HYDROGEOLOGY AND GROUNDWATER QUALITYOF LAFIA AND ITS ENVIRONS, LAFIA SHEET 231 NW, NASARAWA STATE, NORTHCENTRAL NIGERIA

By

MA'AJI USMAN MUSA

M. Sc./Scie./8028/2010-2011

DEPARTMENT OF GEOLOGY

AHMADU BELLO UNIVERSITY, ZARIA

NIGERIA

FEBRUARY, 2015

HYDROGEOLOGY AND GROUNDWATER QUALITY OF LAFIA AND ITS ENVIRONS, SHEET 231, LAFIA NW, NASARAWA STATE, NORTH CENTRAL NIGERIA

By

Ma'ajiUsman MUSA B.Sc. (A.B.U.) 1995

MSc/Scie/8028/10-11

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES,

AHMADU BELLO UNIVERSITY, ZARIA, NIGEERIA

IN PARTIAL FULFILLMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN GEOLOGY (HYDROGEOLOGY)

DEPARTMENT OF GEOLOGY

FACULTY OF SCIENCE

AHMADU BELLO UNIVERSITY, ZARIA,

NIGERIA

FEBRUARY, 2015

DEDICATION

This Research work is dedicated to ALLAH (SWT) The Creator of everything for showing me this moment in my life. Also to my parents, Mallama Aisha Musa and Alhaji Musa Ma'aji, may Allah (SWT) in His Infinite Mercies, pardon them of all their wrong doings and grant them Aljannat-Firdaus, amin.

QUOTATION

The best of a man is what his people can achieve meaningfully from him (Hadith).

Ma'ajiUsman M.

DECLARATION

I declare that the work in this thesis entitled "Geology and Hydrogeology of part of Lafia and Environs, Sheet 231 Lafia NW, Nasarawa State, North Central Nigeria" has been done by me in the Department of Geology, Faculty of Science, Ahmadu Bello University, Zaria, under the supervisions of Dr. M.L. Garba and Dr. V.E.O. Obiosio.

All information derived from literatures has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any University.

Ma'ajiUsman Musa ....

Signature Date

CERTIFICATION

This thesis entitled "Hydrogeology and Groundwater Quality of Lafia and Environs, Lafia Sheet 231 NW, Nasarawa State, Northcentral Nigeria by Ma'aji Usman Musa meets the regulations governing the award of the degree of Master of Science in Applied Geology (Hydrogeology) of Ahmadu Bello University, Zaria, Nigeria and is approved for its contribution to knowledge and literally presentation.

Ma'aji Usman Musa 23/02/2015

Signature Date

Dr. M.L. Garba 23/02/2015

Chairman Supervisory Committee Signature Date

Dr. V.E. Obiosio 23/02/2015

Member Supervisory Committee Signature Date

Dr. H. Hamza ....

Head of Department Signature

Prof. A. Z. Hassan ....

Dean, School of Postgraduate Studies Signature Date

ACKNOWLEDGEMENT

In the Name of Allah, the Beneficent, the Merciful. All praises be to Allah, the Lord of the worlds. Thanks be to the Almighty Allah (SWT) Who spares my life up to this moment for me to complete this programme.

Firstly, my general appreciation goes to the entire members of staff, particularly the academic staff of this department for their immense contribution towards achieving the success of this course. They include; the Head of Department, Dr. H. Hamza, Prof. KryztofSchoeneich, Prof. Peter M. Zaborski, Prof. E.A. Bala, Dr. S.A. Alagbe, Dr. A.E. Ikpokonte, Dr. T. Najime, Dr.Aliyu A. Ibrahim, Dr. I. Hamidu, Mallam Yusuf Isma'il, MallamIsyaka Ahmed, Mallam Mohammad SafyanuElatikpo, Mallam Abdul-GafarKayodeAmuda, MallamUsman Mohammad, Mr. J.A, Eka and others.

My gratefulness and sincere gratitude goes to Dr. M.L. Garba whose countless supports and meaningful contributions as my first supervisor and Post Graduate coordinator hastened the completion of this research. Your assistance with some literatures and constructive criticisms helped me shaped my work to this standard. May Allah (SWT) in His Infinite Mercies guide and reward him abundantly, amin. My regards, thanks and appreciation goes to my second supervisor, Dr. V.E. Obiosio whose suggestions and contributions seriously led to the success of this work. The critical observations and comments of both my supervisors have in no small measures assisted me in the completion of this work.

My hearty prayer of good health and progress goes to the former Head of Department, Professor U.A. Danbatta for his concern and the assistance he rendered towards the successful and timely completion of this programme. May Allah reward him immensely for all his good deeds, amin.

I must not relent to acknowledge the contribution of my friend and classmate at B.Sc. an A.B.U. staff, now transferred to Federal UniversityLokoja, Dr.JerimiahAyok, whose encouragements and supports geared up the speed of this work. May God reward him in earnest.

To Prof. Mudiare of the Department of Agric. Engineering A.B.U. Zaria, father, I am sincerely grateful for the encouragement and support you accorded to me during this programme. God bless you.

Here in A.B.U. Zaria, my classmates and friends such as Innocent Duru C., Anthony Nwanya C. (Arab Contractors, Abuja) Thaddeus ItanyiAku, Madams Christiana AbusuOhwohfasa and Folake Deborah Akpanbiade. I must not forget to mention other friends such as Mallam Jose A. UsmanOkene, AndogmaTendeWanduku, Mr.FabianAdukwuOhieme, Mallam Abba Muhammad Jibrin (M.J), AlhajiNuhu Tilde, Ja'afarFaruq, Musa BalaGirei, Ibrahim AhmaduBasirka (Pol. Science), AminuAnaza (Economics) and my humble brother from the village, SadiqAbubakar Muhammad Daddare, (Alhaji) of department of History ABU Zaria.

To my Ahmadu Bello University friends from Nasarawa State, I must express my thanks to all of you. They are: TankoAbubakarAzara (Min. of Info. Lafia), Sa'aduAdamu (Min. for Youth Devt., Lafia) and AbdullahiMoh'd Kana from Keffi (M.Sc.Hydrogeology) and Malam Hassan Ibrahim (M.Sc. Library science) student.

From Geography department, I acknowledge the financial contribution of Madam Olive Sawa (Ph. D) student and moral support Mr. Stanley (M.Sc.) student.

The contributions of my family members, wives and children are never to be forgotten. Their long time patience and endurance towards this programme made this dream become true. They are MalamaHajara and MalamaZainab (wives) and Hammamata, Rahamatu, Nafisa, A'isha, Musa (Ma'aji), Salamatu and Safiya (children). Their care, patience and support gingered me to endure the rigours and stress of this programme. I must not fail to express my gratitude, gratefulness and sincere prayers to all of you in all of your endeavours. I appreciate your consistent prayers for me during our stay so far.

I also acknowledge the contribution of my brothers by name AbdullahiMoh'dOshafu and Salisu Musa Baure for their support towards me while I was away from home during my long stay in Zaria. May Allah reward them for their deeds, amin.

Finally, I wish to acknowledge the long time patience and support of the Nasarawa State government for the duration of my stay (from February,2011- October,2014) for the programme. God bless Nasarawa State, amin.

Any omission is unintentional and quite regretful.

MA'AJI USMAN MUSA (2015)

ABSTRACT

The researchproject studied the hydrogeology and groundwater quality of Lafia and environs Lafia sheet 231, NW, North Central Nigeria. This included the geology, hydrogeology, evaluation of the total groundwater reserve and water budget of the study area. Field work started with a reconnaissance survey of the study area. This was followed by a detailed geological and hydrogeological mapping. This included measurements of depth to water tables of 83 wells both at the end of dry (April) and rainy (October) seasons with their coordinates and dates recorded. Physical qualities of water such as temperatures, p^H, TDS and conductivities were measured and recorded in situ at the field.Groundwater configuration maps of both seasons were produced to show the directions of groundwater flow. A geological map with its cross-section was also produced. A total of 20 groundwater samples collected from 20 hand dug wells were analysed. The results showed that many wells have elements of pollution from residential effluents and / or organic matter.The water is suitable for drinking, domestic and other purposes as for it is within the WHO 2011 Standard for Permissible Drinking water. Higher concentrations of iron (Fe^{+3})in some wells in the analysis showed that it is derived from the geologically highly ferruginous Lafia sandstone. Photometry using V – 2000 Chemetrics Model, Flame Photometry (FES) and Titrimetry or volumetric analyses were the laboratory methods used for analysis.Results from water quality analyses were used to plot Piper diagram using aquachem 4.0 software, hence classifying these water into 3 types as Na+K-type, (HCO_3^{-2})-type and (HCO_3^{-2}) + (CO_3^{-2})-typeLafia and environs are underlain by the Asu/Awgu (shales) andLafia formations. SRTM Digital Elevation Model (DEM)of the area has been analysed and interpreted in order to determine the lineament trends,lineament density and groundwater potential across the formations in the area. The drainage pattern isstructurally controlled and mostly influences both the groundwater and surface water flowdirections in the area. Rose (azimuth-frequency) diagram of the lineaments delineated onthe digital elevation model (DEM) shows trends in the NW-SE directionsas the major trends. Lineament density maps show that thelineament density is high the Awgu (shales) andLafia formations..Areas having high lineament density representareas with relatively high groundwater potentials. Field observations agreed with theresults from the analysis of the imagery.Lafia town and environs has a total dynamic groundwater resources of 45,599.4 × 10^6 m^3/a, or 45,599,400,000 m^3/a, which can supplement surface water to meet the present and future water demand of people in the area. 2,796,020.4m^3/a, is the current maximum water demand for an estimated population of 152788 people in the study area. With the projected population of 845,604.1477 people in the next 59 years at the growth rate of 2.9 % in the study area, the demand will be 845,604.1477 people × 0.05 m^3/d which is = 42,280.20739 m^3/d or **15,474,555.9 m^3/a**. During the ultimate planning horizon when the area is expected to have well advanced and mechanized agricultural system, the demand will be = **18,569,467.08 m^3/a**. During that time the area will have a large water resources **surplus** of 455,994,000,000 m^3/a – 18,569,467,08m^a/a = **455975430500 m^3/a**.There is going to be a surplus of **455,975,430,500 m^3/a**of water deposit in Lafia and environs at the projected duration of 59 years, including agriculture. This excess is enough to satisfy the projected domestic water demand.

TABLE OF CONTENTS

Contents **Page**

LIST OF TABLES

Table **Description** **Page**

LIST OF FIGURES

LIST OF PLATES

Plate **Description** **Page**

LIST OF APPENDICES

Appendix **Description** **Page**

ACRONYMS

a.m.s.l.-- above mean sea level

cm – centimetre(s)

DTWT -- Depth to Water Table

E -- East

ft -- feet

ft.a.s.l.-- feet above sea level (ground level)

GPS -- Global Positioning System

Km^2 – Square Kilometre

Lat. – Latitude

Long. - Longitude

L/m/d -- Litre per metre per day

l/s. -- litre per second

m - Metres

m.a.s.l. –metres above sea level

m.b.g.l. – metres below ground level

mg / l - milligram per litre

*u*mhos/cm - micro mhos per centimetre

*u*S / cm – micro – Siemens per centimetre

N -- North

P^H -- Hydrogen exponent

ppm -- parts per million

SWL -- Static Water Level

T -- Coefficient of Transmissivity

TDS -- Total Dissolved Solids

W/T or w/t - Water Table

☞✎☛✓☒☛☑ 🗍

✎✌☒☑✗☚⊗☞☒✎✗✌

🗍🗐 🗍 ➮♋♌②♐⑨⑥❶⑤♒

☛❷♏⑨❺ ③⓪♎♏ ♒♏⑦♏⑤♒⑩ ⑥⑤ ❸♋⓿♏⑨ ⓿⑥ ⑩❶⑩⓿♋⓪⑤ ⓪ ⓿⑩ ③⓪❷♏③⓪♐⑥⑥♒🗐 ☒♐♏ ♒♏④♋⑤♒ ♎⑥⑨ ♌③♏♋⑤🗎 ♌③ ♏♋⑨ ♋⑤♒ ♎⑨♏⑩♐ ❸♋ter is increasing rapidly with the drastic increase in population of sub Saharan Africa or Northern Nigeria in particular. Getting adequate water supplies for drinking, domestic, agricultural and industrial activities would not be possible without sufficient groundwater, which is the most reliable of all fresh water resources (Planet earth, 2005, in Kachalla, 2011).

For the study area, the rapid population growth as well as the increase in agricultural activities of Lafia and environs led to inadequate water supply to both the people and their animals. Great awareness of the problems of potable water supply faced by the growing population in Nasarawa State brought about the establishment of the Ministry for Water Resources by the State Government in 1999. Its role is to explore, exploit and provide adequate and safe water for human and animal consumptions. This, as a matter of fact, brings about economic and social development to the people (Nasarawa State Ministry for Water Resources, Lafia, (2011).

It is in line with this problem of inadequate water supply in Nasarawa State, that this research was carried out on the “Evaluation of Groundwater Potentials in Lafia and Environs, Lafia Sheet 321, NW, Nasarawa state, North Central Nigeria.

1.2 Objectives and scope of the Study

The study is aimed at carrying out a comprehensive study of the geology, hydrogeology and groundwater potential of Lafia and its environs Lafia sheet 231 NW, Nasarawa State, North Central Nigeria. This will be achieved through the following:

i). Determine the areas of groundwater availability in the study area.

ii). Assessment of the favourable aquifer that can harness and necessitate groundwater development.

iii). Assessment of the quality of groundwater and its suitability for drinking and other uses.

iv). Providing account or estimate of calculated water budget for the study area.

1.3 Scope of the Study

This study includes reconnaissance survey of the study area; collecting of hydrometeorological and hydrogeological data; locating wells on the map using coordinates; measurements of depth to water tables both at the peak of dry and end of rainy seasons; sampling and analyses of groundwater to determine its suitability both for drinking and other domestic uses; measuring the p^H, temperatures, TDS and conductivities in situ using portable pH and TDS meters; drawing geological and water table configuration maps and directions of groundwater flow. Computing water budgets of the area.

1.4 Significance of the Study: This study will:

(i). map out the areas that have sufficient groundwater;

(ii). reveal the nature of groundwater in the area;

(iii). make proposals for water budgets in the study area

(iv). help hydrogeologists and water related disciplines in the State to know the nature and occurrence of groundwater in area;

(iv). serve as a reference to researchers for further research(s).

1.5 Statement of the Problem

Desk and field studies revealed that the present hydrogeological situations of Lafia sheet 231 NW, has not been studied. This research intends to study the hydrogeology and groundwater quality of Lafia and environs, Lafia sheet 231 NW, Nasarawa State; North Central Nigeria.

1.6 Justification of the Problem

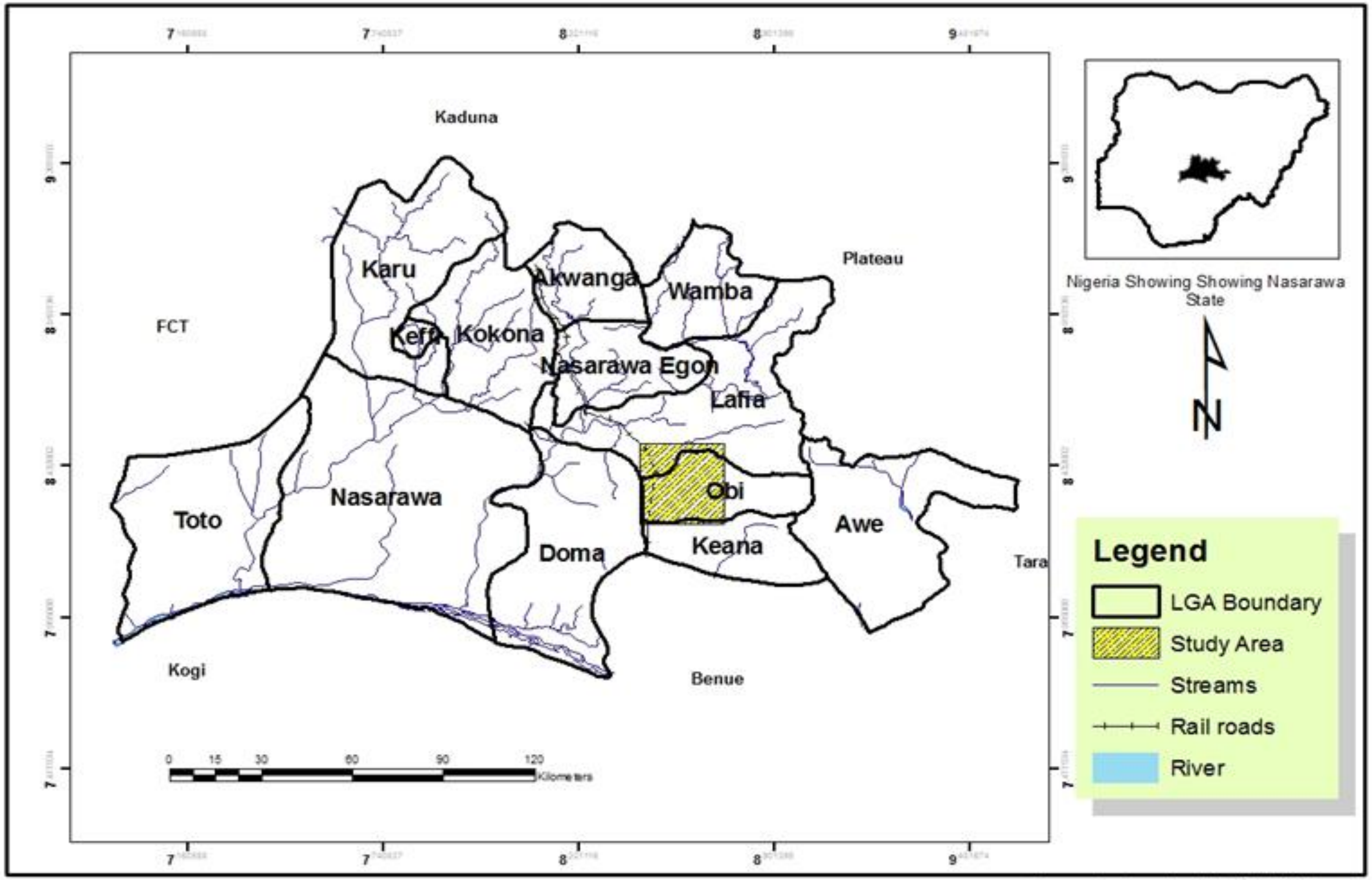
There is therefore the need for this work which intends to evaluate the aquifer potentials of Lafia and its environs, Lafia sheet 231 NW Nasarawa State. The study will lay emphasis on the aquifer potentials (quality, quantity and water budget) of the area with respect to the immense growing population mainly due to the creation of Nasarawa State in October, 1996.

1.7 Location and Accessibility of the Study Area

The study area is located within the Middle Benue Trough, North Central Nigeria on the Federal Survey of Nigeria (FSN), Lafia sheet 231 NW. It is on the scale of 1: 50,000. It is bounded by latitude 8^0 15' to 8^0 30'N and longitude 8^0 30' to 8^0 45'E. It is assessable through Lafia – Obi and Lafia – Kadarko - Makurdi roads, Nasarawa State. It covers an area of about 770 km^2 (Fig. 1.1).

The area is accessible through Lafia – Makurdi and Lafia – Awe trunk 'A' roads, and many rural roads and foot paths linking the area.

It is linked with telephone services or networks thereby making communication very easy. Rivers and annual streams form the drainage networks that cover the entire area of study.



Source: Cartography Lab. BUK (2013)

Figure 1.1: Location Map of the study area

1.8 Climate:

Nigeria is entirely situated in the tropics and is bounded by latitude 4^0N and 14^0N. The climate of the study area is dependent on the movements of the Inter-tropical Convergence Zones (ITCZ), which marks the boundary between the humid air masses of the south and the dry air masses of the north. The ITCZ moves from north to south or south to north depending on the season. In general, the humid air masses and associated rain-bearing south westerly winds dominate the area, while the dry harmattan reaches the area only occasionally in the months of December – February. Thus, there are two main seasons, the rainy season and the dry season.

The rainy season is from April to October, giving an average wet season of seven (7) months and dry season of five (5) months (Nov – April). The area enjoys a mean annual rainfall of 1,290mm–1,595.7mm (Table 1). Generally, rainfall decreases from the north to the south. The annual mean minimum temperature ranges between 21.8^0C – 22.2^0C and the annual maximum mean temperature is about 23.5^0C (Achohwora, 1986; Ariyo, 1987).

1.9 Relief and Drainage:

The area is generally undulating lowland. The highest point is 244m (above sea level) and the lowest point is 132m (above sea level).

The area is well drained by major rivers like Ashara which flows to the NW of Lafia town. Others are Agbaide, Atabula, Duduguru and Agyaragun Tofa, which all eventually drained into River Benue (Figure 1.2).

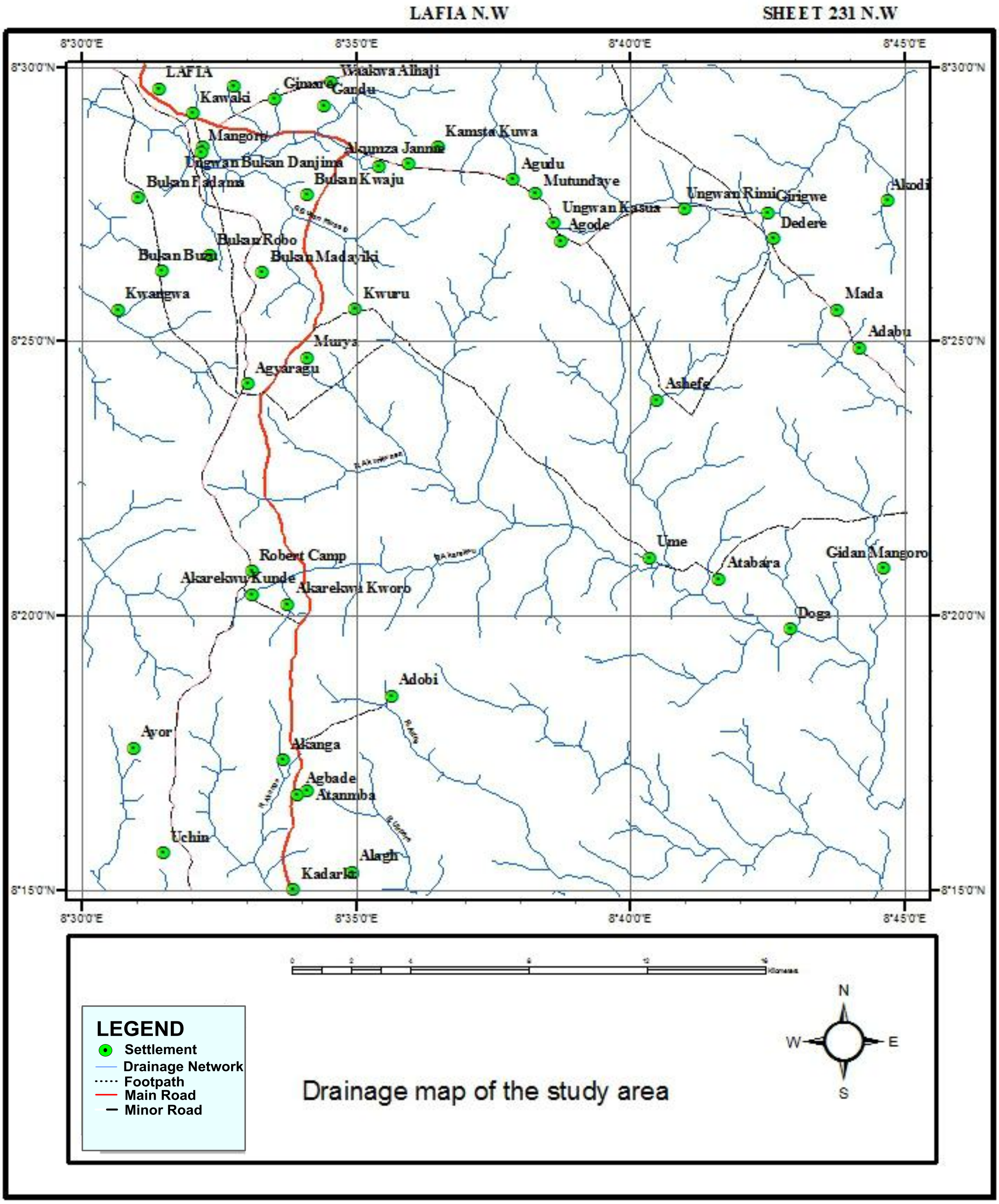


Figure 1.2: Drainage Map of the Study Area

The highest temperatures are recorded between March and April. The relative humidity ranges from 88% during the raining season to 30% during the dry season. However, the later could be lower during the dry harmattan period (NIMET, Lafia, 2012).

The tables (in appendix I) and the charts below (Figs. 1.3,1.4,1.5,1.6,1.7 and 1.8) show records of meteorological data from the years 2001 to 2011, obtained from Nigerian Meteorological Agency (NIMET), Lafia. The illustrations below give a clear picture of meteorological situations in the study area.

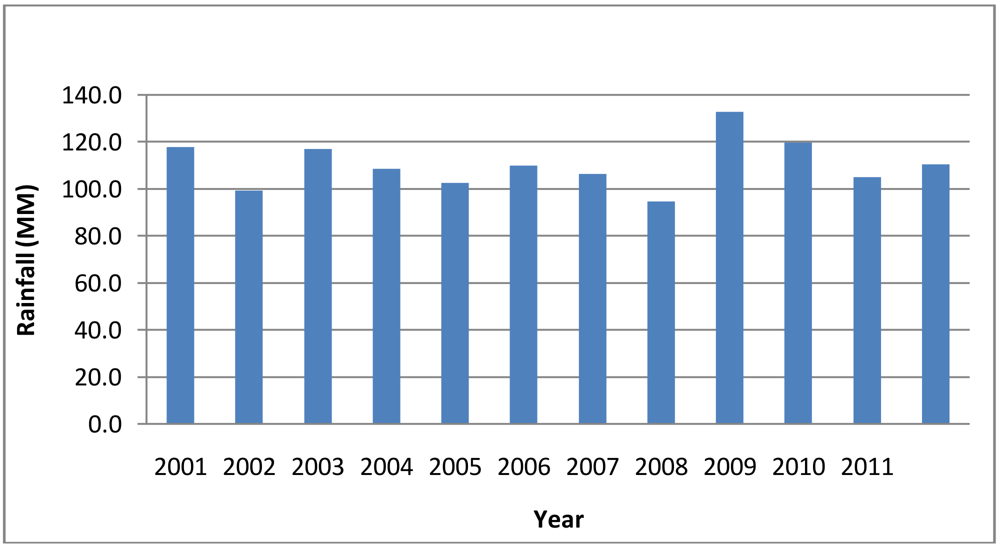


Figure 1.3: Mean Monthly Rainfall from 2001 to 2011 (Source: NIMET 2012)

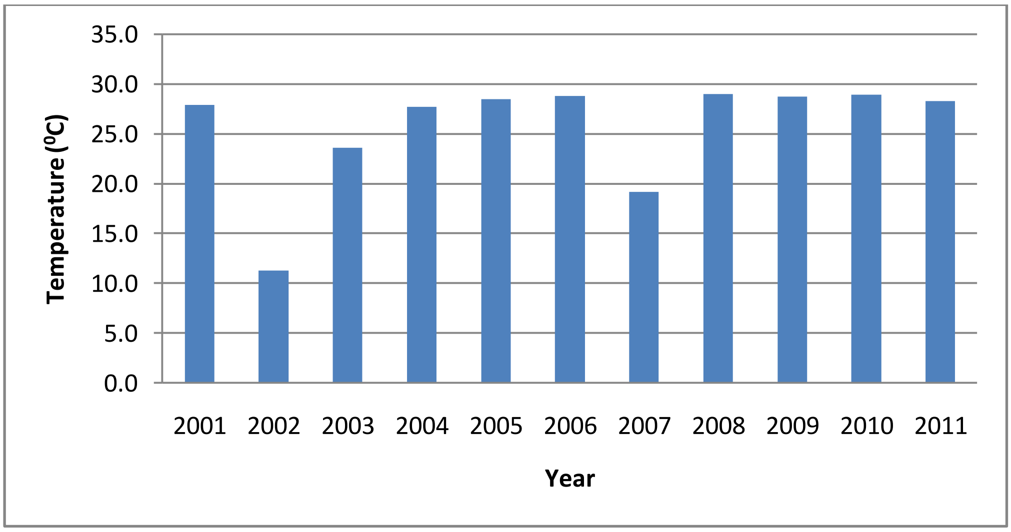


Figure 1.4: Mean Monthly Temperature (^{0}C) from 2001 to 2011

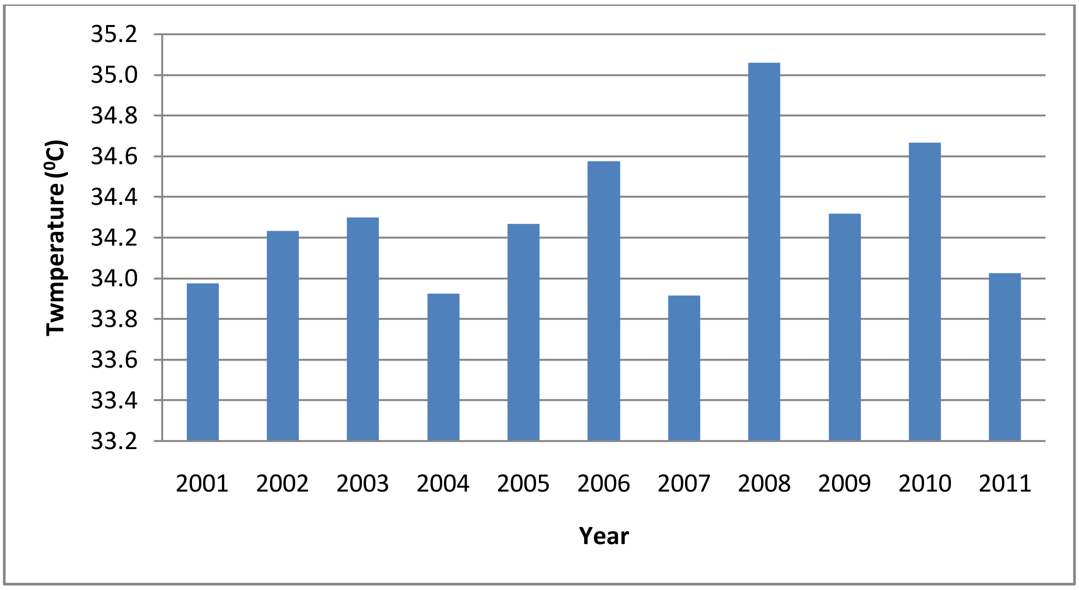


Figure 1.5: Monthly Mean Maximum Temperature (^{0}C) from 2001 to 2011 (NIMET)

