIONS

Depth (m)		Clock Time		Elapsed Time	Formation/Sample Description Fractured dark grey shale	Remarks e.g Water Strike, loss circulation
From	To	From	To			
32	33				Milkish sandstone/siltstone intercalation	
33	34				"	
34	35				"	
35	36				"	
36	37				Greyish sandstone/shale intercalation	
37	38				"	
38	39				"	
39	40				Dark greyish shale	
40	41				"	
41	42				"	
42	43				Greyish shale/sandstone intercalation	
43	44				"	
44	45				"	
45	46				Milkish fine grained sandstone	
46	47				"	
47	48				"	
48	49				Light greyish shale/sandstone intercalation	
49	50				"	
50	51				"	
51	52				"	
52	53				"	
53	54				"	
54	55				"	
55	56				"	
56	57				"	
57	58				"	
58	59				"	
59	60				"	
60	61					
61	62					
62	63					
63	64					
64	65					
65	66					
66	67					
67	68					
68	69					
69	70					