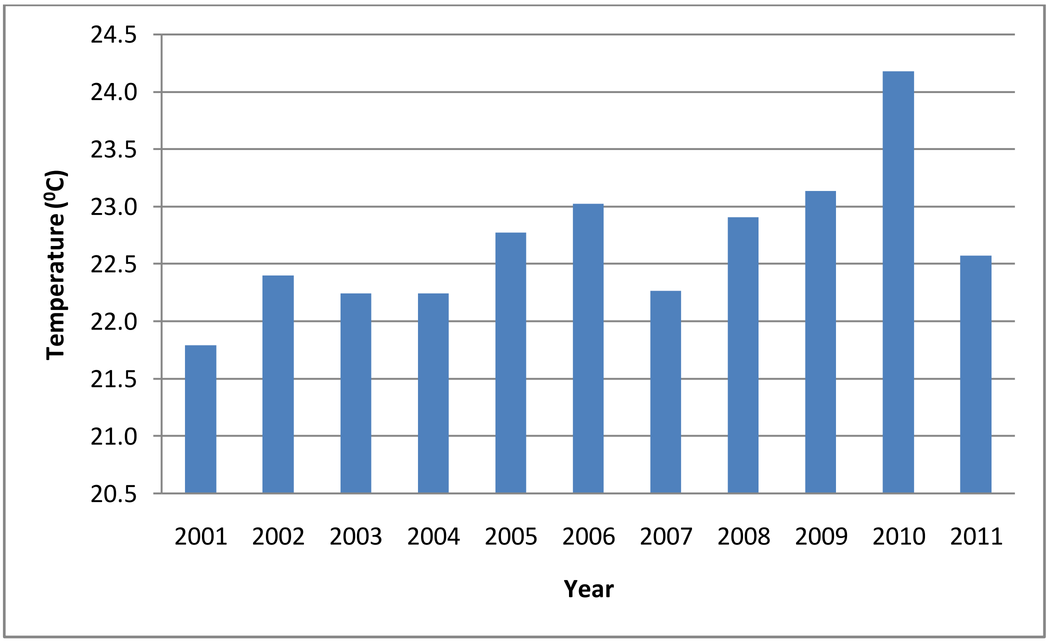


Figure 1.6: Monthly Mean Minimum Temperature (^{0}C) from 2001 to2011

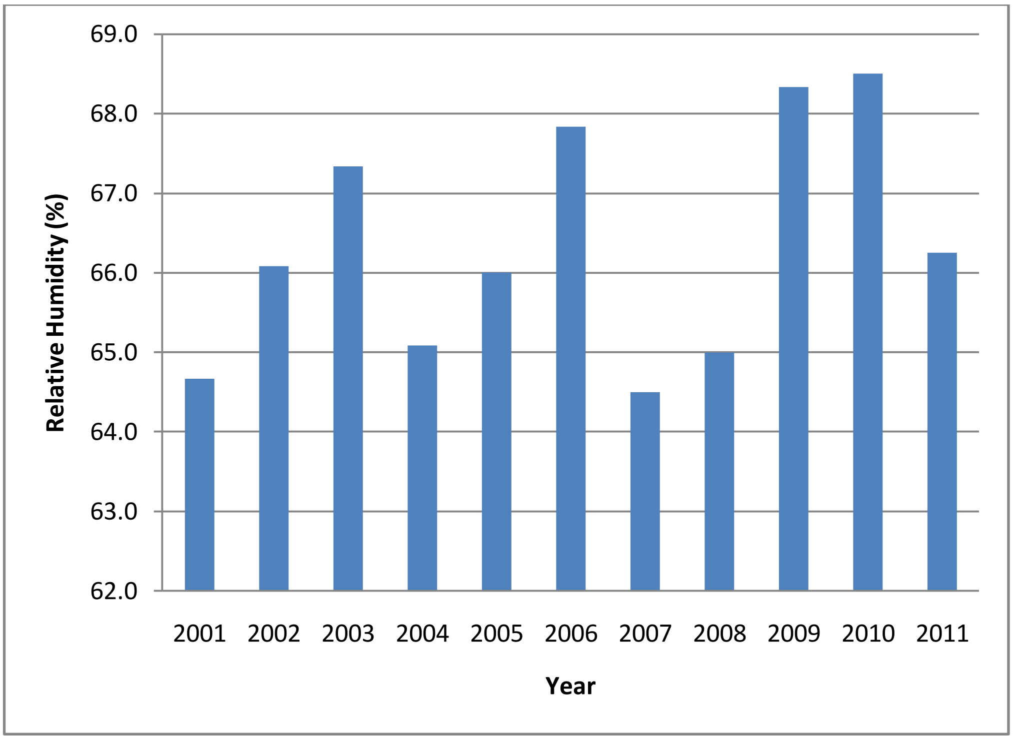


Figure 1.7: Mean Monthly Relative Humidity at 0900Z from 2001 to 2011

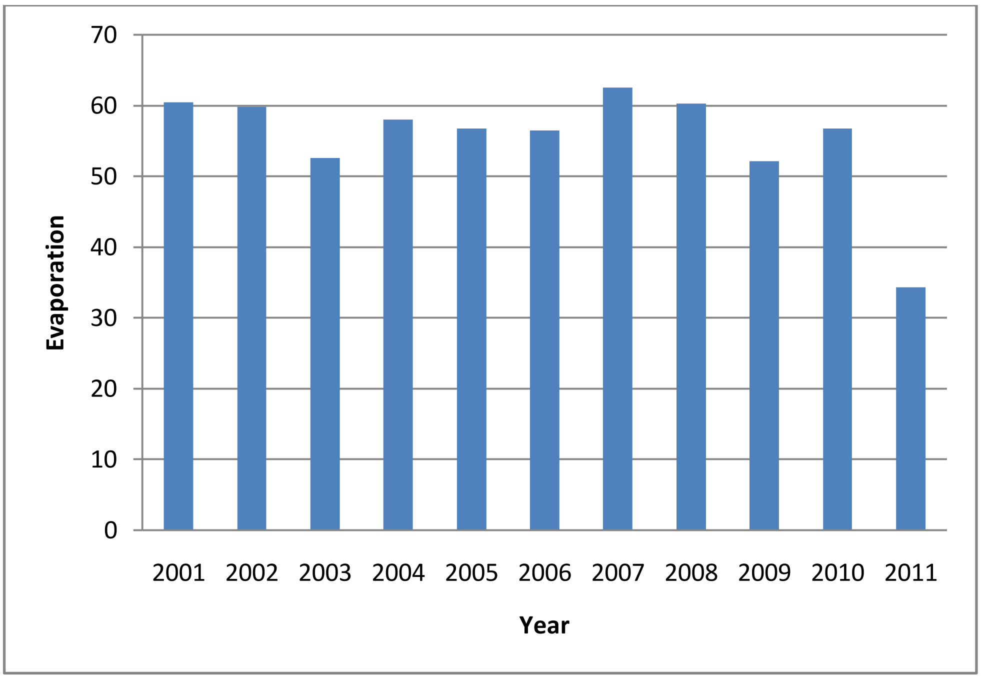


Figure 1.8: Total Annual Evaporation from 2001 to2011 (Source: NIMET, Lafia, 2012)

1.10 Vegetation:

The vegetation is typically of Guinea Savannah characterised by a transition between forest and grassland with typical transition woodland and tall grasses (along the river channels or courses). The rest of the area is covered by open savannah woodland consisting of trees and grasses of varying heights. The original vegetation has been tempered with due to human activities such as farming, bush burning and grazing, hence giving rise to a secondary forest (Achohwora, 1986 and Ariyo, 1987).

1.11 Human Geography:

The people living in this area are the Kanuris, Gwandaras, Eggons, Alagos, Migilis, Fulanis and some other minor tribes. The prominent towns and villages in this area are Lafia, Agyaragu, Agwade, Daddare, Agyaragun Tofa, Gidan Ausa, Duduguru, Ome, Atabula, Wakwa, Gandu, Akunza, Kantsakuwa, Bukan Buzu, Bukan Tambari, e.t.c.

The land is fertile hence the main occupation of people is farming. The farm products are yams, guinea corn, groundnuts, millet, cassava, maize, rice, beans, mellon, beni seed, e.t.c. The Fulanis rear cattle for beef and milk. The inhabitants of this area are known for their production of yams for which people go there from all parts of the country to buy (Achohwora, 1986 and Ariyo, 1987).

CHAPTRE 2

2.1 LITERATURE REVIEW

The study of the geology and hydrogeology of the Middle Benue Trough was to a very good extent carried out by Offodile (1976, 1983 and 2002), who made a brief survey of the water resources of the area in the light of its importance to the development of the region. A highlight of some hydrogeological characteristics of the aquifers of Lafia, Awe and Keana formations using drilled logs and water analyses of some selected wells in the area was made. An immense contribution to the geology of the area was where he worked on the "Geology of the Middle Benue Trough, Nigeria'' on a larger half degree Lafia sheet 231 NW, on a scale of 1:100,000.

Aku, (1983), studied the "Groundwater Resources of the Lafia River Catchment Area". The result found out was that the predominant sedimentary rocks are interbedded sandstones, clays and mudstones. Logs of boreholes drilled in this area placed the thickness of the continental sediments bearing water at 150 m.

Achohwora, (1986), worked on "Some Hydrogeological Aspects of the Lafia Coal Deposit Area Plateau State", (now Nasarawa State). In the work, four types of aquifers for the study area were suggested as identified by Offodile, (1976, 2002). These are; the Awe Formation, the Keana / Ezeaku formation, the Awgu Formation and the Lafia Formation (the youngest).

Ariyo, (1987), on his study of the 'Economic Significance of the Palaeontology of the Obi/Lafia Coal Field of Plateau State' (now Nasarawa State), deduced that water for domestic and industrial purposes could generally be obtained in the area by tapping the aquifers mentioned by Offodile (1976, 2002) and Achohwora (1986), and also from surface waters. It was also mentioned that in Obi village, the Lafia sandstone is sub-artesian and quite near the surface.

Borehole 133 at National Steel Council (N.S.C.) camp at Obi, the borehole at Government Teachers' college, and that which serves Obi community all tap this aquifer. Water from these boreholes is potable and therefore requires no treatment. But hydrogeological studies by National Steel Development Authority from 1973 to 1980 showed that water from shafts 1 and 2 and some boreholes in the area would need to be treated before drinking.

Bako, (2010), studied "The Geothermal Energy Potential of the Sedimentary Hydrogeological Province of Nasarawa State, Nigeria". The work examined the possibilities of utilising geothermal energy in Nasarawa State and Nigeria at large as an alternative source of energy to fuel wood.

Kana, (2012), worked on "The Hydrogeology and Water Supply Situation at Nasarawa town, Nasarawa State, North Central Nigeria.". The work made proposals for water budget and improvement of water supply and suggested possible solution to problems of inadequate water supply to Nasarawa town, Nasarawa State.

Tijani, (2004), studied the "Evolution of saline waters and brines in the Benue Trough, Nigeria". The work outlined the hydrochemical characteristics of saline groundwaters and brines in the Cretaceous Benue Trough of Nigeria with emphasis on their genetic source and hydrochemical evolution. The result revealed that hydrogen ion exponent (pH) values range from 5.1-7.5, Temperature (21^0C-32^0C, av. 28^0C) in the lower region and 22^0C-36^0C in the middle region. TDS (total dissolved solids) - 15263- 88799 mg/l, average was 43487 mg/l in the lower region and middle region, 5418- 747146 mg/l, av. 15,129 mg/l. He concluded that the saline waters are of marine origin/source.

2.2 GEOLOGY OF THE BENUE TROUGH

2.2.1 Origin and Structure of the Benue Trough

There is general acceptance of the theory of the break-up of South America and Africa at the beginning of the separation of the continents. The crystalline basement of the ancient platform was fractured, giving rise to the formation of the Benue and Abakaliki Troughs. This was followed by lateral movement of the continents and the growth of the mid – atlantic ridge. The end product of this was the incursion of the South Atlantic sea into the Benue Trough in three different transgression with accompanying retreats of the sea each of which gave rise to fills (deposition) in the basins (Achohworah, 1986). These events produced six lithological sedimentary units in the Benue Trough between the middle Cretaceous to late Cretaceous period.

The main fold trends in the Lafia – Awe area run roughly northeast – southwest to east – northeast – west – southwest with a plunge of about 8^0 – 9^0 to the southwest(210^0). The various strike trends reflect the curves of the fold axes. This effect is very obvious on the Awe Formation at Awe; the Keana Formation at Ortese and the Awgu Formation at River Dep (Offodile, 1976). The main fold elements are as follows:

The Lafia	Anticline	NW – SW
The Agyaragu	Anticline	NW – SW
The Obi	Anticline	“ “
The Giza	Syncline	“ “
The Keana	Anticline	“ “
The Tokura	Syncline	“ “

The Awe Anticline " "

The Keana anticline is the major structural feature which dominates the geology of the area. The structure is more than 100km long and extends southwards to Makurdi area.

2.2.2 Stratigraphy of the Middle Benue Trough

The history of the Benue Trough started in the Albian, with the Lafia-Keana-Awe region as the best understood part of the Middle Benue Trough. The oldest outcropping beds which occur in the core of the Keana anticline are referred to the Asu River Group (Cratchley and Jones, (1965; Offodile, 1976; Offodile and Reyment, 1977). These beds lie directly on the Precambrian Basement rock, (Zaborski, 1998).

Lying above the Asu River Group is the Awe Formation, from which brines issue out in some places. The Keana Formation overlies the Awe Formation (Offodile, 1976). The contact between the two beds is variously described as gradational and unconformable (Offodile, 1976, 1984; Offodile and Reyment , 1977; Zaborski, 1998).

Offodile (1976) and Offodile and Reyment (1977) described the Keana Formation as in places lying below beds referred to the Eze-Aku Formation. Although not directly dated, the Keana Formation has generally been regarded as late Albian to Cenonmanian. To the south, the Keana Formation passes laterally into the Makurdi Formation (Nwajide, 1985; Benkhelil, 1989). Offodile (1976) suggested the Keana Formation to be Cenomanian and Makurdi Formation to be Cenomanian to Turonian.

In the Keana - Awe area, the beds overlying the Eze-Aku Formation were referred to as the Awgu Formation by Offodile, (1976) and Offodile and Reyment, (1977), by comparing it with the Nkalagu area in the Lower Benue Trough. They suspected that the boundary between the two may be unconformable with the upper part of the Turonian being missing.

Obaje, (1994) believed the contact to be conformable and dated the Awgu Formation as Turonian to Coniacian (or Early Santonian; Table: 1)..

The Lafia Formation (Offodile, 1976), called the “Lafia Sandstone” by Cratchley and Jones (1965), comprises the youngest sediments in the southern part of the Middle Benue Trough and is confined to the “Kadarko sub-basin”. According to Zaborski (1998), it is the youngest Formation in the basin.

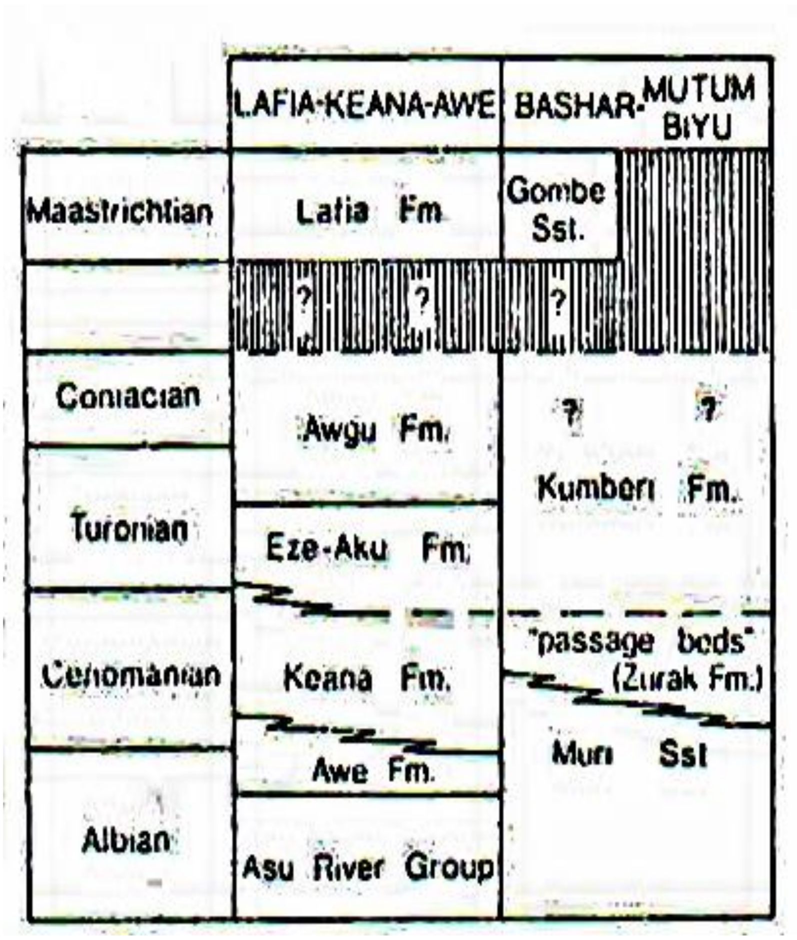


Figure 2.1: Lithostratigraphical subdivisions proposed by Cratchley and Jones, 1965; Offodile, 1976; Offodile and Reyment, 1977; Ayoola, 1981, for parts of the Middle Benue Trough (modified from Zaborski, 1998).

The study area lies within the Nigerian sector of the Middle Benue Trough (MBT) (Fig. 9). The area is part of the Lafia Formation which is the youngest lithological unit in the Middle Benue Valley, and it is underlain by the older Awgu Formation. These formations are underlain by older geological sequences consisting of the Ezeaku, Keana, Awe, and Asu River formations (Table 2.1). The formations of interest to this work are the Lafia and Awgu formations.

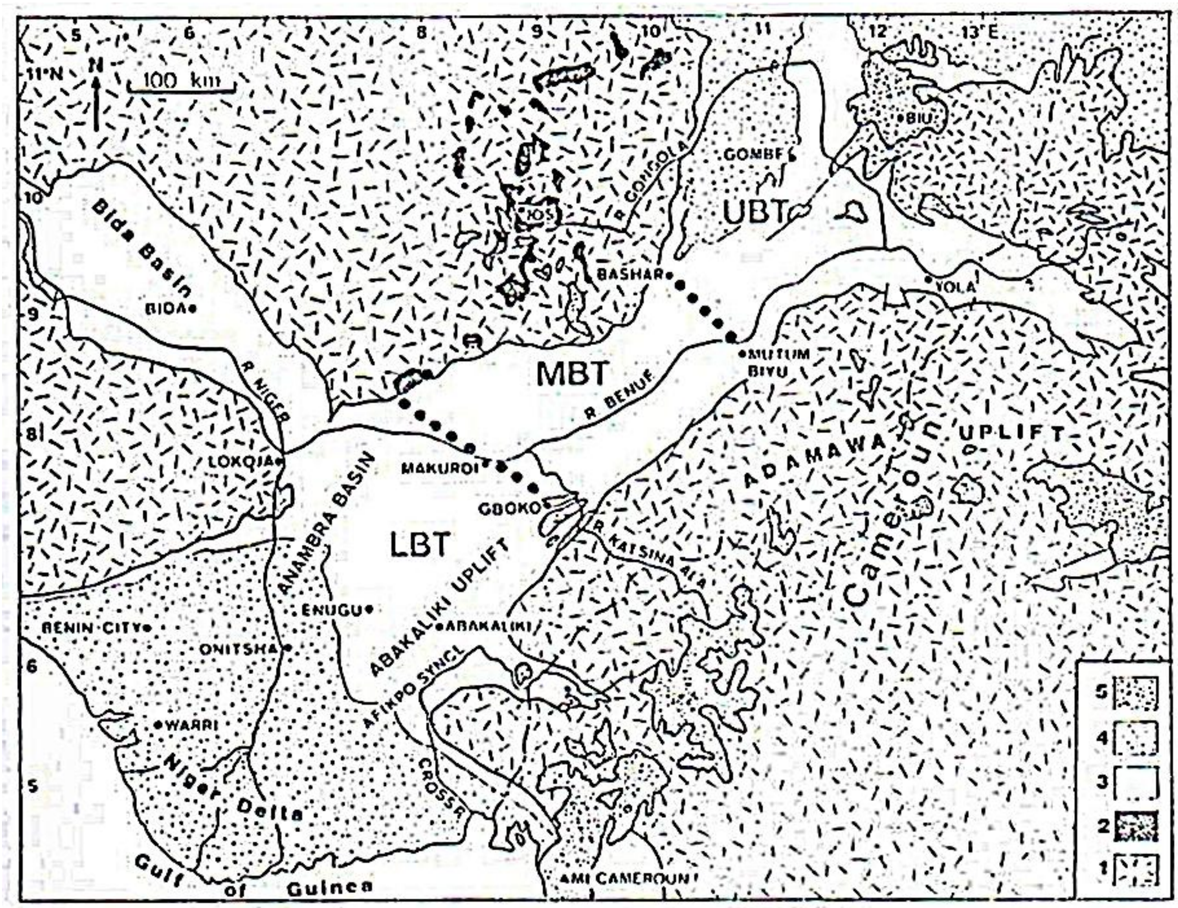


Figure 2.2: Outline geological map of the Benue Trough showing the Middle Benue Trough (MBT). Source: Zaborski, 1998.

Lithologically, the Lafia Formation consists essentially of continental ferruginized sandstones, red, loose sands, flaggy mudstones and clays. The type locality is in and around the town of Lafia, Offodile, (1976). The formation is fined to coarse grained, friable and feldspathic. It ranges in thickness from about 10m to 150m in Lafia area, and much thicker towards the southwest of the town. But to the north, around Shabu, the east and southwest, towards Daddare, Agwatashi and Giza respectively, the formation thins out. In the Lafia-Awe area, the formation seems to be wedging out and its maximum thickness hardly exceeds 50m (Offodile, 1976). Also Offodile (2002) indicated that, there is an established thickness of 150m of the sandstones, which make up the aquifer, including the top sands of the Awgu Formation.

The Lafia Formation covers thinly the Awgu Formation in the Middle Benue Valley, and occupies most areas to the west and northwest of Lafia where the study area is inclusive. Esso West Africa Inc. put its thickness at 500m-1500m, (Offodile, 1976).

The lithostratigraphic descriptions of the formations are presented as:

a). The Asu River Formation: Was deposited during the Mid- Albian marine transgression of the South Atlantic Gulf of Guinea. This formation comprises mainly limestones, shales, calcareous shales, micaceous siltstones, mudstones and clay. It crops out mainly in the anticline east of Keana town and south of Azara.

b). The Awe Formation: It was deposited as transitional beds during the late Albian-Early Cenomanian regression. The type locality is in Awe town with the thickness of about 100 m. The formation consists of flaggy, whitish and medium to coarse grained calcareous sandstones, carbonaceous shales and claystones.

c). The Keana Formation: This resulted from the Cenomanian regression which deposited fluviodeltaic sediments. It consists of cross-bedded, coarse-grain feldsparthic sandstones. The formation flanks both sides of the Keana anticline. Massive outcrops occur at Keana, Noku, Chikinye, Jangargari, Azara and Daudu.

d). The Ezeaku Formation: This is attributed to the beginning of another marine transgression in the late Cenomanian. The sediments are made up of calcareous shales, micaceous fine to medium grain friable sandstones and beds of limestone which are in places shally. The formation is exposed at Ortese, Daudu, River Noko and River Tokura.

e). The Awgu Formation: The peak of deposition of this formation was during the Late Turonian transgression, early Coniacian and terminated in early Santonian. This deposition marks the end of marine sedimentation in this part of the Benue Trough. It consists of bluish-gray to dark black carbonaceous shales, calcareous shale, shaley limestone, limestone, sandstones, siltstones and coal seams. It crops out at the bank of River Dep in Shankoli village.

f) The Lafia Formation: Is the youngest formation in the basin deposited under continental condition during the Maastrichtian. It consists of ferruginized sandstones, red loose sands, flaggy mudstones, clays and claystones. The type locality is in and around the town of Lafia where many sections occur especially along River Amba along the Lafia – Doma road. (Offodile, 1976; 2002). This can also be seen in the two lithologs A and B, in Fig. 2.3 below.

2.2.3 Review of the Hydrogeology of the Middle Benue Trough

The Middle Benue and most areas of the Benue Valley, have difficult hydrogeological situations; these conditions arise from the fact that most of the potential aquifers are either limited in extent, thinly developed with consistent clay and shale interbeddings or even so highly indurated that only the development of secondary voids created by fractures, joints and solution channels can attract hydrogeological interest (Offodile, 2002).

The occurrence of groundwater in the sedimentary rocks of Nasarawa State was studied by Offodile (1976, 2002). He found out that groundwater occur in the rocks within the following formations:

i) The Aquifer of Awe Formation

ii) The Aquifer of Makurdi / Keana and Ezeaku formations.

iii)The Aquifer of Awgu Formation and

iv) The Aquifer of Lafia Formation..

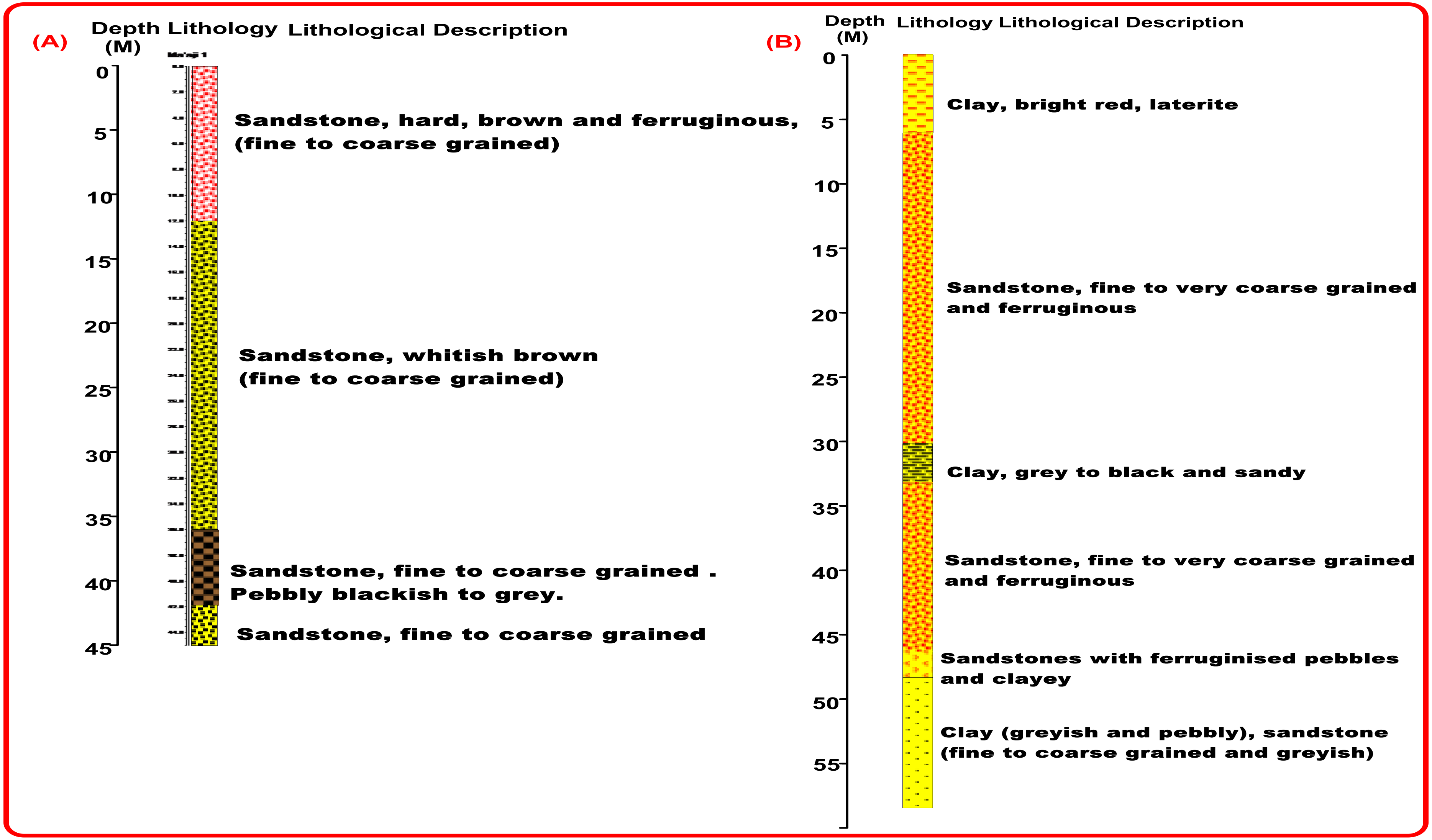


Fig. 2.3: Lithological units of the Lafia Formation in Lafia town (no co-ordinates taken); **(A** at Alkali road and **B,** behind Government House Shendam road**), (Source:** Concast Nig. Ltd. Opposite Sandaji Plaza, Bukan Sidi, Lafia**).**

2.2.3.1 The Aquifer of the Awe Formation

The Awe Formation is underlain by the Asu River Formation, known to be the oldest group of all the formations in Nigeria. The formation is made up of flaggy whitish, medium to coarse –grained sandstones inter-bedded with shales, thin limestone and clays from which brines spring up. The multi-layered beds of sandstone usually appear highly porous (confine aquifer) and yield much water contaminated by the brines from the inter-bedded shales.

Offodile (2002) reported the yields from two boreholes at Awe, one each from New Awe and Old Awe to be 3.0 l/s and 3.3 l/s respectively. By implication, the formation yields much brine or water that could not be used readily for drinking mainly due to high concentration of the brine.

2.2.3.2 Aquifer of the Makurdi / Keana and Ezeaku Formations

The Makurdi Formation is made up of highly indurated medium to coarse grained sandstones which are almost impermeable in some places and act as aquitards (poorly permeable strata with poor yield). In cases where the sandstones are well fractured or less indurated, the formation is porous, permeable and acts as an aquifer.

Offodile (2002), reported the hydraulic characteristics of boreholes from two (2) locations to be as follows:

First borehole: Depth = 79.3 m, drawdown = 31.9 m, yield (Q)= 3 l/s, SWL = 14.7 m, Coefficient of Tranmissivity (T) = 19 and Specific Capacity (Q/S) = 94 L/m/d.

Second borehole: Yield = 3 l/s, T = 29.8, Specific Capacity (Q/S) = 66 L/m/d and drawdown (s) = 5.14 m. The formations of the Makurdi/Keana and Ezeaku are very useful as aquifers. The Sandstones are used as potential reservoirs of groundwater. This depends on secondary permeability which results from fracturing and weathering.

2.2.3.3 Aquifer of the Awgu Formation

The formation is made up of greybedded shales with occasional sandstone beds and limestones. The sandstone beds are usually fine to coarse-grained. Where coarse grained, they are very permeable and bear water. But it is often limited in thickness and lateral extent, hence reducing the groundwater potential. Most boreholes drilled into the Awgu Formation were for coal exploration purposes. It is restricted to Obi and Agwatashi areas and indication of yields or pumping test data can be cited.

Offodile (2002) reported that a borehole drilled in Assakio east of Lafia coincided with artesian water table having a depth of 150 m and yields 3.0 litre/sec with a head of 1.5m above ground level.

2.2.3.4 Aquifer of the Lafia Formation:

The Lafia Formation comprises mainly sandstones that overlie the Awgu Formation. It is fine to coarse grained, highly porous and permeable. At the point of contact between the Lafia Formation the underlying Awgu Formation which is less permeable, many springs outcrop which gives rise to a watershed. Drilling of boreholes enabled the assessment of groundwater potential of the area. Offodile (2002) reported averages of some borehole characteristics to be: Yield = 4.2 l/s, SWL = 8.13 m, draw down = 15.5 m and depth = 152 m.

Table: 2.1 Summary of aquifer characteristics of the sedimentary aquifers of the Middle Benue Trough in Nasarawa State. (**Source:** Nasarawa State Ministry for Resources, Lafia, (2011) and Offodile, (2002).

S/No	Aquifer / Borehole No.	Yield (l/s)	Depth (m)	SWL (m)	Drawdown (s)	Spec. Cap (l/m/d)	Coeff. of Trans.(T)
1	Awe Formation Borehole Nos. 1 & 2	3.0 & 3.3	-	- -	- -	- -	- -
2	Makd / Keana / Ezeaku						
	Borehole No. 1.	3.0	79.3	14.7	31.9	94	19
	Borehole No. 2	3.0	-	-	5.14	66	29.8
3	Awgu Formation	0.3	150	1.5	-	-	-
4	Lafia Formation	4.2	152	8.13	15.5	-	-

2.2.4 Geology of the Study Area

The area studied has three (3) lithologic formations comprising the Asu (at the south-west), Awgu (at the centre) and Lafia Formations at the northern and south-eastern part (Fig. 2.2).

The Asu Formation: This Formation comprises mainly shales and mudstones. Others include limestones, shales, calcareous, micaceous siltstones and clay.

The Awgu Formation: It is mainly made up of shales and limestones. Other constituents are bluish-gray to dark black carbonaceous shales, calcareous shale, shally limestones, limestones, sandstones, siltstones and coal seams.

The Lafia Formation: Is the youngest Formation in the basin deposited under continental condition. It consists of essentially ferruginized sandstones and red loose sands. Others are flaggy mudstones, clays and claystones. The type locality is in and around the town of Lafia.

Geological map: A topographical map of the study area on a scale of 1: 50, 000 was used as a base map to produce the geological map (Fig.2.2) with their lithological boundaries.

Geological Cross-section: Two points A-B were joined with a straight line cutting across the three rock types to show the cross-sectional view of the sub-surface lithologies (Fig. 2.2).

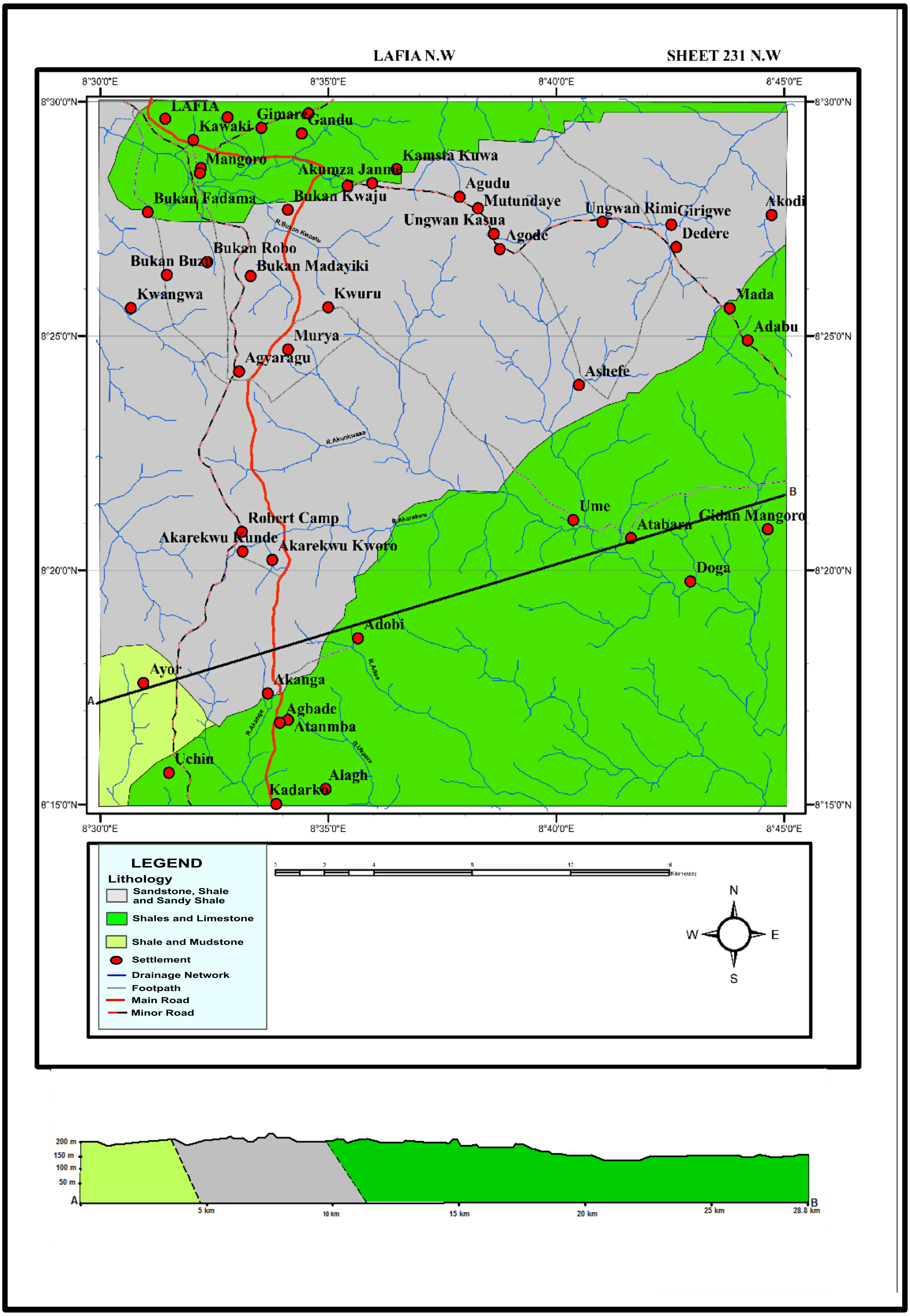


Figure 2.4: Geological and cross-sectional view of the study area **(**adopted from Geological Survey of Nigeria, 2006**).**

2.2.6 Hydrogeology of the Study Area

The area of study lies mostly within the Lafia Formation and partly covers the Agwu formation. Groundwater availability in the sedimentary rocks greatly depends on the degree of porosity and permeability of the rocks.

The aquifers found within the sedimentary rocks of the study area are:

2.2.7.1 Aquifer of the Lafia Formation

The aquifer of the Lafia Formation is a fresh water sedimentary sequence of Maastrichtian age (youngest), containing much groundwater. It covers areas at the western part of Lafia including: Tudun Kauri, Agyaragun Tofa, Bukan Buzu, Bukan Fadama, Agyaragu Station, Gwadenye, Tudun Kwashini, Wakwa, Gandu, Mararba Akunza, Bukan Kwato and Akunza. The Lafia Formation is highly permeable and gives rise to several springs (or marshy areas) called *fadama* at its contact with the less permeable underlying Awgu Formation. At the *fadama* area, irrigation farming is the major practice all year round. It extends to its contact with the Awgu Formation at about 2 km to Daddare town The thickness of the sandstone aquifer is established to be 150 m (Offodile, 2002).

2.2.7.2 The Lafia Formation Deep and Shallow Aquifers

The depth of aquifers in Lafia formation within the study area varies. Deep aquifers or Confined aquifers of this formation could only be found in borehole as in Lafia stadium and are encountered below 50 m (Table 2). Shallow aquifers or water table aquifers are found between 6 – 20 m at Unguwar Mamman and near Daddare (Appendix IX). These shallow aquifers are tapped predominantly by hand dug wells in the study area. This then implies that some areas are deep aquifers.

2.2.7.3 Aquifer of the Awgu Formation

The Awgu Formation which bears less water during the dry seasons covers areas like Daddare, Tudun Adabu and Adabu at the south-eastern part of the studied area. At about 2.5 km from Daddare, the Lafia Sandstone only thinly covers the underlying Older Awgu Formation which is much thicker and is reported to be up to 700m (Offodile, 1976 and 2002). This formation consists of siltstones, sandstones and various types of shales which bear little quantity of water

CHAPTER 3

MATERIALS AND METHODS

This chapter describes the study design, sampling methods and the techniques used in data collection and analysis.

Materials: A topographical map, GPS, measuring tape, portable pH and TDS meters were used for geological investigation / mapping.

3.2 Topographical Map of the study Area

A topographical map of the study area on a scale of 1: 50, 000 was used as a base map for this study. A geological map of the study area and its cross – section (Figure 2.2) was produced from it in which lithological boundaries with their thicknesses were delineated.

3.3 Method of Investigation

3.3.1 Desk Study:

This includes searching, collecting and reviewing of existing related and relevant literatures such as bulletins, journals, text books, geological and topographical maps.

3.3.2 Hydrogeological Investigation

This was done in three stages. These include: field work, laboratory analysis and evaluation of field and laboratory data. A total of 20 groundwater samples were collected from hand dug wells (8^{0}26’59.5”N, 8^{0}42’23.2”E; 8^{0}27’27.0”N, 08^{0}40’50.6”E; 8^{0}25’07.2”N, 08^{0}40’04.5”E; 8^{0}27’54.6”N, 08^{0}37’35.9”E; 8^{0}28’07.4”N, 08^{0}35’59.6”E; 8^{0}22’37.3”N, 08^{0}36’52.3”E; 8^{0}24’55.2”N, 08^{0}44’02.9”E; 8^{0}23’49.0”N, 08^{0}31’38.0”E; 8^{0}24’57.0”N, 08^{0}35’31.4”E; 8^{0}26’17.3”N, 08^{0}34’20.9”E; 8^{0}29’47.0”N, 08^{0}34’31.5”E; 8^{0}29’27.2”N, 08^{0}33’27.1”E; 8^{0}29’39.0”N, 08^{0}32’46.8”E; 8^{0}28’53.7”N, 08^{0}32’09.8”E; 8^{0}26’39.5”N, 08^{0}32’39.0”E;

$8^{0}26^{'}17.7$”N, $08^{0}31^{'}19.1$”E; $8^{0}27^{'}23.0$”N, $08^{0}34^{'}12.2$”E;. $8^{0}21^{'}13.3$”N, $08^{0}41^{'}41.3$”E; $8^{0}23^{'}59.5$”N, $08^{0}33^{'}03.3$”E; $8^{0}23^{'}01.8$”N, $08^{0}30^{'}55.3$”E). These were used to analyse for the chemical contents in order to establish the qualities of groundwater. The field work covered a period of about seven months (October, 2012 – April, 2013) during which data were obtained. This period included both the end of rainy season (October), and the end of dry season (April).

3.4 FIELD WORK

3.4.1 Reconnaissance survey: Reconnaissance survey of the study area was carried out essentially to acquaint the researcher with the topography of the study area. The survey was made to map out existing rivers, boreholes and hand dug wells in the area.

3.4.2 Collection of Hydrogeological Data

This was also done in stages which include field work and interpretation of results, and was undertaken as described below.

3.4.2.1 Location of wells on map:

Wells were located on the map of the study area using the coordinates obtained with the aid of the G.P.S. from the field using a paper co-ordinator. This process starts by gridding the entire map both latitudinal and longitudinally into one minute each.

3.4.2.2 Measurements of water levels:

Measurements of depths to water table at both the peak of dry and end of rainy seasons were carried out by using a thirty meter (100 ft) measuring tape to measure the water levels in wells. This was achieved successfully by tying a heavy object to the tip of the tape in order to straighten it. The tape was then lowered into the wells until it makes contact with the water inside the well and this is achieved or attained when ripples were noticed or observed at the time of contact. At this point, the length of the tape was recorded as the depth to water table after subtracting the elevation of objects or additional construction placed on top of the well to protect the water in the well (Plate 1).

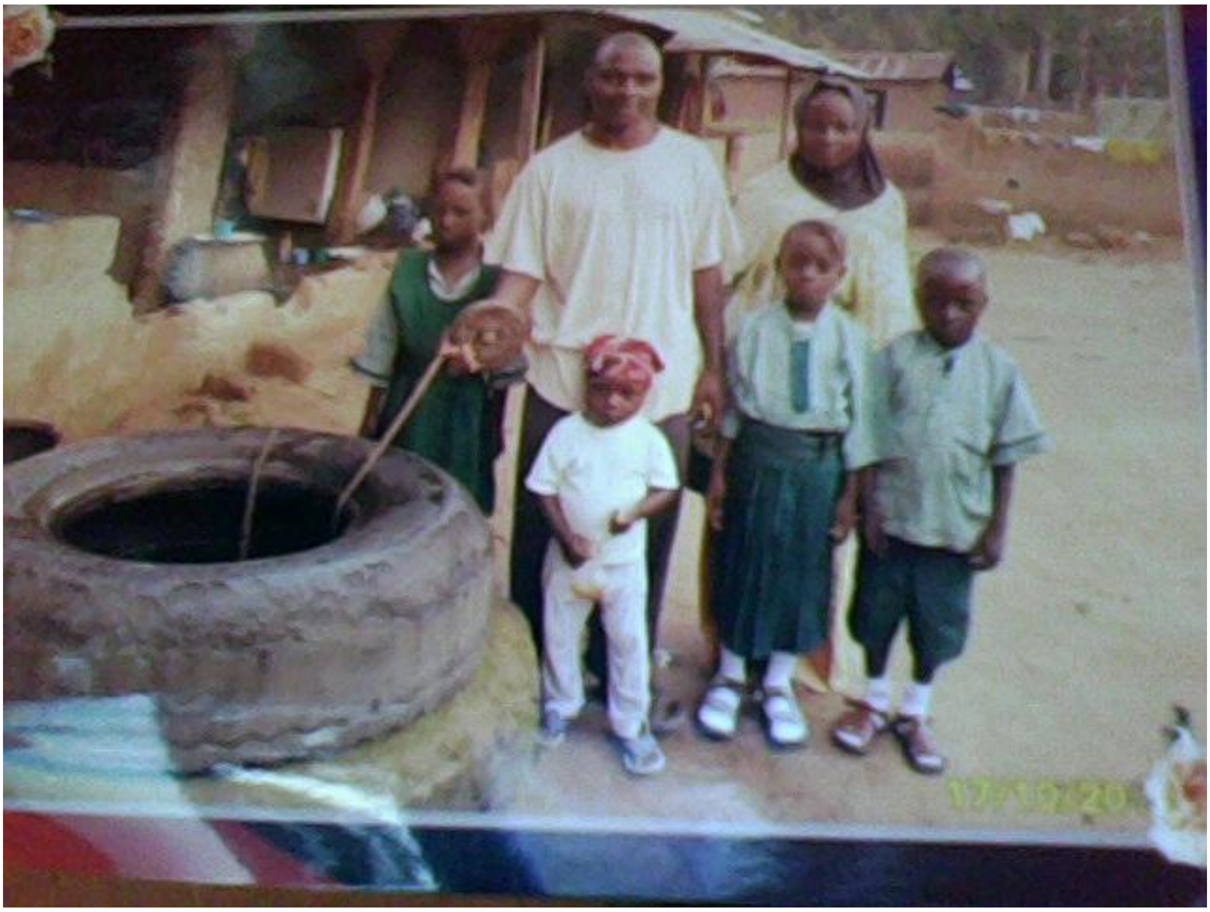


Plate 3.1: Measuring the depth to water table at the peak of rainy season (Pix: Ma'aji 17/10/2011). Co-ordinates: Lat. 08^{0}42'23.2"N, Long. 08^{0}26'59.5"E

3.4.2.3 pH, temperatures, TDS and conductivity:

These measurements were made by fetching water in a clean clear container and inserting these instruments into the water at different time, and then the respective measurements were taken.

Measuring and recording the pH, temperatures, TDS and conductivity of water in situ using portable pH and TDS meters, and taking the time and dates at the points respectively.

To measure the pH, the pH meter was first calibrated to zero (0. 00) reading. Some water sample was collected in a plastic bowl rinsed with the water from well. The calibrated metre was then inserted into the water in the container which starts to read instantly till it stabilises. The static reading was taken to be the pH of that water.

The total dissolved solids (TDS) were also measured in situ. The TDS metre was calibrated to zero (0) reading before taking the reading. This was determined by inserting the TDS probe into the water in the container to start reading immediately and to stabilise at a particular reading which was recorded to be the TDS reading.

Temperature readings were also recorded in situ from the TDS meter.

The conductivity of water sample was determined by multiplying the total dissolved solids by a factor of 0.7 to give the resultant value in micro-Siemens / cm.

3.4.2.4 Collection of water samples: Water samples were collected in-situ from 20 selected hand dug wells in clean and rinsed 1(one) litre plastic containers for analysis. A plastic bailer (a container used for fetching water in the well) was used to fetch water from wells into the sample container at every location.

The samples were collected from 20 wells within the study area and were acidified with 1ml – 2ml concentrated HNO_3. The sample bottles were filled with water to remove air space and tightly fitted with cork and new white cellophane, covered with caps.

3.5 LABORATORY WORK

3.5.1 Water Sample Analysis: The quality of the collected and acidified water from wells were analysed at the Centre for Energy Research and Training (CERT), ABU Zaria, and the Department of Water Resources and Environmental Engineering, ABU, Zaria, respectively.

Concentrations of major anions including chloride (Cl^-), sulphate (SO_4^{-2}), bicarbonate (HCO_3^{-2}) and nitrate (NO_3^{-2}) and cations such as calcium (Ca^{+2}), copper (Cu^{+2}), sodium (Na^+), potassium (K^+), iron (Fe^{+3}), manganese (Mn^{+2}), magnesium (Mg^{+2}), ammonia ($NH^+{}_3$) and Zinc (Zn^{+2}), were determined using Photometer (V-2000 – Chemetrics Model), flame photometer and volumetric analyses.

3.5.2 Analytical Procedures

3.5.2.1 Photometric Method: Analyses for Copper, Iron, Manganese, Zinc, Chloride, Ammonia, Nitrate, were carried out using a Photometer (V - 2000 Chemetrics Model) and Sodium, Potassium and Calcium were done by Flame Emission Spectrometry. Those of Bicarbonate, Sulphate and Magnesium were done by volumetric analysis.

For photometric analysis (V-2000), the first step started with the calibration of the photometer with a standard (i.e. a cylindrical ampoule to 0.00 reading using the various codes for the elements to be analysed. The codes for some individual elements were used as follows:

Fe = 101, Cu = 55, Cl = 26, Zn = 187, Mn = 110, NO_3 = 120. A small measuring cylinder was first rinsed with distilled water, then rinse again with the water sample to remove any impurity. For each element, 25 mls of water sample was measured into the cylinder and then 1 vacu-vial (self filling Ampoules for Photometric Analysis) was then snapped / broken in the cylinder containing the 25ml of the water sample. The vacu - vials automatically sucks the water sample in the measuring cylinder and mixed with its content. The vacu-vial was then shaken well with the bubble inside it. The vacu-vials was cleaned with a neat cloth and then put into the photometer whose button was turned on to show the reading on the screen of the instrument. In determining some of these ions, some particular indicators or activators were added to the water sample as can be seen in Table 3.

Table 3.1: Parameters for analysis of Cations and Anions in water samples

(Source: Laboratory Analysis, 2012)

Anion / Cation	Code	Vol. of sample used	Activator/Indicator or vacu-vial Ampoules used	Method of Analysis used	Instrument(s) Used
Na^+	None	25 ml	Standard Na Solution	Flame Photometry	Flame photometer
K^+	"	25 ml	" K solution	"	"
Ca^+	"	25 ml	" Ca solution	"	"
Fe^{+3}	101	25 ml	1 Ampoule of Fe & K – 6003	Photometry	Photometer V - 2000 Chemetrics
Cu^{+2}	55	25 ml	1 Ampoule of Cu & K – 6003	"	"
Zn^{2+}	187	25 ml	8 drops of A- 9903 & 1Ampoule of Zn	"	"
NH^+_3		25 ml	2 drops of stabilizer solution	"	"
Mn^{+2}	110	20 ml	1 ml of A-6501 & 1 Ampoule of Mn	"	"
NO_3^{-2}	120	15 ml	1 foil Cd crystals	"	"
Cl^-	26	20 ml	1 ml of A-2100 & 1 Ampoule of Cl	"	"
$HCO_3^=$	None	25 ml	EDTA	Volumetric analysis	Burette/pipette
SO_4^{-2}	"	25 ml	"	"	"
Mg^{+2}		25 ml	"	"	"

3.5.2.2 Flame Photometry

The basic principle of flame emission is such that, a sample in liquid form is presented to a Nebulizer which delivers a quantity of the sample as a fine aerosol into a mixing chamber where it is combined and mixed with fuel. The mixture of aerosol and fuel is directed to a burner where it is ignited and allowed to burn. The flame is position in a simple optical chamber where the emission from the flame is collected and directed through an optical filter system and onto a light detection device. The intensity of the light falling on the detector is measured and displayed on a meter. By selection of a suitable filter and calibration of the flame emission spectrometer (FES) with known standard solutions, the instrument is calibrated and set up to read unknown samples.

Setting Up and Running Flame Emission Spectrometer (FES)

In the flame, individual atoms absorb energy and depending on the amount of energy available and element in question, a degree of ionization occurs. The hotter the flame, the more ionization will take place. Some elements are more easily ionized than others, as Potassium is much more easily ionized than Magnesium and is more sensitive in FES.

Operating the Flame Photometer

The Flame Photometer is designed to measure the concentration of certain elements like Sodium (Na), Potassium (K) and Calcium (Ca).

The guide lines for using the flame photometer are as follows:

1. Turn the power switch to ON and let the instrument warm up for 10 minutes.
2. Check to see that the drain siphon has been filled and is functioning satisfactorily.
3. Open the gas valve and light the flame through the side panel.
4. Immediately, open the air valve slightly and adjust the air to 10 Psi.
5. Without aspirating the sample, adjust the flame so that the cones are 0.5cm high. Leave on for 5 minutes to stabilize conditions.
6. Turn sensitivity control fully counter clockwise.
7. Select the appropriate filter using the filter selection knob.

8. Aspirate a sample blank or zero standard and adjust the light spot to zero using the mechanical zero adjustment.
9. Using the combination standards, aspirate 10*u*g Na/ml at 100%using the sensitivity control. Aspirate 6*u*g Na/ml and set at 60%. (Prepare a standard curve for each and plot)
10. Aspirate the sample and check with a standard every 33 samples. Make sure that the zero (0) standard is used for calibration.

Shutting Down Procedure

1. Flush the atomizer with at least 10ml of distilled water.
2. Remove aspiration tube from the water.
3. Switch off the galvanometer.
4. Turn off the gas at the tank and wait for the flame to go off.
5. Turn off air compressor. (Najime, 2010).

3.5.2.3 Titration (Volumetric Analysis): Titration is a common laboratory method of quantitative chemical analysis that is used to determine the unknown concentration of a known reactant.

A reagent called the titrant or titrator, of known concentration (a standard solution) and volume is used to react with a solution of the analyte or titrand, whose concentration is not known. Using a calibrated burette to add the titrant, it is possible to determine the exact amount that has been consumed when the endpoint is reached.

This was the method used for the determination of the concentrations of bicarbonate (HCO_3), magnesium (Mg) and sulphate (SO_4) in each sample which involved the addition of a reactant (EDTA) to the solution (water sample) being analyzed until some equivalence point is reached. In this process, water sample was put into the burette using the funnel. The meniscus of the water in the burette was calibrated to zero reading (0) after removing the funnel. The water was then titrated against a solution of a known standard of HCO_3, Mg and SO_4 each. During the titration, the point of reading where a permanent change in colour was observed marks the concentration of each element or ion in the water sample.

Complexometric titrations are based on the formation of a complex between the analyte and the titrant. The chelating agent EDTA is commonly used to titrate metal ions in solution. These titrations generally require specialised indicators that form weaker complexes with the analyte. Eriochrome Black T was used for the titration of magnesium (Mg) in this study. (Najime, 2010).

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 HAND DUG WELLS IN THE STUDY AREA

Figure 4.1 shows the plot of the distribution of hand dug wells and streams used in this study. All the hand dug wells located at the end of rainy season (October) were useful because they are recharged from rainfall which infiltrates and percolates into the aquifer. The wells have water available for domestic and personal uses. At the peak of dry season (April), most wells visited were almost dry. This is most probably because, they only tap their water from the overburden aquifer, or rather, the shallow part of the Lafia Formation. In other words, the depth of the wells are not deep enough to tap the confined aquifer of Lafia Formation. The wells dug on the areas where the Lafia Formation thins out tap their water from the stream at the contact between the Awgu and Lafia formations. They contain enough water for drinking and domestic uses even during the dry season. Only the wells located on the Lafia formation have enough water issuing out from the confined aquifer starting from 50 m - 150 m metres below the ground surface downwards. The depth to water table in some wells at the point of contact between the Lafia and Awgu formations are shallow to the depth of about 3m during the rainy season and 5m at the end of dry season. A hand dug pit of about 2m deep along the river channel yielded much quantity of water during the dry season.

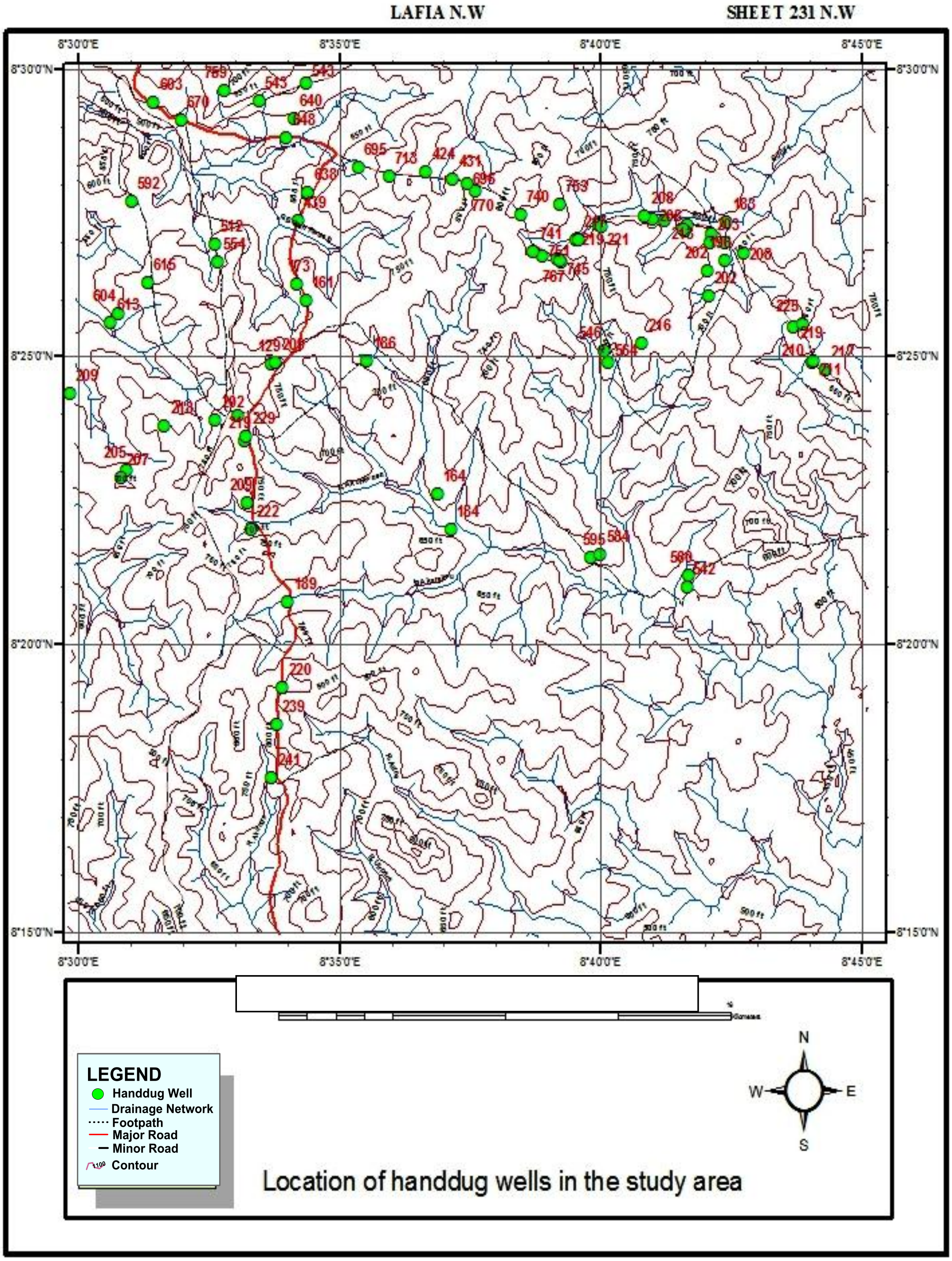


Figure 4.1: Plot of the distribution of hand dug wells in the study area.

4.2 FIELD DATA EVALUATION:

Results of groundwater level measurements obtained from the field were used in the construction of the water table configuration maps.

4.2.1 Water Table Configuration Map

Hand dug wells were located on the topographical map of the study area with their respective values of water level elevations (masl) above sea level plotted against each of the wells. These values of depths to water table measured consist of both the end of dry and end of rainy seasons and were subtracted from the elevations of the areas of the wells to obtain the elevation of the water table (amsl) for each of the wells. The elevation of water table for each of the wells is used in plotting the water table configuration map showing the direction for groundwater flow for both dry and rainy seasons. In other words, a hydrogeological map was produced by manual contouring of points of equal elevation to produce the water table configuration maps (Figs. 4.2 and 4.3).

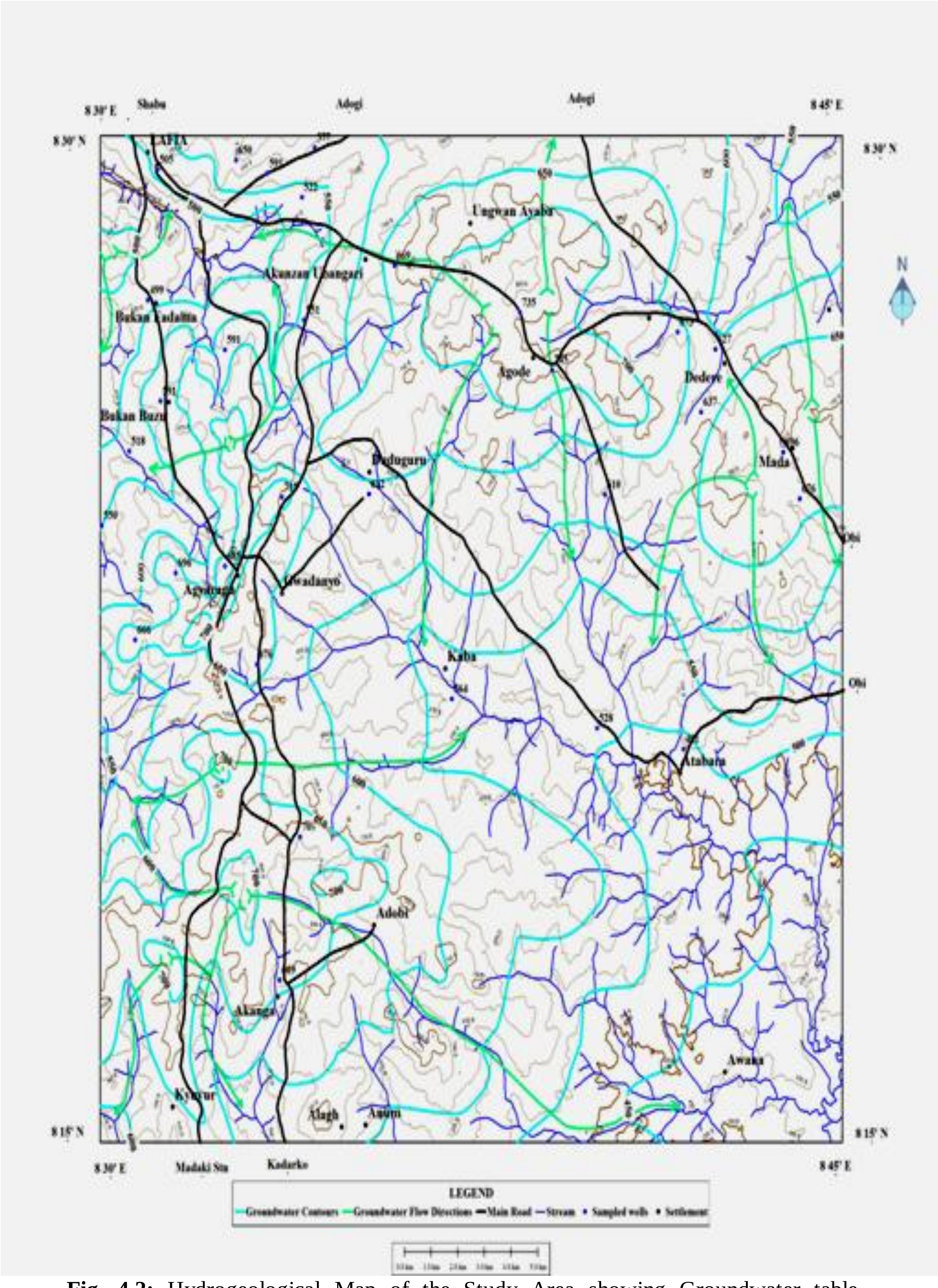


Fig. 4.2: Hydrogeological Map of the Study Area showing Groundwater table Configuration and directions of groundwater flow at the end of dry season

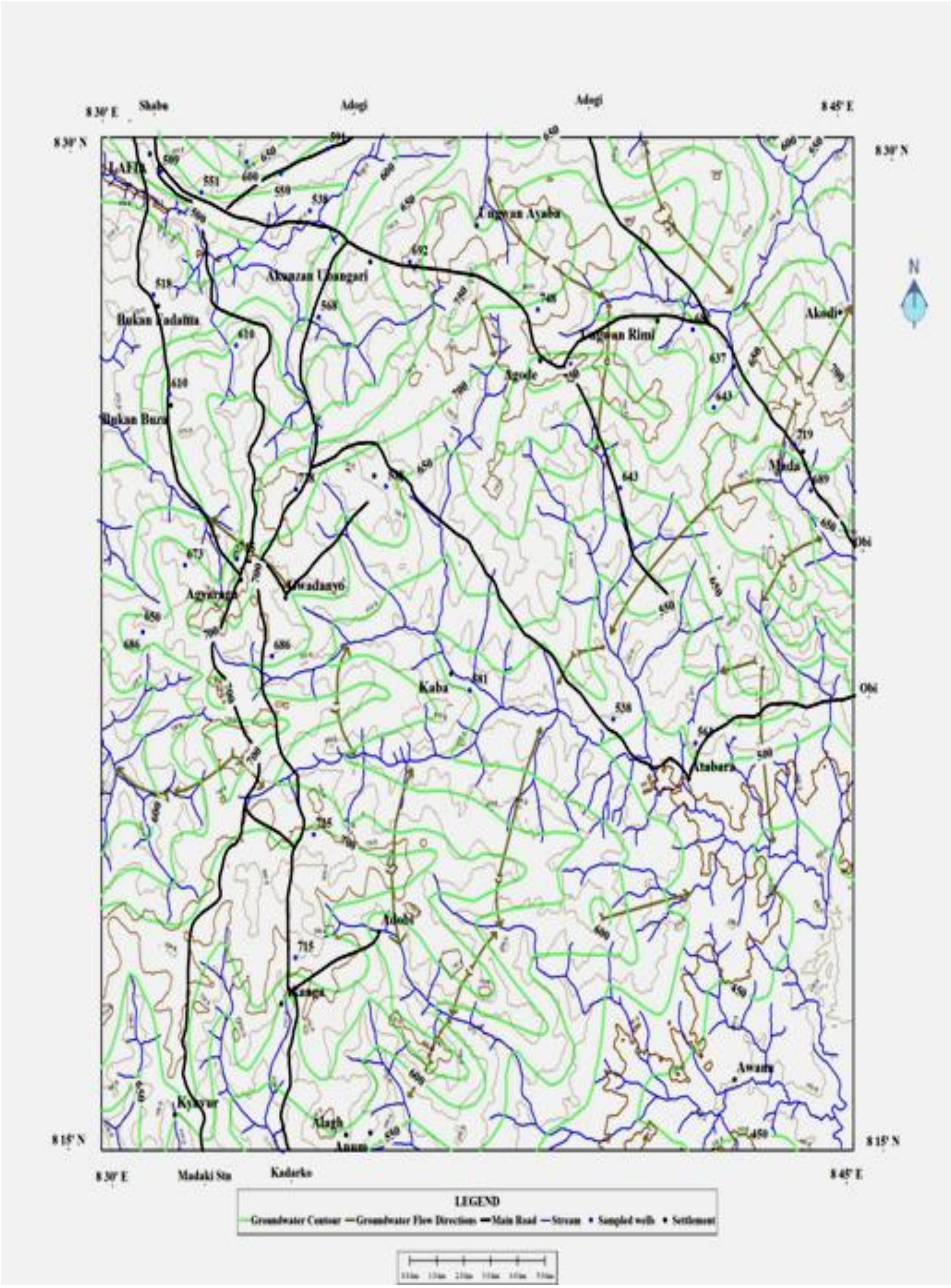


Fig.4.3: Hydrogeological Map of the Study Area showing Groundwater table Configuration and directions of groundwater flow at the end of rainy season

4.2.2 Direction of Groundwater Flow

The measurements of the depths to water table done both at the end of dry and end of rainy seasons reveal that most of the hand dug wells in the area of study are shallow. Empirically, of the 83 hand dug wells measured, only 9 (nine) of them are between 10.2 meters to 30 meters deep. The rest of the 74 wells are shallow, ranging from 0 (zero) meter to 10 meters deep. In the area of study, the average depth to water table at the end of rainy season was 4.7 meters below ground level (b.g.l.). (Appendix VII).

Groundwater occurrence results from recharge by falling rainfall or precipitation which flows laterally after percolation towards the streams, river channels and wells. This is indicated by arrows drawn perpendicularly to equipotential lines which tend to diverge from the recharge areas and converge towards the drainage channels as shown in figures 4.2 and 4.3 (Appendix).

4.2.3 Recharge in the study area

The recharge of groundwater in this study area is by direct infiltration from rain water; this passes through the unsaturated zone into the saturated zone which in turn stores water.

During the rainy season, the recharge of the water table aquifer is identified easily because the levels of water in hand dug wells raise up to some metres in the wells higher above the levels during the dry season. This identification is usually few hours after each heavy down pour in the area. The wells located at the contact between the Lafia and Awgu formations such as those near Daddare (Lat. $8^0 42'23.2''$E, Long. $8^0 26' 59.5''$N), Ungwar Mamman (Lat. $8^0 27' 12.5''$E, Long. $08^0 41' 37.1''$N) and Ungwar Hamidu (Lat. $8^0 27' 27.0''$E Long $08^0 40' 50.4''$N) are recharged during the dry season by the thinly overlying Lafia Formation which is a confined aquifer (Offodile, 1976). This formation is believed to be issuing water continuously to the wells during the dry seasons. This contact area is a watershed and facilitates fadama (or irrigation) farming during dry seasons.

4.2.4 Discharge in the study area

The discharge in aquifers can either occur artificially or naturally. Discharge through hand dug wells in the area studied is artificial by local abstraction mostly for domestic use. The rural communities within the area are quite familiar with the nature of the aquifer(s) in respect of their rate of discharge. As they mostly depend on abstraction of groundwater from hand dug wells, they have adopted some policies for proper planning and management of the water resources especially in dry seasons where the water table declines or fall rapidly.

4.2.5 LINEAMENT ANALYSIS AND INTERPRETATION FOR ASSESSMENT OF GROUNDWATER POTENTIAL OF THE STUDY AREA (LAFIA AND ENVIRONS)

Introduction

Lineament is a mappable linear or curvilinear feature of a surface whose parts align in a straight or slightly curving relationship. They are usually an expression of fractures (joints, faults) and or other lines of weaknesses usually found in crystalline basement rocks and other hard or indurated sedimentary rocks. Groundwater occurrence in hard sedimentary rocks is largely due to the development of secondary porosity and permeability by fracturing and/or weathering of these rocks.

Hence groundwater exploration in such rocks is aimed at delineating fractures and or thick weathered zones since they constitute aquifers in such terrains. Areas with high density of fractures usually have high groundwater potential. Many workers have shown that lineaments (fractures) delineated and interpreted from remote sensing imageries are useful in assessment of groundwater potentials in areas underlain by basement rocks and other hard sedimentary rocks.

Based on interpretation of Surface Reflectance Terrain Modelling Digital Elevation Model, (SRTM DEM) imagery of Lafia and environs sheet 231(NW), the application of lineament trends and lineament density to the assessment of groundwater potentials across the area is presented (Anudu, *et al*, 2011).

4.2.5.1 Lineament Analysis for Groundwater Exploration in Lafia and Environs

Lineaments are commonly analyzed using rose-diagrams or azimuth-frequency and/or lineament density maps. The commonest method used to calculate lineament density is based on the number of lineaments per unit area (number/km^2), or the total length of lineaments per unit area (km/km^2,Fig. 4.4) or combining both. However for this study, rose (azimuth-frequency) diagram using Rock plots 3D software and lineament density maps using the PCI Geomatica, ENVI 4.5 and Arc GIS 9.3 software were used.

The rose (azimuth-frequency) diagram of the lineaments delineated on the imagery shows the trends: NW-SE directions (Fig. 4.5).

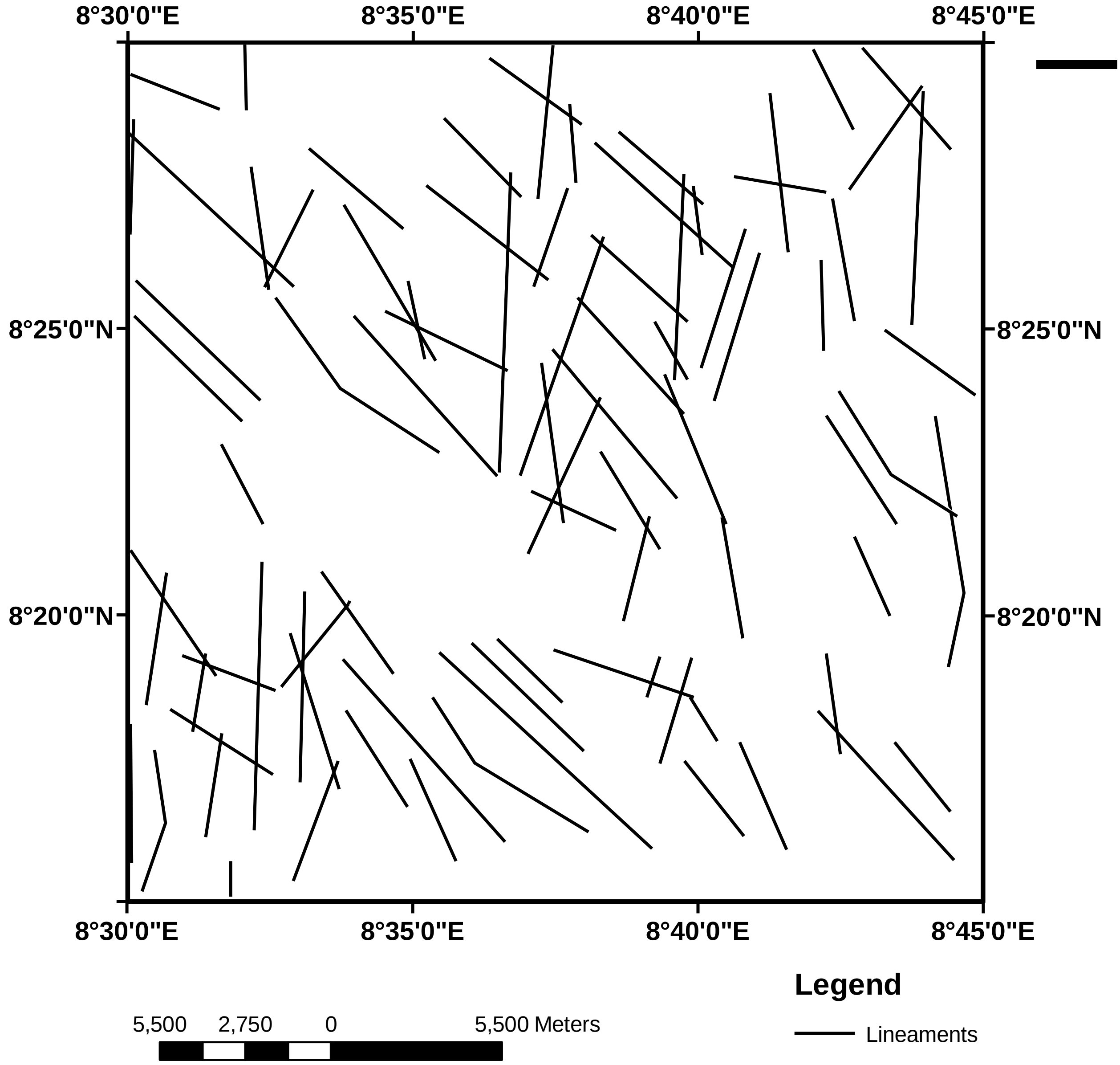


Fig. 4.4: Lineament map based on the number of lineaments per unit area (number/km²)

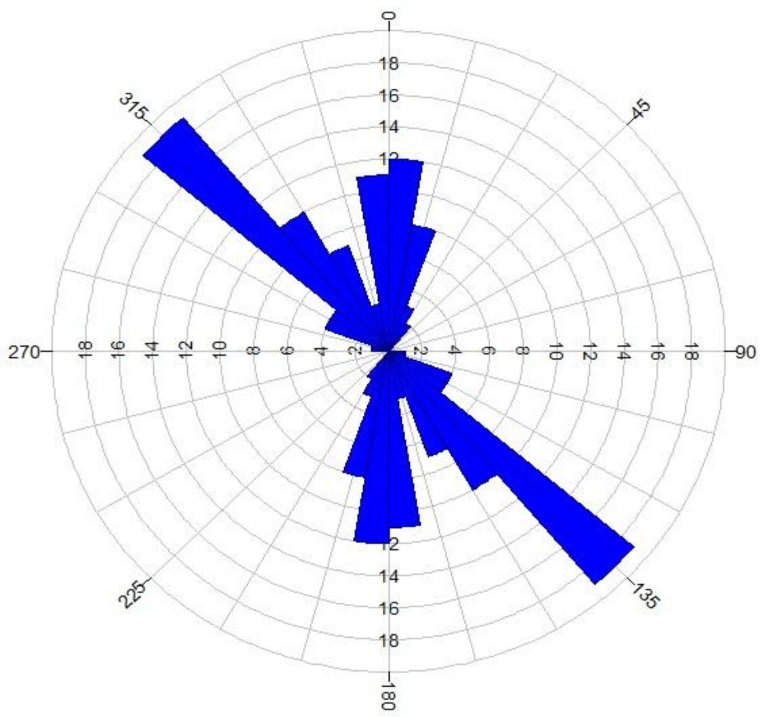


Fig.4.5: Rose (azimuth-frequency) diagram of lineaments orientations.

The lineament density of Lafia and environs was computed based on the number of lineaments per unit area (number/km²) of grid. For quick graphically assessment of the lineament density of the area, two forms of lineament density maps were produced using the lineament density values computed. They are lineament map (Fig. 4.4), and lineament density map (Fig. 4.6). The lineament density maps (Figs. 4.4, and 4.6) show that the lineament density is high on the areas that are underlain by the Agwu and Lafia formations (Fig. 4.7). These areas include: Lafia, Agyaragun Tofa, Agyaragu station, Gwadenye, Mararraba Akunza, Akunza Jarme, Akanga, Bukan Kwato, Bukan Fadama, Bukan Tambari, Gandu,Gimare, Wakwa, etc, in the north and Akanga, Akaleku and Adevi in the south. With regards to groundwater exploration, these aforementioned areas have high groundwater potentials due to high concentration of lineaments and high lineament density, since groundwater occurs within joints and fractures in hard sedimentary rocks. Also from the results, the drainage pattern is structurally controlled and mostly influences both the groundwater and surface water flow directions in the area.

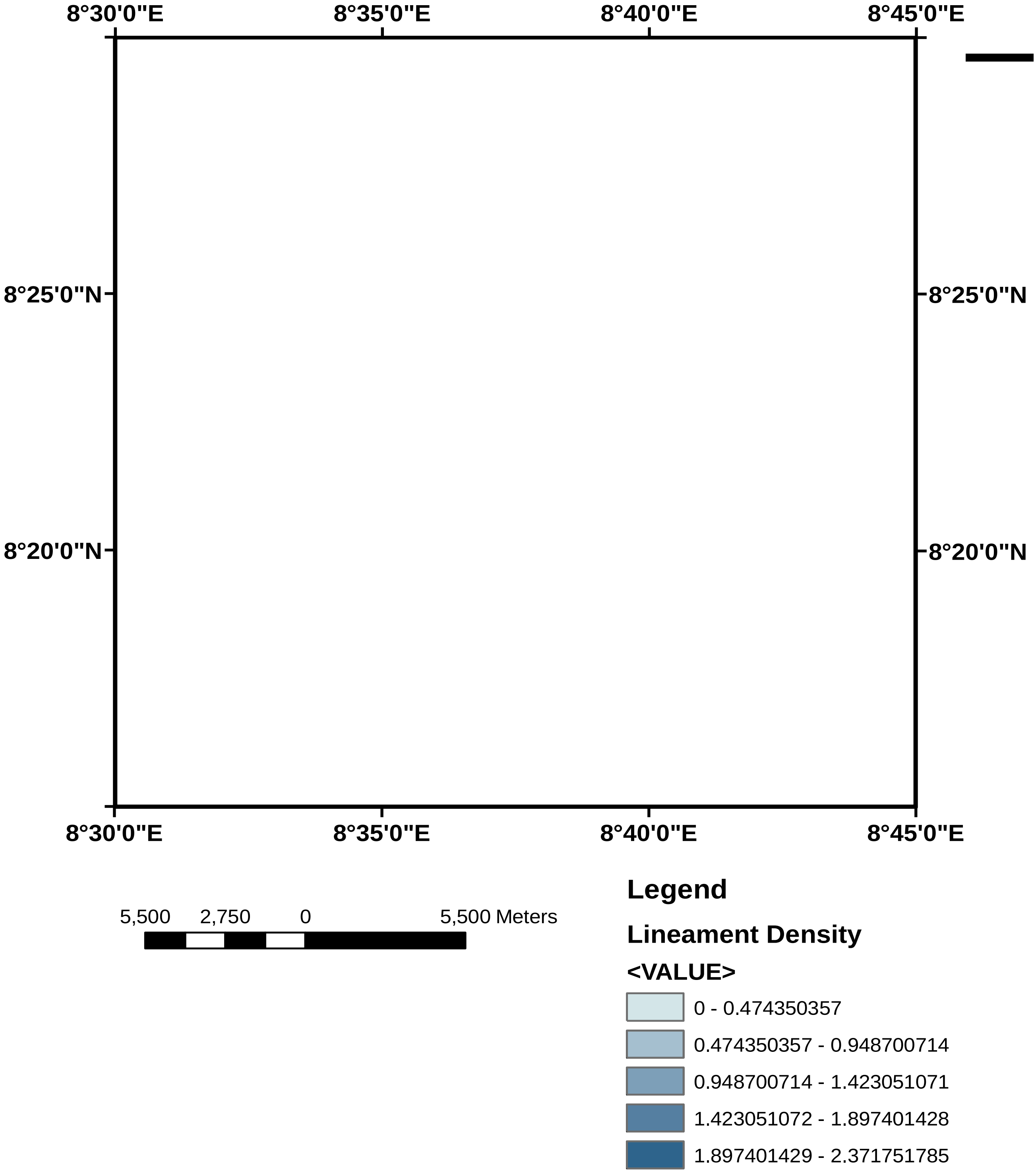
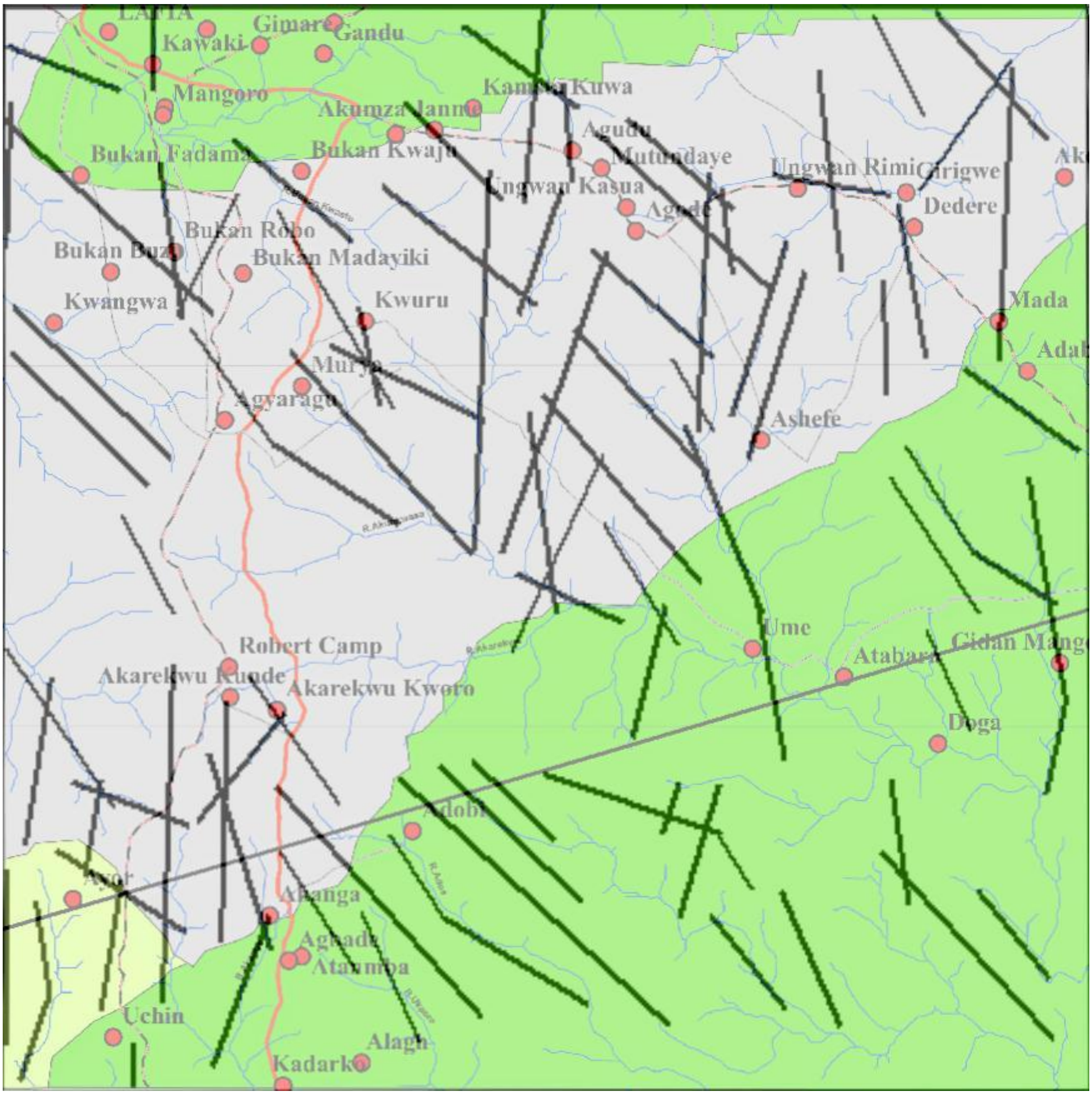


Fig. 4.6: Lineament density map of the study area.

The lineament density maps are very important in groundwater exploration especially in areas underlain by basement rocks and other hard sedimentary rocks. High lineament density areas usually imply areas with high fracture density, (Figs. 4.4 and 4.6). It is certain that groundwater accumulation and water well production or yields increase with increasing lineament density. As a result, areas having high lineament density represent areas with relatively high groundwater potentials. Therefore groundwater exploration in the study area should be concentrated on areas with high lineament density.



. **Fig. 4.7:** Lineament map superimposed on Geological map of Lafia and environs

4.3 CHEMISTRY AND USAGE OF WATER

The quality of a groundwater supply required depends on its intended usage either for drinking, industrial and agricultural uses (e.g. irrigation, e.t.c.). All groundwater contain salts in solution that are derived from the geological formation(s) through which it passes. The chemistry and usage (quality) of groundwater is established by its measures (quantities) of biological, chemical, physical and radiological constituents (Todd, 1980).

The amount of dissolved constituents or minerals in groundwater depends largely on some factors such as rock types through which the water passes, time taken for the passage, temperature, pressure and the amount of dissolved minerals in solution. The purpose of determining the water chemistry in the study area is to evaluate the suitability of the water for drinking an domestic uses, agricultural and industrial purposes (Appelo, 2005).

4.3.1. Physical Qualities

The physical properties of groundwater determines its suitability for drinking and domestic uses (or as set by guide lines or standards), industrial and agricultural purposes (e.g. irrigation). The physical parameters measured are; total dissolved solids (TDS), hydrogen exponents (p^H) and temperatures and the findings from these measurements is as explained below.

The total dissolved solids (TDS) of the hand dug wells in the area of study range from 20 mg/l to 330 mg/l: with an average of 84.5 mg/l (Table 6). The p^H of groundwater in the hand dug wells ranges from 4.0 to 7.0 with an average of 4.43.

Temperature values recorded range from 22.9^{0}C to 30.8^{0}C, with an average of 28.5^{0}C. Colour and turbidity were not measured in situ on the field, but were identified in two (2) wells using the unaided eyes or visually. The water in these wells appeared reddish with soil particles which makes it, turbid.

4.3.1.1. Temperature

This slightly affects p^H and total dissolved solids (TDS) especially in low mineralised water. There is a decrease in p^H of about 0.4 as the temperature raises by 25^{0}C in pure water. However, water stored over night in a bucket is likely to have lower P^H due to low temperature and ultimate precipitation of iron (Shoeneich, 2001).

The recorded temperatures of the water sampled from wells in the study area range from 24.5^{0}C to 26^{0}C with an average of 25^{0}C (Table 6). This range falls within the maximum permissible limit of the Nigeria Industrial Standards (NIS), 2007; (Table 4.1). Hence, no health hazard is attributed to the water of the area studied.

Table 4.1: physical / Organoleptic Parameters (NIS, 2007)

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

4.3.1.2 Total Dissolved Solids (TDS or mineralisation**)**

The mineralisation (TDS) of groundwater in the hand dug wells of the study area range from 20 mg/l to 330 mg/l with an average of 84.5 mg/l. The highest value of 330 mg/l (Table 4.3) in the study area is a very good one which is in line with the desirable level of <500 mg/l (Table 5). In this respect, this makes entirely the water within the study area excellent for drinking.

Table 4.2: WHO 2003 and 2011 Standard Permissible Limit for Physical and Chemical Parameters of Water for Drinking and Domestic Use

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

4.3.1.3 Hydrogen Exponent (pH)

This is a measure of the acid – base equilibrium and is usually controlled by the carbon dioxide-bicarbonate-carbonate equilibrium. It usually depends on free carbon dioxide that is trapped from the atmosphere during rainfall. Others include sulphate materials, decaying vegetation and presence of acidic substances of peaty origin. All these factors cause low pH of water. Low pH may also be caused by precipitation of iron in stored water sampled before testing, especially if several days elapsed between sampling and testing or from water stored in a bucket over night. On the other hand, high pH results from the presence of bicarbonates, carbonates and hydroxides of calcium, magnesium, potassium and sodium, (Shoeneich, 2001)

Depending on the pH, water is described as neutral (pH from 6.8 to 7.2), weakly alkaline, (pH from 7.2 to 7.8), alkaline (pH from 7.8 to 8.2), or strongly alkaline (pH >8.2). It can also be weakly acidic (pH 6.8 to 6.0), acidic (6.0 to 4.5) and strongly acidic (pH < 4.5), as in Table 4.3 below.

In the area of study, water in the hand dug wells has the p^H values ranging from 4.0mg/l – 7.0mg/l, with an average of 4.43mg/l. This falls slightly below the recommended and maximum permissible limits of SON (2007) and WHO (2011) which range between 6.5 mg/l and 8.5 mg/l respectively, (Appendices II and VI). This makes the water weakly acidic but is used for drinking, domestic, agricultural and industrial purposes. However, verbal discussions with some communities revealed that there are no cases of health hazards experienced so far.

4.3.1.4 Conductivity

It is measured in micro-Siemens/cm or micro-mhos/cm in water at the temperature of 25^0C. Optimally, conductivity is measured at the sampling site (in situ) with electrical conductivity cell which is temperature compensated. If the conductivity is multiplied by a factor, ranging from 0.55 – 0.70, then the product is equal to the Total Dissolved Solids expressed in mg/l, (Table 4.3).

Table 4.3: Physical Qualities of sampled groundwater from hand dug wells **(Source:** Field Data, 2011).

S/ no.	Location Description	Sample Identifi-cation number	Coordinates Longitud ^{0} N Latitude ^{0} E	Well Elevn. (masl/ ftasl)	Depth to w/t. masl/ ftasl	Water level Elev m/ft	TDS *10) mg/l	Cond -tivity = (TDS *0.7)	pH	Tem (˚C)
1	Daddare. G. Maaji	DDR 1	$8^0$26’59.5”N $8^0$42’23.2”E	19.2m 632ft	4.3 m 14.1ft	14.9m 617.9ft	190	133	7.0	25
2	Ungwar Hamidu	DDR 2	$8^0$27’27.0”N $08^0$40’50.6”E	195m 639ft	9 m 29.5ft	186m 610ft	70	49	5.3	24
3	Ashupe G.Jonat	DDR 3	$8^0$25’07.2”N $08^0$40’04.5”E	206 m 675.9f	12.3m 10.4ft	193.7m 665.5ft	90	63	4.6	25.4
4	Agudu G.Agwa	DDR 4	$8^0$27’54.6”N $08^0$37’35.9”E	223 m 731.6f	14.5m 47.6 ft	208.5m 684ft	180	126	4.0	26
5	Akunza Jarme	DDR 5	$8^0$28’07.4”N $08^0$35’59.6”E	216 m 708.6ft	12.8m 42 ft	203.2m 666.6ft	200	14	4.7	25
6	Akaba, G.Mailafy	DDR 6	$8^0$22’37.3”N $08^0$36’52.3”E	186 m 610.2ft	8.6 m 28.2 ft	177.4m 582ft	90	63	4.6	25
7	Odobu, Gidan. Danlami	DDR 7	$8^0$24’55.2”N $08^0$44’02.9”E	216 m 708.7ft	8.8 m 26.9 ft	207.6m 681.8ft	30	21	5.2	24.5
8	Kayarda Mosque	DDR 8	$8^0$23’49.0”N $08^0$31’38.0”E	216 m 708.7ft	12.5m 41.7 ft	203.5m 667ft	30	21	4.0	25
9	Dudugur Mkt.well	DDR 9	$8^0$24’57.0”N $08^0$35’31.4”E	167 m 548 ft	9.5 m 31.2 ft	157.5m 516.8ft	30	21	4.0	25
10	Ak.KoroClemt. Adagba	DDR10	$8^0$26’17.3”N $08^0$34’20.9”E	134 m 439.6ft	8.8 m 28.9 ft	125.2m 410.7ft	30	21	4.0	26
11	Bukan Fadama	DDR11	$8^0$29’47.0”N $08^0$34’31.5”E	187.m 616 ft	8 m 26.3ft	179m 589.7ft	20	14	4.0	26
12	Gimare Salih Ibr.	DDR12	$8^0$29’27.2”N $08^0$33’27.1”E	192.m 632 ft	7m 23 ft	185m 609ft	20	14	4.0	25
13	Tudun Kwashin	DDR13	$8^0$29’39.0”N $08^0$32’46.8”E	212.m 697 ft	12.5m 41.0 ft	199.5m 656ft	60	42	4.0	25
14	Tudun Kauri	DDR14	$8^0$28’53.7”N $08^0$32’09.8”E	171.m 563 ft	8.2 m 27 ft	162.8m 536ft	40	28	4.0	26
15	Agyarag Tofa	DDR15	$8^0$26’39.5”N $08^0$32’39.0”E	201.m 660 ft	11.2m 36.8 ft	189.8m 623.2ft	50	35	4.0	25
16	Bukan Buzu	DDR16	$8^0$26’17.7”N $08^0$31’19.1”E	197.m 648 ft	10.5m 34.5 ft	8.5m 613.5ft	330	231	4.0	26
17	Bukan kwato	DDR17	$8^0$27’23.0”N $08^0$34’12.2”E	178.m 585 ft	17m 55.8 ft	161m 529.2ft	190	133	4.0	25
18	Atabala S.Ayima	DDR18	$8^0$21’13.3”N $08^0$41’41.3”E	227.1 745 ft	11 m 36.1 ft	216.1m 708.1ft	180	126	4.0	26
19	Agyarag Borehole	DDR19	$8^0$23’59.5”N $08^0$33’03.3”E	227m 745 ft	11m 36.1 ft	216m 708.1m	250	175	5.2	25
20	Ajerugba	DDR20	$8^0$23’01.8”N $08^0$30’55.3”E	222m 731 ft	7.9 m 26 ft	214.1m 705ft	140	98	5.2	25

4.4. Chemical Quality of Groundwater

The elements that are dissolved in drinking water fall into two categories. The trace elements (or micro-nutrients) which are those essential for human and animal health and those considered to be undesirable or toxic. Many elements fall in both categories. Some are essential at low concentration, and toxic or undesirable at higher level of concentration.

Analysis of the elements in groundwater for the area studied reveals the following results (Table 4.4).

4.4.1 Cations and Anions

Results of elemental analyses of groundwater samples collected from 20 hand dug wells spread across the study area are presented in Table 4.4.

Elements analysed are; Sodium (Na^+) has a concentration ranging from 5.7 mg/l to14.8 mg/l with an average of 9.44 mg/l. Potassium (K^+), in hand dug wells, has concentration of between 0.5 mg/l and 20.7 mg/l, with an average of 8.02 mg/l. Calcium (Ca^+) concentration in the hand dug wells ranges from 2.5 mg/l to 17.2 mg/l, has an average of 6.22 mg/l. Copper (Cu^{+2}) concentration ranges between 0.03 mg/l to 0.84 mg/l, with an average of 0.45 mg/l. Iron (Fe^{+3}) concentration in the hand dug wells ranges from 0.04 mg/l to 1.0 mg/l, with an an average of 1.76 mg/l. Bicarbonate (HCO_3^{-2}) concentration is from 40.4 mg/l to 444.4 mg/l, with an average of 156.1mg/l. Chloride (Cl^-) concentration in the hand dug wells range from 0.00 mg/l to 4.87 mg/l, with an average of 0.69 mg/l. Nitrate (NO_3^{-2}) concentration is between 0.18 mg/l to 22.2 mg/l, with an average of 2.02 mg/l. Sulphate (SO_4^{-2}) concentration in the hand dug wells ranges from 5 mg / l to 15 mg / l, with an average of 7.0 mg / l.

Table 4.4: Results of Elemental Analyses of Water Samples from Hand dug Wells in the Study Area as analysed at CERT and WREEN of Ahmadu Bello University, Zaria. **Source:** Field data (2012).

S/no	Location Description	Coordinates Lt^{0}N/ Lng^{0}E	Na^{+} ppm	K^{+} ppm	Ca^{+2} ppm	Cu^{+2} ppm	Fe^{+3} ppm	Mg^{+2} Ppm	Mn^{+} Ppm	Zn^{+2} ppm	NH_3^{+} Ppm	$HCO_3^{=}$ Ppm	Cl^{-} ppm	$NO_3^{=}$ ppm	$SO_4^{=}$ Ppm
1	Daddare G. Usman	8^{0}26’ 59.5”N 8^{0}42’23.2”E	13	15.0	9.9	0.71	0.30	75	0.30	0,07	0.98	242.4	1.83	0.65	15
2	Ungwar Hamidu	8^{0}27’27.0”N 08^{0}40’50.6”E	7.7	3.8	4.0	0.40	0.26	42	0.20	0.00	0.31	101.0	0.00	3.01	5
3	Ashupe G.Jonathan	8^{0}25’07.2”N 08^{0}40’04.5”E	8.5	5.4	4.6	0.04	0.14	39	0.40	0.00	0.90	111.1	0.00	0.18	5
4	Agudu G.Agwade	8^{0}27’54.6”N 08^{0}37’35.9”E	11.3	10.3	6.6	0.18	0.58	48	0.06	0,16	1.23	131.3	0.00	0.45	5
5	Akunza Jarme	8^{0}28’07.4”N 08^{0}35’59.6”E	11.4	11.0	9.1	0.12	0.53	91	0.24	0.18	0.49	222.2	0.52	0.24	5
6	Akaba Gd. Mailafiya	8^{0}22’37.3”N 08^{0}36’52.3”E	7.8	8.0	2.5	0.03	0.11	44	0.34	0.00	0.84	101.0	0.00	22.0	5
7	Odobu Gd. Danlami	8^{0}24’55.2”N 08^{0}44’02.9”E	5.7	2.7	4.2	0,25	0.20	46	0.4	0.10	0.67	121.2	0.73	0.51	5
8	Kayarda Mosque	8^{0}23’49.0”N 08^{0}31’38.0”E	7.9	3.0	2.6	0.11	0.24	56	**0.50**	0.25	0.61	40.4	0.95	1.00	5
9	Duduguru Conc well	8^{0}24’57.0”N 08^{0}35’31.4”E	7.6	1.8	3.3	0.84	**1.00**	78	0.08	0.10	0.62	60.6	0.53	0.73	25
10	Akunza Koro	8^{0}26’17.3”N 08^{0}34’20.9”E	7.7	1.3	2.8	0.49	**0.74**	60	0.06	0.17	0.59	121.2	0.76	0.35	10
11	Bukan Fadama	8^{0}29’47.0”N 08^{0}34’31.5”E	7.8	1.3	3.9	0.08	**0.98**	58	0.24	0.04	0.98	80.8	0.85	0.63	15
12	Gimare G. Salihu	8^{0}29’27.2”N 08^{0}33’27.1”E	7.7	1.3	3.3	0.12	0.18	66	0.33	0.11	0.77	101.0	0.35	0.46	5

13	Tudun Kwashini	8^{0}29ʾ39.0”N 08^{0}32ʾ46.8”E	9.0	4.1	4.5	0.6	**0.71**	81	**0.4**	0.10	0.65	\`0\`.0	0.00	2.41	5
14	Tudun Kauri	8^{0}28ʾ53.7”N 08^{0}32ʾ09.8”E	8.5	0.5	5.4	0.14	0.05	96	0.3	0.05	0.83	161.6	0.04	2.77	5
15	Agyaragun Tofa	8^{0}26ʾ39.5”N 08^{0}32ʾ39.0”E	8.5	3.7	1.9	0.40	**0.7**	71	0.3	0.33 0.21	0.75	121.2	0.99	0.64	10
16	Bukan Buzu	8^{0}26ʾ17.7”N 08^{0}31ʾ19.1”E	14.8	12.7	17.2	0.30	0.04	150	**0.47**	0.21	1.33	444.4	4.87	**22.20**	5
17	Bukan kwato	8^{0}27ʾ23.0”N 08^{0}34ʾ12.2”E	12.2	13.0	7.6	0.03	0.63	47	0.06	0.23	1.42	191.9	0.13	0.18	10
18	Atabala Gd Sam.Ayima	8^{0}21ʾ13.3”N 08^{0}41ʾ41.3”E	10.5	9.6	11.2	0.28	0.42	47	0.09	0.32	0.62	171.7	1.14	0.26	5
19	Agyaragu Borehole	8^{0}23ʾ59.5”N 08^{0}33ʾ03.3”E	11.5	15.0	13.1	0.15	**0.76**	51	0.00	0.16	0.63	313.1	0.04	1.29	-
20	Ajerugba	8^{0}23ʾ01.8”N 08^{0}30ʾ55.3”E	9.5	8.9	6.7	0.7	0.63	48	**0.50**	1.90	0.74	181.8	0.00	0.28	10

Sodium, (Na^+) in the groundwater of the study area ranges between 5.7 mg/l to 14.8 mg/l. It has an average of 9.44 mg/l. These values are far below those of the Nigerian Standards for

Drinking Water (SON 2007) and International Drinking Water Standards (WHO, 2004 and 2003/2011) for both Recommended and Maximum Permissible Limits of 150 mg/l and 50 mg/l respectively (Appendices II, III and VI). In groundwater, sodium is believed to be released by weathering of plagioclase feldspars. However, it is likely that, the little concentrations of sodium analysed from the water samples in this study area are more or less derived from households or residential effluents. This laboratory result shows that the sodium derived from residential effluents in the study area did not influence pollution of the wells because the concentrations are so small to pollute the wells. These values suggest that the waters are very suitable for usage.

Potassium (K^+): This is released in to water by the weathering of orthoclase and microcline feldspars. From analysis of water samples within the study area, potassium is found to range from 0.5 mg/l at Tudun Kauri – Lafia to 15 mg/l at Daddare and Agyaragu (b/h), with an average of 6.6 mg/l. From the result of analysis in Table 7, the value (15 mg/l) at Daddare and Agyaragu (b/h), is within the maximum permissible limit (15 mg/l) in respect to the WHO (2004) standard as in Appendix III. This value of potassium (15 mg/l) in groundwater represents water in the wells (which may be polluted) and not the aquifer under human settlements. This shows that the two wells were not properly maintained by yearly routine cleaning or removal of dirt. But this analysis suggests that the water is suitable for use for all purposes.

Calcium, (Ca^+) in the water sampled within the area of study is found to range from 2.7 mg/l to 17.2 mg/l with an average of 6.22 mg/l. The highest value is far below the recommended limits of 75 mg/l of both SON 2007 and WHO 2004, 2005 and 2011, as in Appendices II and III, IV and VI respectively.

Copper, Cu^{+2} is a minor constituent in groundwater. It does not reach 1.5 mg/l as the maximum permissible limit of WHO 2005 International Standard for Drinking Water (Appendix IV) and 2.0 m g/l as the recommended value of W.H.O. 2011 respectively. From the analysis of water samples in the area of study, it has values ranging between 0.0 mg/l to 1.26 mg/l, with an average of 0.35mg/l. The value of 1.26 mg/l is not up to the maximum permissible limit which makes the water fit for all uses by both animals and plants. Hence, there is no need for copper treatment before being used for human and animal consumptions. But if the concentration of copper is above maximum permissible limit, gastro-intestinal disorder results as the health hazard, NIS 2007 (Appendix V).

Iron: Fe^{+3} analyses in the water samples of the study area gave higher values ranging from 0.04 mg/l (lowest) at Bukan Buzu to 1.00 mg / l (highest) at Duduguru, with an average of 0.3 mg/l. Comparing these values with standards (Appendices II, III, IV and V) shows that, the highest concentrations of 1.00 mg/l coincide with the maximum permissible limits (1.0 mg/l) of these standards. These higher concentrations of iron in most hand dug wells of the study area are most probably due to the nature of the geologic formation (Lafia formation) underlying the area. This formation is made up of ferruginous sandstone and overlying laterite containing Fe^{+3} (iron). Low iron concentration in some wells of the study area is most probably due to instability of the iron found within the low pH range. Result of the analysis from Table 7 above shows that the areas with higher concentration of iron are on the Lafia formation. By implication, this maximum permissible limit (1.05 mg/l) would not cause any health hazard to the livelihood of the people in the study area (SON and NIS, 2007; WHO 2004 and 2005) as in Appendices II, V, III and IV respectively.

Magnesium (Mg^{+2}) in the hand dug wells of the study area ranges from 39 mg/l – 150 mg/l, with an average of 65 mg/l. The recommended limits and the maximum permissible limits according to the standards of WHO (2004, 2005 and 2011) and SON 2007, are 39 mg/l and 150 mg/l, 39mg/l and 150 mg/l and 50mg/l and 150 mg/l respectively (Appendices III, IV, VI and V). Comparing the values obtained from the analysis of water samples to the values of the four standards mentioned above, it can be deduced that groundwater tapped from the aquifers within the study area is safe to be used for various purposes. In the reverse case however, if results from groundwater show slightly upper extreme and slightly higher average, it is very likely that the aquifer or wells are possibly polluted by household effluents.

Manganese (Mn^{+2}), analysed from the groundwater samples of the study area is found to range between 0.00 mg/l and 0.50 mg/l, and has an average of 0.30 mg/l. Other standards like those of WHO 2005 and 2011 (Appendices IV and VI) and NIS 2007 (Appendix V), stated that the maximum permissible limits of manganese (Mn^{+2}) in water ranges from 0.2 mg/l to 0.5 mg/l. From the result of analysis of Mn^{+2} (Table 7) in the study area, it shows that the average of (0.3 mg/l) manganese concentration is within the standard of WHO 2005 and 2011 (Appendix IV and VI) whose maximum permissible limits are 0.5 mg/l and 0.4 mg/l respectively. In this case, the waters are suggested for drinking and other uses. But according to NIS 2007 (Appendix V), Mn^{+2} concentrations of 0.2mg/l are at the maximum permissible limit and may cause neurological disorder as health hazard.

Shoeneich, (2001) and Shoeneich and Garba (2010) reported that "higher concentration of manganese in groundwater over surface water is theoretically possible. This is because water from public boreholes and hand dug wells represents polluted water in polluted wells under human settlements but not representative of the aquifers that is non-polluted which recharge these wells". This theory is practically applicable to the groundwater tapped from the wells in the study area due to higher values of manganese analysed (table 7).

Ammonia (NH_3^+): Concentrations in the area of study range between 0.3 mg/l and 1.4 mg/l with an average of 0.8 mg/l. According to WHO (2006), the levels of ammonia in the world's non- polluted groundwater are usually below 0.2 mg/l. But, higher concentrations are found in strata rich in humic substances, (Shoeneich, 2001). Results from analysis of water samples in the study area revealed that none of the water sampled from the 20 hand dug wells in the area has ammonia concentration less than 0.3 mg/l. All these values are above the WHO (2006) maximum permissible limit. This result shows the effect and rate of contamination of the water in the hand dug wells by residential effluents in the study area.

Zinc (Zn^{+2}): In the hand dug wells of the research area, Zn^{+2} concentration ranges between 0.0 mg/l to1.9 mg/l, on average, 1.7 mg/l. It is a minor constituent in groundwater. WHO (2006) reported the concentration of Zn^{+2} to be even up to 24mg/l in a finished analysis of water from almost 6,000 wells (Shoeneich, 2001). So, it is far below the permissible limits

Bicarbonate (HCO_3^{-2}): Is believed to originate or have its sources from atmospheric carbon dioxide dissolved by rain water and carbon dioxide present in the humus soil, absorbed by water during percolation. From results obtained from analyses of water samples from hand dug wells of the study area (Table 7), HCO_3^{-2} is found to range between 40.0mg/l to 444.4 mg/l, with an average of 156 mg/l. This is within the recommended limit of WHO (2004) standard for International drinking water which is 500 mg/l (Appendix III). This concentration of bicarbonate in groundwater of the hand dug wells in the study area makes the water to be highly recommended for drinking and other uses.

Chloride (Cl^-), concentration in groundwater of the hand dug wells of the area of study range between 0,00 mg/l to 4.9 mg/l, with an average of 0.69 mg/l. This higher value of 4.9 mg/l concentration is on the average (5.0 mg/l) and is far below even the SON 2007, WHO 2004, 2005 and 2011 recommended limits of 250 mg/l as Appendices II, III, IV and VI respectively. This highly recommends the water in the area for drinking and other uses and reveals that the chloride content or concentration in this water is believed to be meteoric in origin because of its lower values. However, higher values of chloride content are indication of wells not cleaned for long time or chloride in areas of shallow occurrence of salt water from stagnant belt which migrate by diffusion upwards and enters meteoric water of the dynamic belt (Shoeneich and Garba, 2010).

Nitrate (NO_3^{-2}). The concentration of nitrate in groundwater in the study area ranges from 0.18 mg/l to 22.2 mg/l, with an average of 2.02 mg/l. These higher concentrations of nitrate recorded at Akaba (22.0 mg/l) and Bukan Buzu (22.2 mg/l) are not even up to the maximum permissible limits of 50 mg/l as in SON and NIS, 2007; and the recommended values of WHO 2011 as in Appendices II and V; and VI respectively. Even at the highest concentration value of 22.2 mg/l, the groundwater of the study area is within the recommended and permissible limits of WHO 2004 and 2005 standards (20 mg/l and 50 mg/l) as in appendices III and IV and recommended limit of W.H.O, 2003 and 2011 (Appendix VI) respectively. This suggests the usefulness of the water for drinking, domestic, agricultural and industrial uses. But if the concentration is up to the maximum permissible limit of 50 mg/l (SON. 2007; Appendix II), Cyanosis and Asphyxia in infant under 3 months occurs as health hazard.

Sulphate (**SO_4^{-2}**): Concentration of sulphate in the groundwater of the study area ranges from 5 mg/l to 25 mg/l, on average 7.25 mg/l. The source of sulphates in water is decaying organic matter through hydrogen sulphide. Sulphate is an indicator of organic pollution in water especially in shallow aquifers and hand dug wells.

In the area of study, sulphate concentrations at Daddare (15mg/l), Duduguru (25 mg/l), Akunza Koro (10 mg/l), Bukan Fadama (15mg/l), Agyaragun Tofa (10 mg/l), Bukan Buzu (10 mg/l) and Ajerugba (10 mg/l) are even far below the recommended limits (100 mg/l, 150 mg/l, 200 mg/l and 250 mg/l) of SON (2007) and WHO (2011) standards for drinking water respectively (Appendices II, III, IV and VI).

4.5 THE PIPER TRILINEAR DIAGRAM (WATER FACIES)

The chemical parameters of the water samples obtained from the 20 hand dug wells were plotted on Piper (1944) trilinear diagram using the Aquachem 4.0 software. This identifies the following types of water: HCO_3, CO_3+HCO_3 -type and Na + K-type as dominant (Table 4.5).

The Piper plot is useful in showing multiple samples and trends of major ions. In this plot, the major ions are plotted in two base triangles as cations and anions in percentages or milliequivalents per litre (Meq/l). The total cations and anions (in Meq/l) are set to be equal to 100 %. The data points in the two triangles are then projected onto the diamond grid. The projection reveals certain useful properties of the total-ion relationships. Many samples are represented by three data points; one in each triangle and one in the diamond grid.

The plot allows comparisons between a large numbers of samples but it does not portray absolute ion concentrations. The main purpose of this plot is to show clustering of samples. Piper diagram is a combination of cations and anions triangle that lays on a common baseline. It divides water into types or facies according to their placements near the four corners of the diamond shape. Water that plots at the top of the diamond is high in Ca^{2+} + Mg^{2+} and HCO_3^{-2} and is the region of waters with temporary hardness. Water plotted at the lower corner of the diamond is composed primarily of Na^+ + K^+ and HCO_3^{-2}. Thirteen out of the twenty samples analysed fit into the Piper diagram while the remaining seven fall outside the Piper diagram probably due to high/ or low contents of some major cations and anions in them. This results from water quality analyses were used to plot Piper diagram, hence classifying these water into 3 types as Na+K-type, (HCO_3^{-2})-type and (HCO_3^{-2}) + (CO_3^{-2})-type based on the diagram (Fig.4.8).

Table 4.5: Water types (water facies) from the study area

	Water Type	**Station ID**	**Station Name**	**Location**
DDR 1	HCO3	DDR 1	Daddare	8^{0}26'59.7"N 08^{0}42'23.4”E
DDR 2	Na-HCO3	DDR 2	Ung. Mamman	8^{0}27'12.5"N 08^{0}41'37.1”E
DDR 3	Na-HCO3	DDR 3	Ashupe	8^{0}25'07.2”N 08^{0}40'04.5”E
DDR 4	Na-HCO3	DDR 4	Agudu	8^{0}27'54.4"N 08^{0}37'35.8”E
DDR 5	Mg-HCO3	DDR 5	Akunza Jarme	8^{0}28'09.9"N 08^{0}35'56.5”E
DDR 6	Na-HCO3	DDR 6	Akaba	8^{0}22'37.3”N 08^{0}36'52.3”E
DDR 7	HCO3	DDR 7	Odobu – Obi	8^{0}24"55.0"N 08^{0}44'02.8”E
DDR 8	Na-HCO3	DDR 8	Kayarda – Lafia	8^{0}23'49.0”N 08^{0}31'38.0”E
DDR 9	Na-HCO3-SO4	DDR 9	Duduguru	8^{0}24'57.0”N 08^{0}35'31.4”E
DDR 10	Na-HCO3	DDR 10	Akunzan Kwaro	8^{0}25'59.3”N 08^{0}34'20.9”E
DDR 11	Na-HCO3-SO4	DDR 11	Bukan Fadama	8^{0}27'43.7”N 08^{0}31'00.8”E
DDR 12	Na-HCO3	DDR 12	Gimare – Lafia	8^{0}29'27.4”N 08^{0}33'27.0”E
DDR 13	Na-Ca-K-SO4	DDR 13	Tudun Kwashini	Mai Ungwa’s house
DDR 14	Na-HCO3	DDR 14	Tudun Kauri - Lafia	8^{0}29'08.2”N 08^{0}31'57.2”E
DDR 15	Na-HCO3	DDR 15	Agyaragun Tofa	8^{0}26'58.9”N 08^{0}32'35.8”E
DDR 16	Mg-HCO3	DDR 16	Bukan Buzu	8^{0}26'17.6”N 08^{0}31'19.1”E
DDR 17	Na-HCO3	DDR 17	Bukan Kwato	8^{0}27'51.5"N 08^{0}34'22.3”E
DDR 18	Ca-HCO3	DDR 18	Atabula	8^{0}20'59.9”N 08^{0}41'39.6”E
DDR 19	HCO3	DDR 19	Agyaragu Station	8^{0}23'59.2”N 08^{0}33'03.3”E
DDR20	Mn-HCO3	DDR 20	Ajerugba	8^{0}23'01.8”N 08^{0}30'55.3”E

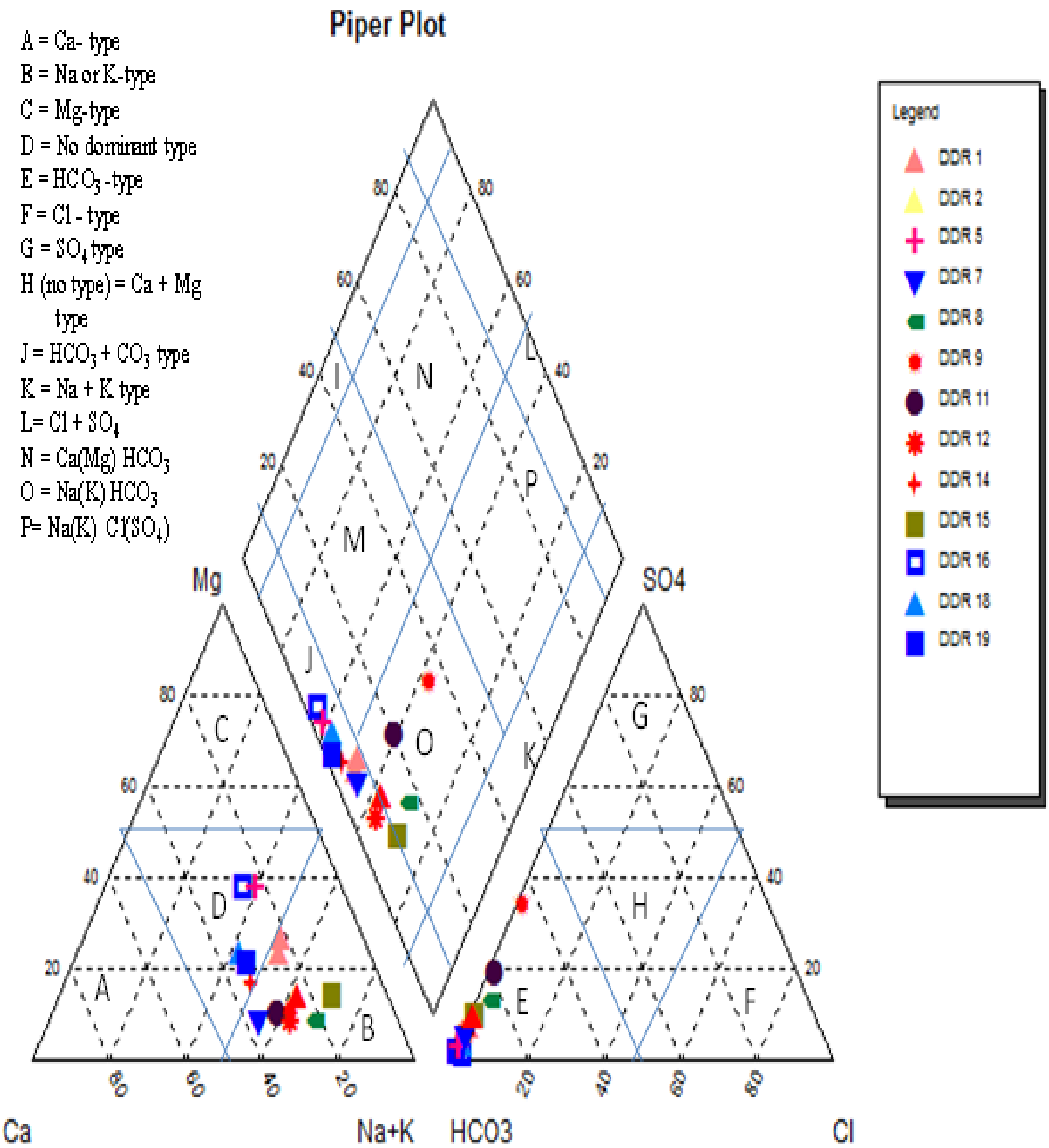


Figure 4.8: Piper Trilinear Diagram (1994) showing different water facies in the study area.

CHAPTER 5

EVALUATION OF TOTAL WATER RESERVE AND WATER BUDGET

A groundwater system consists of a mass of water flowing through the pores or cracks below the earth's surface. Water is constantly added to the system by recharge from precipitation and leaving the system as discharge either artificially by abstraction through wells or naturally by seepage. The source and amount of water flowing through the system is dependent upon external factors such as rate of precipitation, location of streams and other surface water bodies, and the rate of evapotranspiration. The common factor for all groundwater system is that the total amount of water entering, leaving and being stored in the system must be conserved. Human activities such as groundwater withdrawals and irrigation change the natural flow patterns. These changes must be accounted for in the calculation of the water budget. These activities affect the amount and rate of movement of water in the system, entering the system, and leaving the system.

In this study, surface water resources represent waters in the river and stream channels, and evapotranspirated water held up in the atmosphere. On the other hand, groundwater reserves are those stored in the aquifers mentioned in Chapter Two. Shoeneich and Garba, 2010, have classified the total water reserve into two, namely: total static water resources and total dynamic water resources, and total water resources are also divided into utilizable and non-utilizable water resources (Table 5.1). Both portions can be expressed again either in the static or in the dynamic form.

Table 5.1: Classification of total water reserve (Source: Shoeneich and Garba, 2010).

	TOTAL WATER RESOURCES (tWR)	
	Utilisable Water Resources (uWR)	Non-Utilisable Water Resources (nWR)
Total Static Water Resources (tWRs)	Utilisable Static Water Resources (uWRs)	Non-Utilisable Static Water Resources (nWRs)
Total Dynamic Water Resources (tWRd)	Utilisable Dynamic Water Resources	Non-Utilisable Dynamic Water Resources (nWRd)

5.1.1 The Total Static Water Resources (tWRs)

Total static water resources (tWRs) are divided into two: surface static water resources (sWRs) and groundwater static water resources (gWRs). These are defined as the volume (m^3/year) of water contained in a body of surface water (rivers and streams) and in groundwater or aquifer. The surface static water resources (sWRs) are calculated as: sWRs = A × D. Where "A" is the area of water deposit (km^2 or m^2) and "D" is the average depth of water (km or m). The groundwater static water resources (gWRs) are calculated as: gWRs = A × T ×V, where "A" = area of aquifer (groundwater deposit), "T" = mean weighted thickness of water saturation part of the aquifer, and "V" = coefficient of voidity expressed as decimal fraction (dimensionless), (Shoeneich and Garba, 2010).

5.1.2 Total Static Water Resources of the Study Area (tWRs)

Static water resources, WRs depends on the hydrogeology of any given area. Hydrogeology determines the static groundwater resources (gWRs) which constitute most of the total static water resources, tWRs and, to a lesser extent static surface water resources. The study area falls within the Sedimentary Hydrogeological Province of the country which is known to have more water in terms of static water resources as compared to the Crystalline Hydrogeological Province (Shoeneich and Garba, 2010)..

The total static water resources of the study area are both surface and groundwater and can be expressed as: tWRs = gWRs + sWRs, and is also defined as the volume (m^3/year) of water contained in a body of surface water (rivers and streams) and in groundwater per year (Shoeneich and Garba, 2010). In the case of the study area, only that aspect of groundwater resources (gWRs) is calculated using the formula: gWRs = A×T×V.

There are three formation aquifers in the study area namely; the Agwu, the Asu and the Lafia Formations. These formations are characteristically grouped into two; the Agwu/Asu formation and the Lafia formation. This is because; the Agwu and Asu formations are mainly characterized with shales while the Lafia formation is mainly characterized with sandstones. Only the Lafia formation has the thickness of the saturated part of the aquifer to be 100 m, (Offodile, 2002) in accordance to section 2.2.3.4 in the text with varying depths of 150 m and 152 m. Their area coverage is approximately 50% is to 50% (Fig. 10).

To calculate the static groundwater resources (gWRs) of the study area, the above formula was used: gWRs = A×T×V.

Using the dimension of the map (15' × 15') of the study area on the scale of 1:50,000 (Fig. 10) and multiplied by a factor, 1.85 km^2 or 1850 m^2, that is 1' = 1.85 km or 1850 m.

A = area of the aquifer covered by the study = 15' × 1.85 km = 27.75km. Therefore, 27.75 km × 27.75 km = 770 km^2 = 770×10^6 m^2. Therefore, area for the two formations are = 770×10^6 m^2 ÷ 2 = **385×10^6 m^2** for each formation.

T = thickness of water saturated part of all the aquifers = 100 m (Offodile, 2002), and V = the ranges of coefficients of voidity for shaley and sandstone formations expressed as a decimal fraction are = (1-10 and 10-20) %, i.e. = 0.1 and 0.2 for the maximum value of porosity. (Macauly, 2008)

Summary:

If **gWRs** = A ×T × V, (i.e. both for shale and / or plus sandstone formations).

For shale formation = 385×10^6 m^2 ×100 m × 0.1 = **38.5×10^8 m^3/a** and,

For sandstone formation = 385×10^6 × 100 m × 0.2 = **77×10^8 m^3/a.**

Therefore, **tWRs** for the study area = **38.5×10^8 m^3/a + 77×10^8 m^3/a = 115.5×10^8 m^3/a,** or **1155×10^7 m^3/a.**

5.1.3 Total Dynamic Water Resources (tWRd)

These are equal to the volume of water flowing in a unit of time through a water deposit (surface body or aquifer) and are normally expressed in cubic meters per year (m^3/ year). Total dynamic water resources are divided into surface dynamic water resources (sWRd) and groundwater dynamic water resources (gWRs). Surface dynamic water resources (sWRd) are calculated at entry to a water deposit as surface run-off minus evaporation from the open water table. Groundwater dynamic water resources (gWRs) are calculated at the entry to the aquifer (groundwater deposit) as the volume of rainfall (V_R) minus evapotranspiration (Et), or at exit from the aquifer as base flow, (Shoeneich and Garba, 2010). Therefore, gWRs = V_R – Et.

5.1.4 Total Dynamic Water Resources of the Study Area

Dynamic water resources are related to the climatic condition of an area. The study area lies within the Guinea Savannah region of the country and has tropical climate with moderate rainfall. Any area that lies within savannah region has less dynamic water resources as compared to every other area in the rain forest region of the country Achohwora, (1986).

To calculate the dynamic water resources of the study area, the calculated area of the two different formations in the study area which are equal and is = A = (385 km2 × 2 = 770 km^2 = 770 × 10^6 m^2) is multiplied by the depth of rainfall in the study area as, D = 1,316 mm/a, or 1.316 m/a, (Fig. 10, Appendix I), to give the volume of rainfall $V_{R,}$ (m^3/a).

Therefore, the volume of rainfall (V_R) in the area is = 770 x 10^6 m^2 x 1.316 m **= 1, 013.32 x 10^6 m^3/a.** The coefficient of total runoff (cRt) that corresponds to depth of rainfall of 1,316 mm/a, is 0.45 (Fig. 15), (Schoeneich and Garba, 2010). Therefore, **tWRd** (run-off) of the study area is = 1,013.32 x 10^6 m^3/a x 0.45 = **455,994 x 10^6 m^3/a**. From Ayoade (1975, in Oteze, 1981), the mean annual evapotranspition (Et) from open water table in central Nigeria (including the study area) is 1,067 mm/a**.** Therefore, the annual evapotranspiration in the area is = 1.067 m/a × 770 × 10^6 m^2 **= 821.59 × 10^6 m^3/a**. Hence, the dynamic water resources, **WRd,** of the study area is = 1,013.32 x 10^6 m^3/a – 821.59 m^3/a = **191.73 x 10^6 m^3/a, or 191730000 m^3/a.**

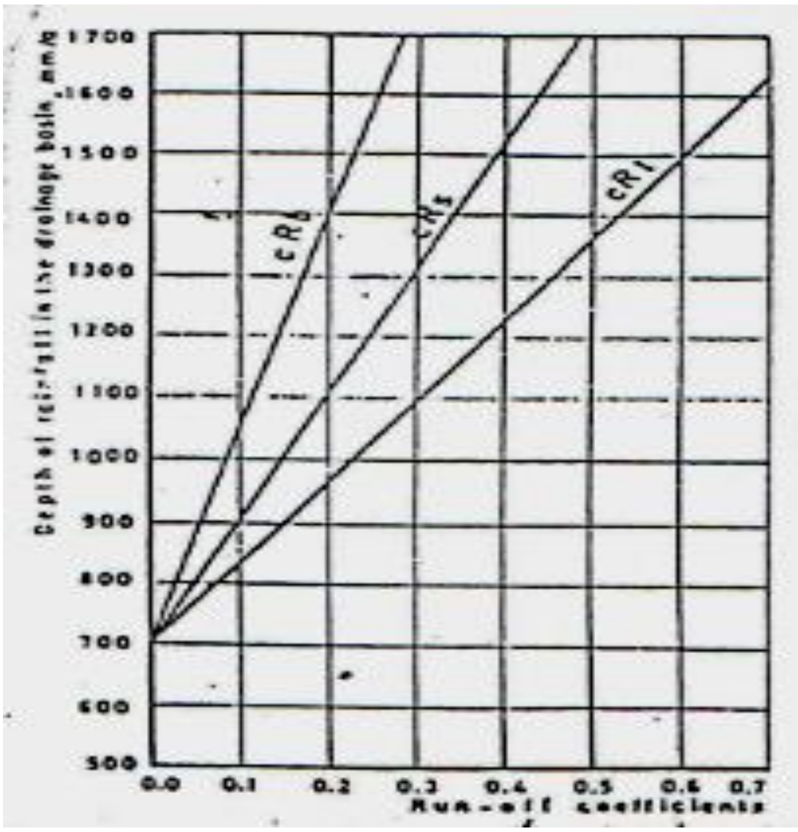


Figure 5.1: Correlation between depth of rainfall and runoff coefficient in drainage basins (Schoeneich and Garba, 2010). Legend: cRt = total runoff coefficient; cRs = surface runoff coefficient; cRb = base flow coefficient

5.1.5 Utilizable Dynamic Water Resources (uWRd)

Schoeneich (1986) in Alagbe (1987) has defined uWRd as "that part of the total dynamic water resources, tWRd, which can be abstracted from a surface or groundwater deposit at a joint, technical (construction and maintenance) and social cost not exceeding the local value of the abstracted water". He put the technical cost as capital cost of constructing the water intake and the recurrent cost of maintenance while the social cost, which is difficult to quantify, is the cost of damage done to the physical and human environment by the lowering of the water table.

5.1.6 Utilizable Dynamic Water Resources of the Study Area (uWRd)

The Utilizable Dynamic Water Resources of Lafia and environs (the study area) can be found based on the following assumptions: out of the total dynamic water resources of the study area, 10 % is set aside for blue belt protection and recharge areas, 20 % is set aside for losses due to evapotranspiration during dry season (821.59 m^3/a), and 20 % is set aside for unaccountable water loss due to wastages and environmental degradation. Therefore Utilizable Dynamic Water Resources will be 50 % of the Total Dynamic Water Resources (tWRd) of the study area, which is uWRd = 45,599,400,000 m^3/a x 50 % = 22,799.7 x 10^6 m^3/a or **22,799,700,000 m^3/a.**

5.2 WATER DEMAND AND CONSUMPTION

5.2.1 Population of Water Consumers

Population is an important aspect of water resources management. For effective water resources management plan, a trend of population growth has to be considered. It is a known fact that since the creation of Nasarawa State in 1996, population of people in the state, including the study area, is increasing on a daily basis. However, only Lafia town in the study area would have many federal government's agencies to be sited which makes it to experience rapid increase in population. Therefore, only Lafia town in the study area falls within the urban residential water consumption category. This is because of the use of modern house hold facilities such as pipe bone water and water system toilets (W.C.).

According to 2006 National Population Census, Lafia and Obi Local Government Areas have a summed population of 479,586 people (Table 9). However, according to 1991 National Population Census which was on locality bases, the population of towns and villages within the study area (Lafia and environs) is summed at 152788, (National Population Commission, 1991). This figure will be used to calculate the population projection in study area from 1991 to 2050 (that is 59 years from 1991). This is because; the population of Nigeria is expected to stabilize by the year 2050. The National Bureau for Statistics put the growth rate of Nasarawa State based on the 2006 population census at 2.9 % = 0.029. For a viable water resources management plan of an area, the planning horizon should be at least for 30 years. Therefore the population of Lafia town and environs is projected for the next 59 years using the formula: **P** e^{rn} **(Kpedekpo, 1982).**

Where P is the present population, e is exponential, r is the population growth rate, and n is the projected year. That is P = 152788, $e^{0.029 \times 59,}$ r = 0.029 and n = 59.

Therefore, population of Lafia and environs in 59 years from 1991 census is: = **P** e^{rn}

152788 $e^{0.029 \times 59}$ = 152788 $e^{1.711}$ = 845,604.1477 people, while that of Lafia town alone is: 78247 $e^{0.029 \times 59}$ = 78247 $e^{1.711}$ = 433,057.4898 people.

Table 5.2: Details of the Breakdown of Nasarawa State Provisional 2006 Census Results by Local Governments (Source: National Population Commission, Lafia)

LGA	Population	Males	Females
Karu	205477	107308	98169
Keffi	92664	47801	44863
Kokona	109749	54941	54808
Akwanga	113430	57023	56407
Wamba	72894	36542	36352
Nasarawa Eggon	149129	77888	71241
Lafia	330712	169398	161314
Awe	112574	56205	56369
Obi	148874	74412	74462
Keana	79253	39233	40020
Doma	139607	70545	69062
Nasarawa	189835	95168	94667
Toto	119077	59092	59985
State Total	1863275	945556	917719

5.2.2 Water Demand in the Study Area

Water use falls into several major classes, each of which is associated with certain quantity and quality requirements (Table 10). These classes include water for drinking and cooking, waste disposal, crop production, aquaculture, livestock, industrial use, recreational use, navigational uses, and ecological values such as survival of natural lake, riverine or wetland communities (Martins, 2001). The quantity of water required for activities within each of these classes is influenced mainly by variables such as climate and precipitation.

Table 5.3: Breakdown of minimum water requirement for an average Nigerian; total water volume of 80 lpcd is required to sustain a moderate living standard (Idowu *et al.*, 1999)

Usage Items	Water Volume Required (lpcd)
Cloth washing	10
Cooking and drinking	10
Utensils	5
Bathing	15
Body washing	5
House cleaning	5
Water closet (WC)	15
Wastage	5
Miscellaneous	10
Total	80

The proportion of total water used for any specific purpose is controlled by socio-economic conditions, tradition, culture and water availability. The human needs about 2-10 litres of water per day for normal physiological functions, depending on the climate and workload. About 1 litre of water is provided by daily food consumption. The total water consumption per capita per day (pcd) is determined by a number of factors, such as availability, quantity, cost income, size of family, cultural habits, standard of living, ways and means of water distribution and climate (World Bank Water Research Team, 1993).

Current water demand in the country is above the current water supply. Water consumption in Lafia town by people is mainly urban residential, while in its environs, it is local consumption. In 2007, Schoeneich in his work on water resources management in Nigeria gave 50 lpcd for urban dwellers and 15 lpcd for rural dwellers. For the purpose of this research, 50 lpcd will be adopted as maximum value including wastages. Therefore, for Lafia town and environs, the maximum value is = 50 lpcd or 0.05 m^3/d x 152788 people = 7,639.4 m^3/d or 2,796,020.4 m^3/a.

Table 5.4: Breakdown of minimum water requirement for the study area; with the total water volume of 50 lpcd required to sustain a moderate living standard (**Source:** Field data, 2012)

Usage Items	Water Volume Required (lpcd)
Cloth washing	10
Cooking and drinking / Utensils	10
Bathing	15
Water closet (WC)	10
Wastage	5
Total	50

As the present water demand for Lafia town and environs, is = 7, 639.4 m^3/d or 2,796,020.4 m^3/a, the projected water demand for 59 years (1991-2050) will be: = 845,604.1477 people x 0.05 m^3/d = 42, 280.20739 m^3/d or **15, 474,555.9 m^3/a.** It is expected that in 59 years from 1991, well advanced and mechanized agriculture will be established and this perhaps will take 20% of the future estimated water demand in the study area, which is 20% of 15, 474,555.9 m^3/a = 3,094,911.18 m^3/a. This gives a total of **18,569,467.08 m^3/a.**

5.3 WATER BUDGET

This is the total accounting of all the inflows, outflows, changes in storage of surface and groundwater resources or reserve in terms of quality and quantity. Groundwater evaluation and budgeting is necessary for effective planning, executing and management of the available water resources. Because of the intensive need of water for utilization by the present population and the time beyond, it becomes imperative to particularly evaluate or computed the quantity and quality of water available in the area of study.

5.3.1 Water Budget for the Study Area

The water tapped by shallow wells (<50 m) from Lafia formation cannot meet the domestic water need of Lafia town except when supplemented with groundwater from deep boreholes (> 50m deep). In 2002, Offodile stated that "proper management practices are necessary to highlight the need and to quantify the available water resources (both surface and groundwater) through a well-coordinated water resources study". But when groundwater in an area is extracted continuously, there is going to be changed in the hydrogeological condition of the area. This will result in increased inflow from other aquifers and increased infiltration from surface water (rivers and streams). All these will increase decompression of abstracted groundwater in the study area. Through these processes, current water demand in the study area will be met.

At the projected time (59 years from 1991), if well advanced and mechanized agricultural system is established in the study area to provide food security, 20 % of the estimated water demand will be allocated to dry season irrigation farming, which is 20 % of 15,474,555.9 m^3/a = **3,094,911.18 m^3/a**. Therefore, projected water demand plus irrigation is = 15,474,555.9 m^3/a + 3,094,911.18 m^3/a = **18,569,467.08 m^3/a**. Since the projected water demand of Lafia and environs is = 18,569,467.08 m^3/a, it means that at the planning horizon in 59 years from 1991, the water to be extracted from the groundwater resources will be = uWRd (resource) **minus** projected water demand (i.e. 22,799.7 x 10^6 m^3/a, or 22,799,700,000 m^3/a – 18,569,467.08 m^3/a) which is = **22,781,130,530 m^3/a (surplus)**. This is summarised in table 12.

Table 5.5: Summary of Water Budget for Lafia and Environs, 1991-2050 (845,(604.1477 people).

Water Resources	Total volume (m^3/a)
Total Static Water Resources (tWRs)	1155 × 10^7 m^3/a
Total Dynamic Water Resources (tWRd)	455,994 × 10^6 m^3/a
Dynamic Water Resources (WRd) i.e. tWRd - Et	191.73 × 10^6 m^3/a
Utilizable Dynamic Water Resources (uWRd)	22,799.7 × 10^6 m^3/a
Projected Water Demand for the people, 1991-2050 (Pwd)	15,474,555.9 m^3/a
Projected water demand for irrigation (Irwd)	3,094,911.18 m^3/a
Projected water demand (Pwd) + water demand for irrigation (Ir)	18,569,911.18 m^3/a
Result = uWRd – (Pwd + Ir)	**22,781,130,530 m^3/a**
Surplus	**22,781,130,530 m^3/a**

Therefore, 18,569,467.08 m^3/a are the projected water demand in the study area that is to be extracted from the groundwater. If this is achieved, the utilizable dynamic groundwater resources of the area which is 22,799,700,000 m^3/a, can meet the projected water demand of the area, 18,569,467.08 m^3/a, and there is going to be a surplus of **22,781,130,530 m^3/a (surplus)** of water deposit. This excess is enough to satisfy the projected domestic demand.

CHAPTER 6

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

6.1 Summary

The area studied lies within part of the Middle Benue Trough in Nasarawa State, North Central Nigeria. It is underlain by the Lafia Formation (youngest), Awgu Formation (underlying) and a small portion of the Asu River Formation (oldest). The distribution and spread of hand dug wells used in this work are as shown on figure 4.1. The difference in geology of the formations (Lafia and Awgu/Asu formations in Fig. 2.3) in the study area gave distinctions in the availability of groundwater such that the Lafia Formation (being sandstones) yields water in economic quantity over the Awgu/Asu Formation (mainly shales) which has more but releases less water due to poor conductivity or interconnectivity of the pore spaces.

The water table contour maps of the study area were constructed using the differences between the elevations of the groundwater surface (amsl) and the water levels (amsl) in hand dug wells. The groundwater flow directions of the aquifers of the study area were drawn in relation to the topography. The contact between these Awgu and Lafia formations has the shallowest water level which recharges the wells in the area for drinking and domestic uses, and the river channel for irrigation purposes as *fadama irrigation farm*.

Assessments of some physical and chemical parameters of groundwater in 20 hand dug wells were carried out in situ and in two other laboratories which 20 samples were analysed. The result of the analysis obtained was compared with the Nigerian Standards for Drinking Water of (SON) 2007, World Health Organisation (WHO) drinking water standards of 2004, 2005, 2011 and Nigerian Industrial Standard, NIS (2007): Nigerian Standard for Drinking Water.

Water quality of the area was determined and analyzed (Table 4.4 and Figure 4.8).

The major ions, Sodium, Na^{+} (9.44 mg/l); Potassium, K^{+}, (8.02 mg/l); Calcium, $Ca^{+,}$ (6.22 mg/l). Copper, Cu^{+2} (0.45 mg/l); Iron, Fe^{+3}, (0.5mg/l); Magnesium, Mg^{+2}, (65 mg/l); Manganese, Mn^{+2}, (0.35 mg/l); Ammonia, NH_3^{+}, (0.8 mg/l); Zinc, Zn^{+2}, (1.76 mg/l); Bicarbonate, HCO_3^{-2}, (156.1mg/l); Chloride, Cl^{-}, (0.69 mg/l); Nitrate, NO_3^{-2}, (2.02 mg/l); Sulphate,SO_4^{-2},(7.0mg/l); fall within the standard limits of SON, WHO and NIS for drinking and domestic uses.

Due to some elements of pollution probably from organic matter or residential effluents, the concentrations of Mg^{+2}, Mn^{+2} and $NO^{-2}{}_3$ are up to the maximum permissible limits of 150 mg/l, 0.2 mg/l and 50 mg/l in some settlements such as Ajerugba and Bukan Buzu. This may result to gastrointestinal disorder, consumer acceptability, neurological disorder and; cyanosis and asphyxia in infant under 3 months as health hazards respectively according to NIS 2007 (Appendix V).

Also based on the analysis, three (3) water-types were established in the area using the AQUACHEM 4.0 software as, Na+K-type, ($HCO^{-}{}_3$)-type and ($HCO^{-}{}_3$) + ($CO^{-2}{}_3$)-type. The origin of these water types is most probably from the interaction of rain water with the atmospheric carbon dioxide (($HCO^{-}{}_3$ and ($HCO^{-}{}_3$) + ($CO^{-2}{}_3$) water-types).

Hydrogeology and water budget of the study area was evaluated to have a surplus. It

was discovered that the utilizable dynamic groundwater resources of Lafia and environs can supplement the water supply from the shallow aquifer in other to meet the current and the future water demand in the area (water budget). The current Water Demand in the study area was determined as 2,796,020.4 m^3/a, whereas the projected water demand is 15,474,555.9 m^3/a. At the planning horizon or level of budgeting, the water demand is 18, 569,467.08 m^3/a.

6.2 Conclusion

This study reveals that shallow wells dug to the depth of about 3 m at the contact between Lafia and Agwu formations yield much water even during the dry season as in the case of those dug to the depth of 100 m and above. Whereas, wells dug in the shallow aquifer of the Lafia sandstone (formation) less than 50 m yield only small amount of water even during the raining season. Experience has shown that, due to the complex nature of the Awgu Formation, any borehole that was cited on the terrain is not productive even if it undergoes a thorough geophysical survey. Therefore, in the Awgu Formation, hand dug wells yield very small amount of water for drinking and domestic use at the peak of dry season even at great depths.

The people at Daddare generally depend on the water issuing out from the contact between the two formations at Unguwar Mamman (2 km from Daddare) during this period.

The contact between these two formations has the shallowest water tables in the area of study. Water which issues from this contact recharges the wells for drinking and domestic uses, and the river channel for irrigation purposes as *fadama irrigation farms*. Groundwater analysis in the study area reveals the classes of the water into 3 types as Na+K-type, (HCO_3^-)-type and (HCO_3^-) + (CO_3^{-2})-type. This shows that some wells seem to be polluted with residential effluents due higher concentrations Mg and Mn. This is because these wells were located within the clusters of residential households in the communities. The element identified in higher concentration in some wells in the analysis is iron (Fe^{+3}) which is most likely derived from the geologically highly ferruginous Lafia sandstone. Verbal discussions with some communities revealed that there was no any health hazard caused by the drinking water. This is because water fetched in a container or local pot, and is left to stand for a period of time reacts with the atmosphere and reduces Fe^{3+} to Fe^{2+} and also undergo many other changes which makes it not to cause any health hazards as in NIS, 2007; Appendix V

Lineament analysis for groundwater exploration in Lafia and environs shows that the study area is underlain by the Awgu (shale) and Lafia Formations. Plots of the lineaments observed on the imagery show dominant trends in NW-SE directions on the Awgu due to shrinkage and Lafia formations (Fig. 4.7, pg. and Lafia formations. Lafia and environs have a total dynamic groundwater resources of 45,599.4 × 10^6 m^3/a, or 45,599,400,000 m^3/a, which can supplement surface water to meet the present and future water demand of people in the area. 2,796,020.4 m^3/a, is the current maximum water demand for an estimated population of 152788 people in the study area. With the projected population of 845,604.1477 people in the next 59 years at the growth rate of 2.9 % in the study area, the demand will be 845,604.1477 people × 0.05 m^3/d which is = 42,280.20739 m^3/d or **15,474,555.9 m^3/a**. During the ultimate planning horizon when the area is expected to have well advanced and mechanized agricultural system, the demand will be = **18,569,467.08 m^3/a**. During that time the area will have a large water resources **surplus** of 455,994,000,000 m^3/a – 18,569,467,08m^a/a = **455975430500 m^3/a**. There is going to be a surplus of **455975430500 m^3/a** of water deposit in Lafia and environs at the projected duration of 59 years, including agriculture. This excess is enough to satisfy the projected domestic water demand. Lineament analysis for groundwater exploration in Lafia and environs shows that the study area is underlain by the Awgu (shale) and Lafia Formations. Plots of the lineaments observed on the imagery show dominant trends in NW-SE directions. The lineament density of the area was calculated using the number of lineaments per unit area (number/km^2) of grid. Two forms of lineament density maps were produced; they are lineament map and lineament density map of the area. These maps show that lineament density is high in areas underlain by the Agwu and Lafia formations covering places like Lafia, Agyaragun Tofa, Agyaragu station, Gwadenye, Mararraba Akunza, Akunza Jarme, Akanga, Bukan Kwato, Bukan Fadama, Bukan Tambari, Gandu,Gimare, Wakwa, etc, in the north and Akanga, Akaleku and Adevi in the south. Result from the lineament analysis shows that groundwater potential is high in areas with high lineament density. Surface water and groundwater exploitation structures should be constructed taking cognisance of the high lineament density areas and the general lineament strike orientation directions in the area.

6.3 Limitation

The limitation encountered from the beginning of the research to its completion was the unavailability of geophysical and pumping test data from the State Ministry for Water Resources and private companies carrying out drilling activities. This hinders the calculations and computations of: Hydraulic Conductivity, K; Storativity, S and Transmisivity, T of the area of study as can be seen in table 2 (pg. 21).

6.4 Recommendations

Due to the roles that groundwater resources play in meeting the water needs for the people of the area and their animals, it is therefore very important to control and manage it for sustainable development and economic advancements of the people. In light of this, the followings are recommended;

1. Wells and boreholes should be dug or drilled to the depth of more than 50 m below ground level in the Lafia formation within the area of study. This is particularly due to the fact that the area is made up of sedimentary formations that have deep seated potential aquifers.

2. Due to the complex and unproductive nature of the Agwu formation, any borehole that is to be sited on the terrain should undergo a thorough geophysical survey.

3. Wells should be located far from areas with residential effluents such as toilets, soak away and waste bins or pits, or even at the outskirts of towns and villages to avoid contamination. This is because residential effluents such as toilets soak away, waste bins or refuse dumps pollut the wells which contaminate the groundwater and this pose health hazards to life.

4. In the communities or residences that must unavoidably consume or use the only available contaminated or polluted water, fresh and potable water from other areas should be use for drinking to avoid chemical hazards to the body from the water. Boiling water before use also reduces and gets rid of or kills micro- organisms contained in the water due to residential effluents.

5. In communities like Daddare, Tudun Adabu and Adabu that are situated on the Agwu Formation, the only way to alleviate the people from water scarcity is by building a mini dam or an impounding reservoir down/or along the river catchment or watershed at the contact between the two formations at Unguwar Mamman near Daddare. The water that issues out from this contact can be used if properly developed and maintained.

6. There should be efficient management of water resources in the study area if the health and well-being of the people is of utmost importance, particularly in the rural areas where safe potable water is not readily available; Care should be taken to make sure that the rate of groundwater exploitation does not exceed the recharge rate in order to avoid mining of the aquifer, which could have grave environmental consequences.

7. Access to safe drinking water is essential to health, indeed a basic human right and a component of effective policy for health. The importance of water, sanitation and hygiene for health and development has been rightly emphasized in the outcomes of a series of international policy forums especially the Millennium Development Goal Number 7 which is concerned with providing access to safe drinking water to over 1 billion slums dwellers.

8. An impounding reservoir is needed to be constructed downstream the Lafia drainage basin at western part of Lafia, to conserve and store huge dynamic water resources so as to meet the current and future water demand of people of the area through surface water supply. When this is constructed it can also be used for irrigation farming during the dry season at the downstream of the reservoir drainage basin. It can also reduce groundwater abstraction thereby saving the environment from degradation.

6.5: CONTRIBUTIONS TO KNOWLEDGE

1. Producing geological, hydrogeological and groundwater table maps.
2. Providing the present state of the quality of water that people use considering the rapid population growth of the study area (due to state creation).
3. Providing account or estimate of calculated water budget for the study area.
4. Help to control and manage the groundwater resources of the area for sustainable development.
5. To enlighten, alert and create awareness to the Ministry for Water Resources, Nasarawa state on the areas that might have polluted aquifers due to high population which could lead to health hazards if used for domestic purpose.
6. To demarcate between areas of high and low groundwater potentials in the study area.

REFERENCES

Achohwora, P. (1986). *Some Hydrogeological Aspects of the Lafia Coal Deposit. Plateau State.* (Unpublished master's thesis). Ahmadu Bello University, Zaria. p. 1 - 37.

Aku, I. M. (1983).*Groundwater Resources of the Lafia Water Catchment Area. Plateau state, Nigeria.* (Unpublished master's thesis). Ahmadu Bello University, Zaria. p. 3.

Alagbe, S.A. (1987). *Hydrogeology of the River Kangimi Catchment Area, Kaduna State.* (Unpublished M.Sc. Thesis). Ahmadu Bello University, Zaria. pp. 73-82.

Appelo, C.A.J. and Potma .D, (2005). *Geochemistry, groundwater and pollution.* Mc Graw Hill Higher Education, New Jersey, (2nd edition).

Ariyo, S.K. (1987).*The Economic Significance of the Palaeontology of Obi/Lafia Coalfield, Plateau State, now Nasarawa State, Nigeria.* (Unpublished master's thesis). Geology Deparment, Ahmadu Bello University, Zaria. p. 4 - 6.

Bako, A.S.J., (2010). *Geothermal Energy Potential in the Part of Middle Benue Trough Located in Nasarawa state.* (Unpublished master's thesis). Ahmadu Bello University, Zaria. p. 12.

Benkhelil, J. 1989. The origin and evolution of the Cretaceous Benue Trough (Nigeria). *Journal African Earth Sciences* 8, 251 – 282.

Bouwer, H. (1979). *Groundwater Hydrology*. (P. 210). McGraw Hill, New York.

Cratchley, C.R. and Jones, G.P. 1965. An Interpretation of the geology and gravity anomalies of the Benue Valley, Nigeria. *Overseas Geological Surveys Geophysical Paper* 1, p. 1-26.

GSN, (2006) Geological Survey of Nigeria. Map of Nigeria 1:2000, 000. *Published by Geological Survey of Nigeria (GSN).*

G.K. Anudu, B.I. Essien, L.N. Onuba and A.E. Ikpokonte, 2011.Lineament Analysis and Interpretation for Assessment of Groundwater Potential of Wamba and Adjoining Areas, Nasarawa State, Northcentral Nigeria. *Journal of Applied Technology in Environmental Sanitation, 1 (2): 185-198.*198

Idowu, O. A., Ajayi, O. and Martins, O. (1999); Occurrence of Groundwater in Parts of Dahomey Basin, Southwestern Nigeria. *Nigeria Journal of Mining and Geology 35 (2)*

Kachalla, M. (2011).*Groundwater occurrence in Damaturu and its environs, Yobe State, North Eastern Nigeria.* (Unpublished master's thesis) Department of Geology, Ahmadu Bello University, Zaria. pp. 1 – 75.

Kana, M.A. (2013). *The Hydrogeologigy and Water Supply Situation in Nasarawa town and Environs, Nasarawa state.* (Unpublished master's thesis). Department of Geology, Ahmadu Bello University, Zaria. pp.18 - 55.

Kpedekpo, G. M. K. (1982). *Essentials of Demographic Analysis in Africa* Publication of Heinemann London, PP 159-172..

Macaulay, O. O. (2008) *Revision Notebook on Hydrogeological Practices, with application to Nigerian Groundwater Terrains.* PIOS Publications, Ilorin. P.34

Martins, O. (2001) Water Resources Management and Development in Nigeria- Issues and Challenges in a New Millennium. *Netherlands Journal of Sea Research 22 (2) 1-59.*

Najime, T. (2010.). *Geology 803 Preparation and Analysis of Geochemical Samples, Lecture notes.*

Nasarawa State Ministry for Water Resources, Lafia, (2011). Characteristics some Sedimentary Aquifers in Nas. St. part of the Middle Benue Trough. Field records.

Nasarawa State Ministry of Information, Lafia. Political map (modified 2011).

National Population Commission, Lafia, (1991). Final Results of 1991 Population Census of Nigeria

National Population Commission, Lafia, (2006). Details of Breakdown of Nasarawa State Provisional 2006 Census Result By Local Government Area.

Nigerian Meteorological Agency (NIMET), Lafia (2012). Records of meteorological data 2001-2011.

NIS (2007): Nigerian Industrial Standard, Nigerian Standard for Drinking Water Quality Physical / Organoleptic Parameters, p.554

Nwajide, C.S. (1985). A systematic lithostratigraphy of the Makurdi Sandstones, Benue Trough. *Journal of Mining and Geology* 22, p. 9-23.

Obaje, N. G.(1994). Coal petrography, microfossils and paleoenvironments of Cretaceous caol measures in the middle Benue Trough of Nigeria. *Tubinger Mikropalaontlogische Mittei lungen* 11, pp 1-150

Offodile, M. E. (1976). The Geology of the Middle Benue Trough, Nigeria. Publication from the Palaeontological Institution of the University of Uppsala vol. 4, p 1- 167.

Offodile, M.E. (1976). A Review of the Geology of the Cretaceous of the Benue Valley, in Geology of Nigeria. Edited by Kogbe, C.A. .Elizabeth Publishing Co. Lagos, pp .319-330.

Offodilie, M.E. and Rayment, R.A. 1977. Stratigraphy of the Keana – Awe area of the middle Benue region of Nigeria. *Bulletin Geology Institutions University, Uppsalla (N.S.) 7, pp. 37-66.*

Offodile, M.E. (2002).Groundwater Study and Development in Nigeria. Mecon Geology and Engineering Services Ltd. Jos, Nigeria.

Oteze, G,E, (1981) Water Resources in Nigeria. *Journal of Environmental Geology 3, 177 84, Springer-Verlag New York Inc.*

Piper, A.M. (1944) A graphic procedure in the geochemical interpretation of water analysis Trans Am Geophy 25(6):914–928

Rex, B. and Robert, W.B. (1993).Kansas Groundwater. An Introduction to the State`s Water Quality, Quantity and Management Uses.

Schoeneich, K. and Garba, M.L. (2010). *Geol.405 Hydrogeology*: *Undergraduate lecture Notes.* Geology Department. Ahmadu Bello University, Zaria.

Schoeneick, K.(2001). *Geol. 809 Water quality: Lecture notes in hydrogeology.* Ahmadu Bello University, Zaria.

Schoeneick, K.(2007). Nigeria's Water Resources. *Printout from Borno Journal of Geology, Vol. 4, No. 2, pp 39 – 72.*

Standard Organisation of Nigeria (SON 2007). Nigerian Standards for Drinking Water.

Tijani, M.N.,(2004).Evolution of saline waters and brines in the Benue Trough, Nigeria *Journal of Applied Geochemistry vol. 19. Pp. 1355-1365.*

Todd, D. K, (1980). Groundwater Hydrology. John Willey and Sons, New York, p 42.

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

World Health Organisation (WHO, 2005): International Standards for Drinking Water.

World Health Organisation (WHO, 2003 and 2011); Standard Permissible Limit for Physical and Chemical Parameters of water for drinking and domestic use.

World Health Organisation (W.H.O.,(2006). Guidelines for Drinking Water Quality, Water Sanitation and Health Vol.1.

World Bank Water Research Team, (1993), The Demand for Water in Rural Areas: Determination and Policy Implication: The World Bank Research Observer 8(1)

p. 47-70.

Zaborski, P.M. (1998). A Review of the Cretaceous System in Nigeria. *Africa Geosciences Review, Vol.5, No.4. pp -387.*

APPENDICES

APPENDIX I

Table 1.1: Mean Monthly Rainfall Depth (in mm) from 2001 to 2011 **(Source:** NIMET, Lafia).

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Mean
Jan	0	0	0	0	0	0	0	0	0	0	0	0.0
Feb	0	0	26	0	0	0	0	0	0	0	9.3	3.2
Mar	0.4	0	0	0	58	40	21	14	0	0	0	12
Apr	118	55	109	148	43	1.9	89	92	128	75	28	81
May	205	143	170	159	162	225	164	181	190	116	198	176
Jun	231	48	128	181	106	166	255	229	324	125	222	183
Jul	278	298	262	268	242	304	244	188	230	382	74	252
Aug	312	337	266	283	356	251	233	241	193	230	275	271
Sep	216	162	319	183	154	248	274	109	146	312	228	214
Oct	54	139	105	84	169	84	0	77	376	177	227	136
Nov	0	12	24	0	0	0	0	0	8.8	20	0	5.9
Dec	0	0	0	0	0	0	0	0	0	0	0	0.0
Total	1415	1192	1406	1305	1129	1319	1279	1136	1595	1438	1261	**1316**

Table 1.2: Mean of Monthly Temperature (^{0}c) from 2001-2011. (Source, NIMET, 2012)

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Jan	26.7	0	0	27.3	26.5	29.5	26.5	29.8	29	33.2	26.3
Feb	29.15	37.1	0	29.4	32	31.4	30.5	31.8	31.4	32.1	30.6
Mar	32.55	0	32.4	31.6	32.3	31.6	31.9	32	33.1	32.3	32.6
Apr	30.6	0	30.1	30.3	30.6	32.8	31.3	30.8	30.6	32.3	30.7
May	28.6	34.3	30.7	28.4	29	28.5	28.9	28.7	29.4	29.3	29.8
Jun	27.45	33.1	27.2	27.1	27.5	27.9	27.4	27.8	27.5	23.6	26.6
Jul	26.65	31	26.9	26.6	26.9	27.5	27.1	27.3	27.1	27	27.7
Aug	25.85	0	26.7	26.5	26.6	26.6	26.1	26.8	27.2	26.8	26.6
Sept	26	0	26.5	26.6	27	27.6	0	27.5	27.3	26.9	27.1
Oct	27.6	0	28	27.9	27.5	28.1	0	28.5	27.3	27.8	27.5
Nov	27.75	0	28.2	23.2	28.3	27.5	0	28.8	27.8	28.9	27.5
Dec	25.7	0	26.3	27.1	27.7	26.5	0	28.1	27.3	26.8	26.3
Total	2335.6	135.5	283	332	341.9	345.5	229.7	347.9	345	347	339.3
Mean	27.9	11.3	23.6	27.7	28.5	28.8	19.1	29.0	28.8	28.9	28.3

Table 1.3: Monthly Mean of Maximum Temperature (^0C) (Source, NIMET, Lafia, 2012)

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Jan	35.9	35.5	34.4	36.2	35.1	37.1	35.3	37.5	36.5	39.5	35.5
Feb	36.9	37.1	38.6	37.2	39	37.6	38.4	37.8	38.5	39.1	37.4
Mar	38.8	40	39.1	38.8	39.8	37.2	38.5	41	39.7	39	39.1
Apr	36.2	37.2	36	35.2	36.2	39	36.1	39.7	35.5	37.5	36.1
May	33.8	34.3	35.6	32.4	33	33.3	33	33.7	34	34.1	34.3
Jun	31.9	33.1	31.4	31.1	31.3	32.2	31	31.8	31.9	32.5	30.3
Jul	30.1	31	30.9	30.4	30.8	31.5	31	30.8	30.9	30.5	31.6
Aug	29.7	29.8	30.6	30.5	30	30	29.3	30.4	30.7	30.2	29.8
Sept	29.6	31.5	30.7	30.8	31	32.2	30.6	31.6	31.5	30.5	31
Oct	33.1	31.2	32.9	32.9	32.2	33	32.7	33.4	31.7	31.8	31.9
Nov	36	34.5	35.5	35.2	36.5	35.9	35.5	36.7	34.2	35	35.6
Dec	35.7	35.6	35.9	36.4	36.3	35.9	35.6	36.3	36.7	36.3	35.7
Mean	34.0	34.2	34.3	33.9	34.3	34.6	33.9	35.1	34.3	34.7	34.0

Table 1.4: Monthly Mean of Minimum Temperature (^0C) (Source, NIMET, 2012)

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Jan	17.5	19.2	18.3	18.4	18	21.9	17.7	22	21.5	26.8	17.1
Feb	21.4	23.4	22.2	21.6	25	25.2	22.5	25.8	24.3	25	23.8
Mar	26.3	26.2	25.6	24.4	24.8	26	25.2	23	26.4	25.6	26.2
Apr	25	25.3	24.1	25.4	25.6	26.6	26.5	21.8	25.7	27.1	25.3
May	23.4	24.5	25.1	24.4	25	23.8	24.8	23.7	24.4	25.6	25.4
Jun	23	24.1	23	23.1	23.8	23.7	23.7	23.8	23.2	24.7	23.3
Jul	23.2	23	22.9	22.8	23	23.4	23.2	23.8	23.3	23.5	23.8
Aug	22	22	22.7	22.6	23.2	23.2	22.8	23.2	23.6	23.5	23.4
Sept	22.4	22.6	22.3	22.4	23	23	22.7	23.4	23.2	23.4	23.1
Oct	22.1	22.3	23.1	23	22.8	23.3	22.6	23.7	22.8	23.8	23.1
Nov	19.5	20.4	20.9	21.1	20.1	19.2	18.8	20.9	21.5	23.8	19.5
Dec	15.7	15.8	16.7	17.7	19	17	16.7	19.8	17.7	17.3	16.9
Mean	21.8	22.4	22.2	22.2	22.8	23.0	22.3	22.9	23.1	24.2	22.6

Table 1.5: Relative Humidity at 0900Z (%), (10:00a.m. local time) (Source: NIMET, Lafia, 2012)

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Jan	30	37	48	41	38	58	32	35	53	54	46
Feb	37	45	54	42	57	60	45	33	57	56	49
Mar	58	60	50	45	51	62	52	59	54	53	53
Apr	68	70	70	69	55	59	68	66	70	63	58
May	75	75	71	78	65	76	77	75	75	76	69
Jun	80	76	81	90	81	81	84	83	80	80	89
Jul	85	85	83	86	85	82	84	83	84	84	91
Aug	88	86	86	88	85	87	88	86	86	86	87
Sept	85	84	86	78	84	85	83	80	83	85	83
Oct	77	81	80	61	85	80	68	74	81	81	79
Nov	56	56	58	55	54	47	50	53	57	68	56
Dec	37	38	41	48	52	37	43	53	40	36	35
Mean	64.7	66.1	67.3	65.1	66.0	67.8	64.5	65.0	68.3	68.5	66.3

Table 1.6: Monthly Means of Evaporation (Aver. mean evaporation = 4.2) **Source:** NIMET, Lafia, 2012

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Jan	8.7	8.1	6.8	8.5	9	6.3	10	9.2	7	7.8	2.4
Feb	10.4	9.4	7.5	6.8	8.2	7.1	9.9	11.6	6.8	8.2	2.1
Mar	8	9	8.4	10.4	7.7	6.8	8.9	7.4	5.6	9.5	2.4
Apr	3.9	7.8	4.6	5.1	5.2	8.1	5.7	5	5.1	7	2.1
May	3.3	3.4	4.4	4.4	4.6	3.5	2.9	2.7	4.8	3.5	1.9
Jun	2.4	3	1.8	3.5	2.4	2.3	2	2.3	2.9	2.7	1.3
Jul	1.8	1.8	1.7	1.7	1.9	1.8	2	2.4	1.8	1.8	1.5
Aug	1.5	1.4	1.5	1.5	1.8	1.6	1.8	1.7	1.6	1.5	2.1
Sept	1.4	1.7	1.6	1.9	1.9	1.9	1.7	2	2	1.6	1.9
Oct	2.6	2	2.1	2.4	1.8	2.3	4.5	2.7	2.1	1.9	2.2
Nov	5.6	4.8	4.7	5	5.6	6.4	5.8	6.3	4.8	3.9	6.2
Dec	10.8	7.4	7.4	6.8	6.6	8.3	7.3	6.9	7.6	7.3	8.2
Total	60.4	59.8	52.5	58	56.7	56.4	62.5	60.2	52.1	56.7	34.3
Mean	5.02	5.0	4.4	4.8	4.7	4.7	5.2	5.0	4.3	4.7	3.0

APPENDIX II

Nigerian Standards for Drinking Water (after SON 2007)

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

APPENDIX III

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

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

APPENDIX IV: International Standards for Drinking Water (WHO, 2005)

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

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

Parameter	Unit	Maximum permitted levels	Health impact	Note
Aluminium (Al)	mg/l	0.2	Potential neuro-degenerative disorders	Note 1
Arsenic (As)	mg/l	0.01	Cancer	
Barium (B)	mg/l	0.7	Hypertension	
Cadmium (Cd)	mg/l	0.003	Toxic to the kidney	
Chloride (Cl)	mg/l	250	None	
Chromium (Cr^{6+})	mg/l	0.05	Cancer	
Conductivity	µS/cm	1000	None	
Cupper (Cu^{2+})	mg/l	1	Gastrointestinal disorder	
Cyanide (CN^-)	mg/l	0.01	Very toxic to the thyroid and the nervous system	
Fluoride (F^-)	mg/l	1.5	Fluoresces, skeletal tissue morbidity	
Hardness ($CaCo_3$)	mg/l	150	None	
Hydrogen Sulphide (H_2S)	mg/l	0.05	None	
Iron (Fe^{+2})	mg/l	0.3	None	
Lead (Pb)	mg/l	0.01	Cancer, Interference with Vitamin D metabolism, etc.	
Magnesium (Mg^{+2})	mg/l	0.20	Consumer acceptability	
Manganese (Mn^{+2})	mg/l	0.2	Neurological disorder	
Mercury (Hg)	mg/l	0.001	Affect the kidney and central nervous system	
Nickel (Ni)	mg/l	0.02	Possible carcinogenic	
Nitrate (NO_3)	mg/l	50	Cyanosis and asphyxia in infant under 3 months	

Nitrite (NO_2)	mg/l	0.2	Cyanosis and asphyxia in infant under 3 months	
pH	mg/l	6.5-8.5	None	
Sodium (Na)	mg/l	200	None	
Sulphate (SO_4)	mg/l	100	None	
Total Dissolved Solids	mg/l	500	None	
Zinc (Zn)	mg/l	3	None	

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

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

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

APPENDIX VII: Measurements of depth to water table in hand dug wells at the peak or end of rainy season (October), 2011 **(Source:** Field data, April, 2012).

S/N	Location Description	Coordinates Of locations Lat. (^{0}N) Long. (^{0}E)	Date of msmts inrainy season	Well Elevations (masl/ftasl)	Depth to W/T (masl,ftasl)	Elevatn of w/ t (masl, ftasl)
1	GidanUsman Ma'aji Daddare 1	8^{0}26'59.7"N 08^{0}42'23.4"E	15/10/ 2011	195 643.5	1.3 4.29	194 637
2	Agewu, Daddare 2	8^{0}27'20.8"N 08^{0}42'24.7"E	"	184 607.2	1.1 3.63	183 600
3	Agewu, Daddare 3	8^{0}27'09.5"N 08^{0}42'06.9"E	"	156 514.8	3.5 11.55	153 502
4	U.Murtala conc well	8^{0}26'30.2"N 08^{0}42'02.9"E	"	206 679.8	4 13.2	202 663
5	Ung Ado conc well	8^{0}26'05.0"N 08^{0}42'34.5"E	"	206 679.8	4.3 14.19	202 663
6	Gd.Alhassan Liman Daddare	8^{0}26'04.9"N 08^{0}42'04.0E	"	206 679.8	10.5 34.65	196 643
7	Gidan Alh. Borno	8^{0}26'48.9"N 08^{0}42'44.1E	"	217 716.1	9.5 31.35	208 682
8	Tudun Adabu PHC Clinic	8^0 25' 15.5"N 08^{0}40'47.5"E	"	222 732.6	6 19.8	216 709
9	Odobu1 gd Danlami well	8^{0}24'55.0"N 08^{0}44'02.8"E	"	214 706.2	4 13.2	210 689
10	Odobu 2	8^{0}24'55.7"N 08^{0}44'04.7"	"	215 709.5	4.4 14.52	211 692
11	Gidan Ipaa. Odobu	8^{0}24'46.7"N 08^{0}44'18.0"E	"	219 722.7	7.2 23.76	212 696
12	Tudun / Adabu 3	8^{0}25'32.5"N 08^{0}43'42.0"E		223 735.9	4.4 14.52	219 719
13	Tudun /Adabu 4	8^{0}25'35.5"N 08^{0}43'51.7"E	"	232 765.6	7.5 24.75	225 738
14	Govt Sec Sch Daddare	8^{0}27'00.3"N 08^{0}42'06.2"E	16/10/ 2011	208 686.4	4.9 16.17	203 666
15	Daddare Ctrl Msq cncrt Well	8^{0}26'41.7"N 08^{0}42'23.6"E	"	199 656.7	3.4 11.22	196 643
16	Ung Mamman central Msq.	8^{0}27"18.0'N 08^{0}41'39.8"E	"	207 683.1	3.1 10.23	204 669
17	Ung. Mamman Borehole	8^{0}27'12.5"N 08^{0}41'37.1"E	"	213 702.9	5.1 16.83	208 682
18	Ung Mamman western well	8^{0}27'14.1"N 08^{0}41'34.5"E	"	207 683.1	4.7 15.51	202 663
19	Ung. Sule.Gd Hussaini Aku	8^{0}27'23.5"N 08^{0}41'13.6"E	"	216 712.8	3.0 9.9	213 699
20	Ung. Sule Soda Factory	8^{0}27'25.2"N 08^{0}41'00.2"E	"	213 702.9	4.9 16.17	208 682
21	Ung. Hamidu concrete well	9^{0}27'27.0"N 08^{0}40'50.4"E	"	211 696.3	3.5 11.55	208 682
22	Kaduna Koro Gidan Ogu	8^{0}27'19.6"N 08^{0}39'59.6"E	"	209 689.7	5.7 18.81	203 666

23	Kaduna Koro Gidan Giwa	$8^0$27'18.7"N $08^0$39'57.5"E	"	167 551.1	6.3 20.79	161 528
24	Kaduna Koro gd Michael Ila	$8^0$27'17.1"N $08^0$40'00.7"E	"	226 745.8	5.0 16.5	221 725
25	Agwade mission Gidan Solo Tukura	$8^0$27'03.1"N $08^0$39'31.6"E	"	224 739.2	5.0 16.5	219 719
26	Agwade mission gidan James Ajeh	$8^0$27'03.5"N $08^0$39'34.5"E	"	222 732.6	5.5 18.15	217 712
27	Ung Amaku 1 Gd. Agya Audu	$8^0$26'42.1"N $08^0$29'09.4"E	"	240 792	7.7 25.41	232 761
28	Ung Amaku 2 Gd. Danj .Simon	$8^0$26'39.2"N 08^0'39'14.4"E	16/10/ 2011	234 772.2	8.1 26.73	226 742
29	Ung Amaku 3G. A. Akwayi	$8^0$26'41.5"N $08^0$39'13.6"E	"	236 778.8	8.5 28.05	228 748
30	U.Kasuwa 1Gd Yakub Makam	$8^0$26'46.7"N $08^0$38'52.9"E	"	232 765.6	7.5 24.75	225 738
31	Ung Kasuwa 2 Behnd Baptist ch	$8^0$26'50.8"N $08^0$38'42.7"E	"	232 765.6	7.7 25.41	224 735
32	Mutum DayaG.Yakubu Kb	$8^0$27'29.3"N $08^0$38'27.6"E	"	235 775.5	6.7 22.11	228 748
33	Mutum Daya Gidan Ogesa	$8^0$27'39.6"N $08^0$39'12.4"E	"	246 811.8	12.8 42.24	233 764
34	Agudu 1 Gd Agwade	$8^0$27'54.4"N $08^0$37'35.8"E	17/10/ 2011	221 729.3	10 33	211 692
35	Agudu 2 Int'l. pri. sch.	$8^0$28'01.2"N $08^0$37'26.1"E	"	244 464.2	10.2 33.66	234 768
36	Ung Ayaba. Gidan mai ungwa	$8^0$28'06.5N $08^0$37'10.2"E	"	138 455.4	9.5 31.35	129 423
37	Kantsakuwa.Kunwarke clinic	$8^0$28'14.1"N $08^0$36'39.1"E	"	219 722.7	3.0 9.9	216 709
38	Akunza Jarme central Msq	$8^0$28'09.9"N $08^0$35'56.5"E	"	214 706.2	3.5 11.55	211 692
39	Akunza Ubangri PHC clinc	$8^0$28'18.6"N $08^0$35'21.1"E	"	208 686.4	3.0 9.9	205 673
40	Bukan kwato Ekoson clinic 1	$8^0$27'51.5"N $08^0$34'22.3"E	"	200 660	6.6 21.78	193 633
41	Bukan kwato Ekoson clinic 2	$8^0$27'51.6"N $08^0$34'23.3"E	"	139 458.7	5.9 19.47	133 436
42	Buk.kwato near the river	$8^0$27'23.2"N $08^0$34'12.1"E	"	178 587.4	5.2 17.16	173 568
43	Akunza Koro 1 Yam mrkt Mkd road	$8^0$26'17.3"N $08^0$34'11.3"E	"	165 544.5	3.7 12.21	161 528
44	Akunza Koro 2 Mkd rd. Gidan Clement Adagba	$8^0$25'59.3"N $08^0$34'20.9"E	"	132 435.6	3.3 10.89	129 423
45	Murya 1Gidn Mailafiya	$8^0$24'53.8"N $08^0$33'41.0"E	"	219 722.7	11.2 36.96	208 682
46	Murya 2 PHC clinic conc well	$8^0$24'54.7"N $08^0$33'46.2"E	"	229 755.7	7.0 23.1	222 728

47	Agyaragu Borehole	8^{0}23'59.2"N 08^{0}33'03.3"E	"	211 696.3	9.5 31.35	202 663
48	Agyaragu ERCC churc No. 1.Gd Hassan	8^{0}23'55.4"N 08^{0}32'36.7"E	"	227 749.1	9.2 30.36	218 715
49	Gwadenye 1 Zhe migili rdAgyaragu	8^{0}23'33.1"N 08^{0}33'10.9"E	"	226 745.8	2.2 7.26	224 735
50	Gwadenye 2 Alh. Dantsoh fill,stn GdAlabi Ida	8^{0}23'37.6"N 08^{0}33'12.5"E	"	225 742.5	2.8 9.24	222 728
51	Mutum daya Gidan Zawee	8^{0}22'30.2"N 08^{0}33'17.7"E	18/10 2011	218 719.4	9.0 29.7	209 686
52	Mutum daya 2 Gd Batuu	8^{0}22'28.8N 08^{0}33'13.4"E	"	196 646.8	9.2 30.36	187 614
53	Akaleku 1 Gidan Udam	8^{0}20'45.2"N 08^{0}34'00.2"E	"	201 663.3	2.9 9.57	198 650
54	Akaleku 2 Gidan Sarkin Akaleku	8^{0}20'14.9"N 8^{0}34'03.6"E	"	223 735.9	2.3 7.59	221 725
55	Adevi concrete well	8^{0}19'15.6"N 08^{0}33'54.3"E	"	243 801.9	6.1 20.13	237 778
56	Adevi Gidan Waya	8^{0}18'36.3"N 08^{0}33'47.4"E	"	248 818.4	6.2 20.46	242 793
57	Akanga. Gd. Ladan	8^{0}17'41.6"N 08^{0}33'41.7"E	"	232 765.6	14.5 47.85	218 715
58	Kayarda Msq Gd Usman Eka	8^{0}23'49.0"N 08^{0}31'38.0"E	"	214 706.2	9.3 30.69	205 673
59	Jerugba. Gd Ilesha Ibrahim	8^{0}23'01.8"N 08^{0}30'55.3"E	"	207 683.1	4.4 14.52	203 666
60	Jerugba Gd Iliya Akwe	8^{0}22'54.3"N 08^{0}30'48.5"E	"	213 702.9	4.0 13.2	209 686
61	Gidan Ausa.Pri. Sch.	8^{0}24'22.9"N 08^{0}29'49.8"E	"	189 623.9	2.5 8.25	187 614
62	Duduguru Mkt sq c/well Ung.kasuwa	8^{0}24'57.0"N 08^{0}35'31.4"E	"	165 544.5	1.3 4.29	164 538
63	Akaba Gidan Mailafiya	8^{0}22'37.3"N 08^{0}36'52.3"E	"	184 607.2	3.6 11.88	180 591
64	Akaba (farm) concrete well	8^{0}22'1.0"N 08^{0}37'07.8"E	"	177 584.1	0.0 0.0	177 581
65	Ome Gd Michael Obadiah	8^{0}21'30.6" 08^{0}39'48.6"E	"	175 577.5	5.20 17.16	170 558
66	Ome Gd, Emma Yakub	8^{0}21'34.2"N 08^{0}39'59.7"E	"	171 564.3	6.7 22.11	164 538
67	Atabla Gidan Samuel Ayimadu	8^{0}21'13.3"N 08^{0}41'41.3"E	"	174 574.3	3 9.9	171 561
68	Atabla conc well mkt sq	8^{0}20'59.9"N 08^{0}41'39.6"E	"	169 557.7	3.5 11.55	166 545
69	Ashupe Gd Michael Jonathn	8^{0}24'55.6"N 08^{0}40'09.1"E	"	203 669.9	6.6 21.78	196 643
70	Ashupe Gd. Jonathan Anjebe	8^{0}25'07.2"N 08^{0}40'04.5"E	"	204 673.2	10.2 33.66	194 637

71	Mararabar.Gandu Mkd rd	8^{0}28'48.7"N 08^{0}33'58.7"E	20/10/ 2011	167 551.1	2.4 7.92	165 541
72	Old Gandu Conc. Well	8^{0}29'09.2"N 08^{0}34'07.1"E	"	170 561	5.6 18.48	164 538
73	Wakwa Alh.central msq.	8^{0}29'47.0"N 08^{0}34'21.4"E	"	187 617.1	7.2 2376	180 591
74	Gimare Gidan Salihu Ibrahim	8^{0}29'27.4"N 08^{0}33'27.0"E	"	189 623.7	6.2 20.46	183 600
75	Tudun kwashini gid. Mai Ung	8^{0}29'38.8"N 08^{0}32'46.7"E	"	210 693	7.0 23,1	203 666
76	Lafia behind NEPA Hqtrs.	8^{0}29'25.9"N 08^{0}31'25.7"E	"	177 584.1	21.7 71.61	155 509
77	Lafia Tudun Kauri /NYSC Hqs	8^{0}29'08.2"N 08^{0}31'57.2"E	"	180 594	12.0 39.6	168 551
78	Agyaragun Tofa conc Well	8^{0}26'58.9"N 08^{0}32'35.8"E	21/10/ 2011	189 623.7	2.8 9.24	186 610
79	Bukan Tambari conc. Well	8^{0}26'39.4"N 08^{0}32'39"E	"	189 623.7	6.0 19.8	183 600
80	Bukan Buzu central Msq	8^{0}26'17.6"N 08^{0}31'19.1"E	"	190 627	4.4 14.52	186 610
81	Akwangwa 1 prim. sch.	8^{0}25'45.2"N 08^{0}30'46.0"	"	181 597.3	1.6 5.28	179 587
82	Akwangwa 2 kofar Agya concrete well	8^{0}25'36.1"N 08^{0}30'36.5"	"	170 451	4.2 13.86	166 545
83	Bukan Fadama conc well	8^{0}27'43.7"N 08^{0}31'00.8"E	"	160 528	2.4 7.92	158 518

APENDIX VIII: Measurements of depth to water table in hand dug wells at the peak or end of dry season (April, 2012.) **(Source:** Field Data)

S/N	Location description	Coordinates of locations. Lat. (^{0}N) Long. (^{0}E)	Date of Msmts	Well Elevn (masl, ftasl)	Depth to W/T (mbg/ ftbgl)	Elevn of W/T (masl, ftasl)
1	G/UsmanMa'aji Daddre 1	8^{0}26'59.7"N 08^{0}42'23.4"E	05/04/20 12	195 643.5	4.3 14.2	191 627
2	Agewu, Daddare 2	8^{0}27'20.8"N 08^{0}42'24.7"E	"	184 607.2	6.1 20.1	178 584
3	Agewu, Daddare 3	8^{0}27'09.5"N 08^{0}42'06.9"E	"	156 514.8	8.5 28.1	148 486
4	Ung.Murtala concrete well	8^{0}26'30.2"N 08^{0}42'02.9"E	"	206 679.8	9.5 31.2	197 646
5	Ungwar Ado concrete well	8^{0}26'05.0"N 08^{0}42'34.5"E	"	206 679.8	15.3 50.5	191 627
6	Gid Alhassan Liman Daddr	8^{0}26'04.9"N 08^{0}42'04.0E	"	206 679.8	12.5 41.3	194 637
7	Gidan Alhaji. Borno	8^{0}26'48.9"N 08^{0}42'44.1E	"	217 716.1	13.5 44.6	204 669

8	Tudn Adabu PHC Clinic	8^{0} 25' 15.5"N 08^{0}40'47.5"E	"	222 732.6	9 29.7	213 699
9	Odobu1gd Danlmi well	8^{0}24"55.0"N 08^{0}44'02.8"E	"	214 706.2	8.5 28.1	206 676
10	Odobu 2	8^{0}24'55.7"N 08^{0}44'04.7"	"	215 709.5	7.4 24.4	208 682
11	Gidan Ipaa. Odobu	8^{0}24'46.7"N 08^{0}44'18.0"E	"	219 722.7	10.2 33.7	209 686
12	Tudun Adabu 3	8^{0}25'32.5"N 08^{0}43'42.0"E	"	223 735.9	11.4 37.6	212 696
13	Tudun Adabu 4	8^{0}25'35.5"N 08^{0}43'51.7"E	"	232 765.6	11.5 37.95	221 725
14	Govt. Sec. Sch, Daddare	8^{0}27'00.3"N 08^{0}42'06.2"E	06/04/2012	208 686.4	12.9 42.6	195 640
15	Daddare Ctrl Msq c/ well	8^{0}26'41.7"N 08^{0}42'23.6"E	"	199 656.7	13.4 44.2	186 610
16	U/Mamman central Mosq	8^{0}27"18.0'N 08^{0}41'39.8"E	"	207 683.1	9.1 30.03	198 650
17	Un/Mamman Borehole	8^{0}27'12.5"N 08^{0}41'37.1"E	"	213 702.9	8.1 26.7	205 673
18	U/Mamman western well	8^{0}27'14.1"N 08^{0}41'34.5"E	"	207 683.1	9.7 32.0	197 646
19	Ung.Sule.Gd Hussaini Aku	8^{0}27'23.5"N 08^{0}41'13.6"E	"	216 712.8	9.0 29.7	207 679
20	Ungwar Sule Soda Factory	8^{0}27'25.2"N 08^{0}41'00.2"E	"	213 702.9	8.9 29.4	204 669
21	Ung. Hamidu concrete well	9^{0}27'27.0"N 08^{0}40'50.6"E	"	211 696.3	9.5 31.4	202 663
22	Kaduna Koro Gidan Ogu	8^{0}27'19.6"N 08^{0}39'59.6"E	"	209 689.7	10.7 35.3	198 650
23	Kaduna Koro Gidan Giwa	8^{0}27'18.7"N 08^{0}39'57.5"E	"	167 551.1	11.3 37.3	156 512
24	Kaduna Koro Gidan Michl Ila	8^{0}27'17.1"N 08^{0}40'00.7"E	"	226 745.8	12.0 39.6	214 702
25	Agwade mission. Gd Solo.Tukura	8^{0}27'03.1"N 08^{0}39'31.6"E	"	224 739.2	10.0 33	214 702
26	Agwade miss g/ Jmes Ajeh	8^{0}27'03.5"N 08^{0}39'34.5"E	"	222 732.6	9.5 31.4	213 699
27	U/.Amaku 1 g Agya Audu	8^{0}26'42.1"N 08^{0}29'09.4"E	"	240 792	12.7 41.9	227 745
28	U.Amaku 2 g Danj. Simon	8^{0}26'39.2"N 08^{0}'39'14.4E	07/04/2012	234 772.2	13.1 43.2	221 725
29	U/.Amaku 3 G/ Au kwayi	8^{0}26'41.5"N 08^{0}39'13.6"E	"	236 778.8	12.5 41.3	224 735
30	U.Kasuwa1G/Yakubu M	8^{0}26'46.7"N 08^{0}38'52.9"E	"	232 765.6	13.5 44.6	219 719
31	Ung.Kasuwa Baptist churc	8^{0}26'50.8"N 08^{0}38'42.7"E	"	232 765.6	12.7 41.9	219 719

32	Mutum Daya Gidan Yakubu Kubi	8^{0}27'29.3"N 08^{0}38'27.6"E	“	235 775.5	10.7 35.3	224 735
33	Mutum Daya 2 Gd Ogesa	8^{0}27'39.6"N 08^{0}39'12.4"E	“	246 811.8	14.8 48.8	231 758
34	Agudu 1 Gd Agwade	8^{0}27'54.4"N 08^{0}37'35.8"E	08/04/20 12	221 729.3	14 46.2	207 679
35	Agudu 2 Intt'l pri. Sch	8^{0}28'01.2"N 08^{0}37'26.1"E	“	244 464.2	14.2 46.9	230 755
36	Ung.Ayaba. gd maiungwa	8^{0}28'06.5N 08^{0}37'10.2"E	“	138 455.4	13.5 44.6	225 738
37	Kantsakuwa. Kunwarke clinic	8^{0}28'14.1"N 08^{0}36'39.1"E	“	219 722.7	9.0 29.7	210 689
38	AkunzaJarme ctrl Msq	8^{0}28'09.9"N 08^{0}35'56.5"E	“	214 706.2	10.5 34.7	204 669
39	Akunza Ubangari PHC clinic	8^{0}28'18.6"N 08^{0}35'21.1"E	“	208 686.4	8.9 29.4	199 390
40	Bukan kwato Ekos.clinic 1	8^{0}27'51.5"N 08^{0}34'22.3"E	“	200 660	10.6 35.0	189 620
41	Bukan kwato Ekos.clinic 2	8^{0}27'51.6"N 08^{0}34'23.3"E	“	139 458.7	11.9 39.3	127 417
42	Bukan kwato near the river	8^{0}27'23.2"N 08^{0}34'12.1"E	“	178 587.4	10.2 33.7	168 551
43	Akunza Koro mkt Mkd rd	8^{0}26'17.3"N 08^{0}34'11.3"E	“	165 544.5	8.7 28.7	156 512
44	Akunza Koro Mkd rd.	8^{0}25'59.3"N 08^{0}34'20.9"E	“	132 435.6	8.3 27.4	124 407
45	Murya 1 Gid Mailafiya	8^{0}24'53.8"N 08^{0}33'41.0"E	“	219 722.7	14.2 46.9	205 673
46	Murya PHC clnc c/well	8^{0}24'54.7"N 08^{0}33'46.2"E	“	229 755.7	11.0 36.3	218 715
47	Agyaragu b/h. Post offi.	8^{0}23'59.2"N 08^{0}33'03.3"E	“	211 696.3	12.5 41.3	199 653
48	Agyaragu ERCC no 1 Gid. Hassan	8^{0}23'55.4"N 08^{0}32'36.7"E	“	227 749.1	12.2 40.3	115 377
49	Gwadenye 1 Zhe Agyaragu	8^{0}23'33.1"N 08^{0}33'10.9"E	“	226 745.8	7.2 23.8	219 719
50	Gwadenye opp.fill stn G. Alabi	8^{0}23'37.6"N 08^{0}33'12.5"E	“	225 742.5	6.8 22.4	218 715
51	Mutum daya Gidan Zawee	8^{0}22'30.2"N 08^{0}33'17.7"E	09/04/20 12	218 719.4	12.0 39.6	206 676
52	Mutum daya 2 Gid. Batuu	8^{0}22'28.8N 08^{0}33'13.4"E	“	196 646.8	12.2 40.3	184 604
53	Akaleku 1 Gidan Udam	8^{0}20'45.2"N 08^{0}34'00.2"E	“	201 663.3	8.9 29.4	192 630
54	Akaleku G. Sarkin Akale	8^{0}20'14.9"N 8^{0}34'03.6"E	“	223 735.9	7.3 24.1	216 709
55	Adevi concrete well	8^{0}19'15.6"N 08^{0}33'54.3"E	“	243 801.9	10.1 33.33	233 764

56	Adevi Gidan waya	8^{0}18'36.3”N 08^{0}33'47.4”E	“	248 818.4	10.2 33.66	238 781
57	Akanga. Gidan Ladan	8^{0}17'41.6”N 08^{0}33'41.7”E	“	232 765.6	19.5 64.4	213 699
58	Kayarda Msq G. Usmn Eka	8^{0}23'49.0”N 08^{0}31'38.0”E	“	214 706.2	12.3 40.6	212 696
59	Jerugba. Gid Ilesha Ibrhm	8^{0}23'01.8”N 08^{0}30'55.3”E	“	207 683.1	9.4 31.0	198 650
60	Jerugba Gd Iliya Akwe	8^{0}22'54.3”N 08^{0}30'48.5”E	“	213 702.9	10.0 33.0	203 666
61	Gidan Ausa. Primary Sch	8^{0}24'22.9”N 08^{0}29'49.8”E	“	189 623.9	8.5 28.1	181 594
62	Duduguru Mkt square	8^{0}24'57.0”N 08^{0}35'31.4”E	10/04/20 12	165 544.5	9.3 30.7	156 512
63	Akaba Gidan Mailafiya	8^{0}22'37.3”N 08^{0}36'52.3”E	“	184 607.2	6.6 21.8	177 581
64	Akaba (farm) concrete well	8^{0}22'1.0”N 08^{0}37'07.8”E	“	177 584.1	5.0 16.5	172 564
65	Ome Gidan MichlObdiah	8^{0}21'30.6” 08^{0}39'48.6”E	“	175 577.5	10.20 33.66	165 541
66	Ome Gidan EmmaYakub	8^{0}21'34.2”N 08^{0}39'59.7”E	“	171 564.3	9.7 32.0	161 528
67	Atabla Gidan Sam.Ayimad	8^{0}21'13.3”N 08^{0}41'41.3”E	“	174 574.3	9.0 29.7	165 541
68	Atabla c.well mkt square	8^{0}20'59.9”N 08^{0}41'39.6”E	“	169 557.7	9.5 31.6	160 525
69	Ashupe Gidn (Mich Jnthn)	8^{0}24'55.6”N 08^{0}40'09.1”E	“	203 669.9	10.6 35.0	186 610
70	Ashupe Gidn JonthnAnjeb	8^{0}25'07.2”N 08^{0}40'04.5”E	“	204 673.2	14.2 46.9	190 623
71	Mararabar .Gandu Mk rd	8^{0}28'48.7”N 08^{0}33'58.7”E	11/04/20 12	167 551.1	8.4 27.7	159 522
72	Old Gandu concrete well	8^{0}29'09.2”N 08^{0}34'07.1”E	“	170 561	10.6 35.0	159 522
73	Wakwa Alh. Cntrl msq	8^{0}29'47.0”N 08^{0}34'21.4”E	“	187 617.1	11.5 38.0	176 577
74	Gimare Gd Salihu Ibrhm	8^{0}29'27.4”N 08^{0}33'27.0”E	“	189 623.7	9.5 31.4	180 591
75	T/kwashini gMai Ungwa	8^{0}29'38.8”N 08^{0}32'46.7”E	“	210 693	12.0 39.6	198 650
76	Lafia behind NEPA Hqtrs.	8^{0}29'25.9”N 08^{0}31'25.7”E	“	177 584.1	22.7 74.9	154 505
77	Lafia T kauri NYSC Hqtr	8^{0}29'08.2”N 08^{0}31'57.2”E	“	180 594	17.0 56.1	163 535
78	Agyaragun Tofa conc. well	8^{0}26'58.9”N 08^{0}32'35.8”E	12/04/ 2012	189 623.7	9.8 32.3	179 587
79	Buk Tambari concrete well	8^{0}26'39.4”N 08^{0}32'39”E	“	189 623.7	11.0 36.3	178 584
80	Bukan Buzu central Mosq	8^{0}26'17.6”N 08^{0}31'19.1”E	“	190 627	10.4 34.3	180 591

81	Akwangwa 1 near prim.sch	8⁰25'45.2"N 08⁰30'46.0"	"	181 597.3	8.6 28.9	172 564
82	Akwangwa 2 k.Agyac/well	8⁰25'36.1"N 08⁰30'36.5"	"	170 451	12.2 40.3	158 518
83	Buk.Fadama concrete well	8⁰27'43.7"N 08⁰31'00.8"E	"	160 528	8.4 27.7	152 499

APPENDIX IX: Measurements of depth to water table in hand dug wells at the peak of rainy season (October,2011) and the peak of dry season (April, 2012) **(Source:** Field Data)

S/N	**Location description**	**Coordinates of locations Lat. (⁰N) Long. (⁰E)**	**Date of dry seaso nmsm ts**	**Well Elevn (m) / (ft)**	**Dry season grdw Elevate (masl, ftasl)**	**Dry seasn grdw table (mas, ftasl)**	**Date of msmt durin rainy seasn**	**End of rainy season Water table(ma sl,ftasl)**	**End of rainy season grdwater elevn(ma sl, ftasl)**	**Water table fluctua tion (m)**
1	G.Usman Ma'aji Daddare 1	8⁰26'59.7"N 8⁰42'23.4"E	05/04/ 2012	195 643.5	191 627	4.3 14.2	15/10 / 2012	1.3 4.29	194 637	3.0
2	Agewu,Daddare 2	8⁰27'20.8"N 8⁰42'24.7"E	"	184 607.2	178 584	6.1 20.1	"	1.1 3.63	183 600	5.0
3	Agewu, Daddare 3	8⁰27'09.5"N 8⁰42'06.9"E	"	156 514.8	148 486	8.5 28.1	"	3.5 11.55	153 502	5.0
4	Ung.Murtala conc well	8⁰26'30.2"N 8⁰42'02.9"E	"	206 679.8	197 646	9.5 31.2	"	4 13.2	202 663	4.5
5	Ung Ado conc well	8⁰26'05.0"N 8⁰42'34.5"E	"	206 679.8	191 627	15.3 50.5	"	4.3 14.19	202 663	11.0
6	Gd.Alhassan Lman.Daddar	8⁰26'04.9"N 8⁰42'04.0E	"	206 679.8	194 637	12.5 41.3	"	10.5 34.65	196 643	2.0
7	Gid.Alh. Borno	8⁰26'48.9"N 8⁰42'44.1E	"	217 716.1	204 669	13.5 44.6	"	9.5 31.35	208 682	5.0
8	Tud Adabu PHC Clnc	8⁰25'15.5"N 8⁰40'47.5"E	"	222 732.6	213 699	9 29.7	"	6 19.8	216 709	3.0
9	Odobu Gd. Danlami conc. well	8⁰24'55.0"N 8⁰44'02.8"E	"	214 706.2	206 676	8.5 28.1	"	4 13.2	210 689	3.5
10	Odobu 2	8⁰24'55.7"N 8⁰44'04.7"	"	215 709.5	208 682	7.4 24.4	"	4.4 14.52	211 692	3.0
11	Gid.Ipaa. Odobu	8⁰24'46.7"N 8⁰44'18.0"E	"	219 722.7	209 686	10.2 33.7	"	7.2 23.76	212 696	3.0
12	Tudun/ Adabu 3	8⁰25'32.5"N 8⁰43'42.0"E	"	223 735.9	212 696	11.4 37.6		4.4 14.52	219 719	7.0
13	Tudun / Adabu 4	8⁰25'35.5"N 8⁰43'51.7"E	"	232 765.6	221 725	11.5 37.5	"	7.5 24.75	225 738	4.0
14	Govt.SecSch Daddare	8⁰27'00.3"N 8⁰42'06.2"E	06/04/ 2012	208 686.4	195 640	12.9 42.6	16/0/ 2012	4.9 16.17	203 666	8.0
15	Daddare Ctral Msq. C. well	8⁰26'41.7"N 8⁰42'23.6"E	"	199 656.7	186 610	13.4 44.2	"	3.4 11.22	196 643	10.0
16	U/Mamman cntrl Msq	8⁰27'18.0"N 8⁰41'39.8"E	"	207 683.1	198 650	9.1 30.3	"	3.1 10.23	204 669	6.0

17	Ung.Mamma Borehole	$8^0$27'12.5"N8 ^{0}41'37.1"E	“	213 702.9	205 673	8.1 26.7	“	5.1 16.83	208 682	3.0
18	U/Mamman west well	$8^0$27'14.1"N $8^0$41'34.5"E	“	207 683.1	197 646	9.7 32.0	“	4.7 15.51	202 663	5.0
19	Ungw.Sule.G Hussaini Aku	$8^0$27'23.5"N $8^0$41'13.6"E	“	216 712.8	207 679	9.0 29.7	“	3.0 9.9	213 699	6.0
20	Ung Sule Soda Factory	$8^0$27'25.2"N $8^0$41'00.2"E	“	213 702.9	204 669	8.9 29.4	“	4.9 16.17	208 682	4.0
21	U/Hamidu Concr. Well	$9^0$27'27.0"N $8^0$40'50.6"E	“	211 696.3	202 663	9.5 31.4	“	3.5 11.55	208 682	6.0
22	Kaduna Koro Gidan Ogu	$8^0$27'19.6"N $8^0$39'59.6"E	“	209 689.7	198 650	10.7 35.3	“	5.7 18.81	203 666	5.0
23	Kaduna Koro Gidan Giwa	$8^0$27'18.7"N $8^0$39'57.5"E	“	167 551.1	156 512	11.3 37.3	“	6.3 20.79	161 528	5.0
24	Kaduna Koro gi Michl Ila	$8^0$27'17.1"N $8^0$40'00.7"E	“	226 745.8	214 702	12.0 39.6	“	5.0 16.5	221 725	7.0
25	Agwade mission. G. Tukura	$8^0$27'03.1"N $8^0$39'31.6"E	“	224 739.2	214 702	10.0 33	“	5.0 16.5	219 719	5.0
26	Agwade mission gd James Ajeh	$8^0$27'03.5"N $8^0$39'34.5"E	“	222 732.6	213 699	9.5 31.4	“	5.5 18.15	217 712	4.0
27	Ung.Amaku gidan Agya Audu	$8^0$26'42.1"N $8^0$29'09.4"E	“	240 792	227 745	12.7 41.9	“	7.7 25.41	232 761	5.0
28	U.Amaku 2 g. Danj. Simon	$8^0$26'39.2"N 8^0'39'14.4"E	07/04/ 12	234 772.2	221 725	13.1 43.2	16/0/ 2012	8.1 26.73	226 742	5.0
29	U.Amaku3G. AuduAkwa	$8^0$26'41.5"N $8^0$39'13.6"E	“	236 778.8	224 735	12.5 41.3	“	8.5 28.05	228 748	4.0
30	Ung.Kasuw Gid.Yakubu	$8^0$26'46.7"N $8^0$38'52.9"E	“	232 765.6	219 719	13.5 44.6	“	7.5 24.75	225 738	6.0
31	Ung. Kasuwa 2 Baptist chc	$8^0$26'50.8"N $8^0$38'42.7"E	“	232 765.6	219 719	12.7 41.9	“	7.7 25.41	224 735	5.0
32	Mutum Daya Gd.Yakubu	$8^0$27'29.3"N $8^0$38'27.6"E	“	235 775.5	224 735	10.7 35.3	“	6.7 22.11	228 748	4.0
33	Mutum Daya 2 Gd Ogesa	$8^0$27'39.6"N $8^0$39'12.4"E	“	246 811.8	231 758	14.8 48.8	“	12.8 42.24	233 764	2.0
34	Agudu 1Gd. Agwade	$8^0$27'54.4"N $8^0$37'35.8"E	08/04/ 12	221 729.3	207 679	14 46.2	17/0/ 2012	10 33	211 692	4.0
35	Agudu2Int'l prm. Sch.	$8^0$28'01.2"N $8^0$37'26.1"E	“	244 464.2	230 755	14.2 46.9	“	10.2 33.66	234 768	4.0
36	Ung.Ayaba. Gd.mai Ung.	$8^0$28'06.5N $8^0$37'10.2"E	“	138 455.4	225 738	13.5 44.6	“	9.5 31.35	129 423	4.0
37	Kantsaku Kunwarke cln	$8^0$28'14.1"N $8^0$36'39.1"E	“	219 722.7	210 689	9.0 29.7	“	3.0 9.9	216 709	6.0
38	AkunzaJarme ctral Mosque	$8^0$28'09.9"N $8^0$35'56.5"E	“	214 706.2	204 669	10.5 34.7	“	3.5 11.55	211 692	7.0
39	Akunza Ubangari PHC clinc	$8^0$28'18.6"N $8^0$35'21.1"E	“	208 686.4	199 390	8.9 29.4	“	3.0 9.9	205 673	6.0

40	Buk. kwato clinic 1	8^{0}27'51.5"N 8^{0}34'22.3"E	“	200 660	189 620	10.6 35.0	“	6.6 21.78	193 633	4.0
41	Bukan kwato clinic 2	8^{0}27'51.6"N 8^{0}34'23.3"E	“	139 458.7	127 417	11.9 39.3	“	5.9 19.47	133 436	6.0
42	Bukan kwato wellnear river	8^{0}27'23.2"N 8^{0}34'12.1"E	“	178 587.4	168 551	10.2 33.7	“	5.2 17.16	173 568	5.0
43	Akunzan Koro mkt	8^{0}26'17.3"N 8^{0}34'11.3"E	“	165 544.5	156 512	8.7 28.7	“	3.7 12.21	161 528	5.0
44	Akunza Koro ClemtAdagba	8^{0}25'59.3"N 8^{0}34'20.9"E	“	132 435.6	124 407	8.3 27.4	“	3.3 10.89	129 423	5.0
45	Murya Gd Mailafiya	8^{0}24'53.8"N 8^{0}33'41.0"E	“	219 722.7	205 673	14.2 46.9	“	11.2 36.96	208 682	3.0
46	Murya PHC clncconc.well	8^{0}24'54.7"N 8^{0}33'46.2"E	“	229 755.7	218 715	11.0 36.3	“	7.0 23.1	222 728	4.0
47	Agyaragu borehole	8^{0}23'59.2"N 8^{0}33'03.3"E	“	211 696.3	199 653	12.5 41.3	“	9.5 31.35	202 663	3.0
48	Agyaragu ERCC no. 1	8^{0}23'55.4"N 8^{0}32'36.7"E	“	227 749.1	215 705	12.2 40.1	“	9.2 30.2	218 715	3.0
49	Gwadenye Zhemigili rd	8^{0}23'33.1"N 8^{0}33'10.9"E	“	226 745.8	219 719	7.2 23.8	“	2.2 7.26	224 735	5.0
50	Gwadenye Alh. Dntsho fill. statn	8^{0}23'37.6"N 8^{0}33'12.5"E	“	225 742.5	218 715	6.8 22.4	“	2.8 9.24	222 728	4.0
51	Mutum daya Gdn Zawee	8^{0}22'30.2"N 8^{0}33'17.7"E	09/04/ 12	218 719.4	206 676	12.0 39.6	18/10 2012	9.0 29.7	209 686	3.0
52	Mutum daya Gidan Batuu	8^{0}22'28.8N 8^{0}33'13.4"E	“	196 646.8	184 604	12.2 40.3	“	9.2 30.36	187 614	3.0
53	Akaleku 1 Gidan Udam	8^{0}20'45.2"N 8^{0}34'00.2"E	“	201 663.3	192 630	8.9 29.4	“	2.9 9.57	198 650	6.0
54	Akaleku2 G SarkinAkalek	8^{0}20'14.9"N 8^{0}34'03.6"E	“	223 735.9	216 709	7.3 24.1	“	2.3 7.59	221 725	5.0
55	Adevi conc. well	8^{0}19'15.6"N 8^{0}33'54.3"E	“	243 801.9	233 764	10.1 33.3	“	6.1 20.13	237 778	4.0
56	Adevi Gidan waya	8^{0}18'36.3"N 8^{0}33'47.4"E	“	248 818.4	238 781	10.2 33.6	“	6.2 20.46	242 793	4.0
57	Akanga. Gdan Ladan	8^{0}17'41.6"N 8^{0}33'41.7"E	“	232 765.6	213 699	19.5 64.4	“	14.5 47.85	218 715	5.0
58	Kayarda Msq G Usman Eka	8^{0}23'49.0"N 8^{0}31'38.0"E	“	214 706.2	212 696	12.3 40.6	“	9.3 30.69	205 673	3.0
59	Jerugba. Gd Ilesha Ibrahm	8^{0}23'01.8"N 8^{0}30'55.3"E	“	207 683.1	198 650	9.4 31.0	“	4.4 14.52	203 666	5.0
60	Jerugba Gid Iliya Akwe	8^{0}22'54.3"N 8^{0}30'48.5"E	“	213 702.9	203 666	10.0 33.0	“	4.0 13.2	209 686	6.0
61	Gidan Ausa. Pri. Sch.	8^{0}24'22.9"N 8^{0}29'49.8"E	“	189 623.9	181 594	8.5 28.1	“	2.5 8.25	187 614	6.0
62	Dudugurumkt Ung.kasuwa	8^{0}24'57.0"N 8^{0}35'31.4"E	10/04/ 12	165 544.5	156 512	9.3 30.7	“	1.3 4.29	164 538	8.0
63	Akaba Gidan Mailafiya	8^{0}22'37.3"N 8^{0}36'52.3"E	“	184 607.2	177 581	6.6 21.8	“	3.6 11.88	180 591	3.0

64	Akaba(farm) conc. well	8^{0}22'1.0"N 8^{0}37'07.8"E	"	177 584.1	172 564	5.0 16.5	"	0.0 0.0	177 581	5.0
65	OmeG/Michl Obadiah	8^{0}21'30.6" 8^{0}39'48.6"E	"	175 577.5	165 541	10.2 33.7	"	5.20 17.16	170 558	5.0
66	Ome, Gidan Emma Yakub	8^{0}21'34.2"N 8^{0}39'59.7"E	"	171 564.3	161 528	9.7 32.0	"	6.7 22.11	164 538	3.0
67	Atabla Gd Sam.Ayimad	8^{0}21'13.3"N 8^{0}41'41.3"E	"	174 574.3	165 541	9 29.7	"	3 9.9	171 561	6.0
68	Atabla conc. well mkt sq.	8^{0}20'59.9"N 8^{0}41'39.6"E	"	169 557.7	160 525	9.5 31.6	"	3.5 11.55	166 545	6.0
69	Ashupe (Michael Jona	8^{0}24'55.6"N 8^{0}40'09.1"E	"	203 669.9	186 610	10.6 35.0	"	6.6 21.78	196 643	4.0
70	Ashupe Gd. Jnthn Anjebe	8^{0}25'07.2"N 8^{0}40'04.5"E	"	204 673.2	190 623	14.2 46.9	"	10.2 33.66	194 637	4.0
71	MararabGand u Mkd road	8^{0}28'48.7"N 8^{0}33'58.7"E	11/04/ 12	167 551.1	159 522	8.4 27.7	2010/ 2012	2.4 7.92	165 541	6.0
72	Old Gandu concrete well	8^{0}29'09.2"N 8^{0}34'07.1"E	"	170 561	159 522	10.6 35.0	"	5.6 18.48	164 538	5.0
73	Wakwa Alh.cntrl msq	8^{0}29'47.0"N 8^{0}34'21.4"E	"	187 617.1	176 577	11.5 38.0	"	7.2 2376	180 591	4.0
74	Gimare Gdn Salihu Ibrahm	8^{0}29'27.4"N 8^{0}33'27.0"E	"	189 623.7	180 591	9.5 31.4	"	6.2 20.46	183 600	3.0
75	Tud kwashini G mai Ungwa	8^{0}29'38.8"N 8^{0}32'46.7"E	"	210 693	198 650	12.0 39.6	"	7.0 23,1	203 666	5.0
76	Lafia behd NEPA Hqs.	8^{0}29'25.9"N 8^{0}31'25.7"E	"	177 584.1	154 505	22.7 74.9	"	18.7 71.61	155 509	4.0
77	Lafia T Kauri NYSC Hqtr	8^{0}29'08.2"N 8^{0}31'57.2"E	"	180 594	163 535	17.0 56.1	"	12.0 39.6	168 551	5.0
78	Agyaragun Tofa c/well	8^{0}26'58.9"N 8^{0}32'35.8"E	12/04/ 12	189 623.7	179 587	9.8 32.3	21/0/ 2012	2.8 9.24	186 610	7.0
79	Bukn.Tambar i c/ well	8^{0}26'39.4"N 8^{0}32'39"E	"	189 623.7	178 584	11.0 36.3	"	6.0 19.8	183 600	5.0
80	Bukan Buzu cntrl. Mosq.	8^{0}26'17.6"N 8^{0}31'19.1"E	"	190 627	180 591	10.4 34.3	"	4.4 14.52	186 610	6.0
81	Akwangwa 1 near pri. sch.	8^{0}25'45.2"N 8^{0}30'46.0"	"	181 597.3	172 564	8.6 28.9	"	1.6 5.28	179 587	7.0
82	Akwangwa 2 k/Agyac. well	8^{0}25'36.1"N 8^{0}30'36.5"	"	170 451	158 518	12.2 40.3	"	4.2 13.86	166 545	8.0
83	Bukan Fadama conc. well	8^{0}27'43.7"N 8^{0}31'00.8"E	"	160 528	152 499	8.4 27.7	"	2.4 7.92	158 518	6.0

Appendix X: Details of the Breakdown of Plateau State Provisional 19991 Census Results by localities in the study area (Obi and Lafia Local Governments Areas (Source: National Population Commission, Lafia)

Locality	Males	Females	Both sexes	1996 projection
Atabula	796	361	1657	1913
Tudun Adabu	1632	1692	3324	3837
Ume	303	331	1634	1886
Ungwar Amidu	415	321	736	850
Ashupe	643	575	1218	1406
Duduguru U/musa	160	197	357	412
Daddare	4040	4047	8187	9450
Agwade Amaku	1680	1633	3313	3824
Kyakale / others	290	317	607	701
Kantsakuwa	385	327	712	822
Ungwar Ayaba	327	336	662	764
Agudu	460	489	949	1095
Tudun kwashini	69	77	146	169
Gimare	292	344	636	734
Wakwan Alhaji	166	204	370	427
Gandu	224	260	484	559
Bukan magayaki	173	199	372	429
Tudun Kawari	1433	1189	2622	3026
Lafia	40813	37434	78247	90317
Kayarda	941	962	1903	2197
Abioga	514	576	1090	1258
S/garin G/ Ausa	117	104	221	255
Gidan Ausa	939	827	1766	2038
Bukan Buzu	540	623	1163	1342
Agyaragun Tofa	1027	1040	2067	2386
Bukan Tambari	264	306	570	658
Bukan Kwato	967	1106	2073	2393
Akunzan Ubangari	340	393	733	846
Maraban Lafia	568	431	999	1153
Akunzan Jarme	549	626	1175	1356
Agudu Baptist Church & others	231	230	461	532
Akunza Happy 1	117	146	265	306
Akunza Happy 2	181	208	389	449
Akunza Migili	203	219	422	487
Murya	90	83	173	200
Gwadanye	1995	1940	3935	4542
Atukwasa	288	252	540	623
Akaleku	552	835	1687	1947
Akalekun Sidi	369	412	781	901
Akanga 1	161	174	335	387
Akanga 2	243	319	562	649
Akanga 3	205	182	387	447
Kyakale Duduguru	240	303	543	627
Ajerugba	446	501	947	1093
Kyakale Obi District	482	468	950	1097
Agyaragu	8380	8175	16555	10109
Total	76255	74336	152788	167358