THE HYDROGEOLOGY OF KANKARA AND ENVIRONS, SHEET 78 FUNTUA NE, NORTH WESTERN NIGERIA

BY

CHRISTIANA OHWOFASA ABUSU B.Sc.(ABU,2002)

M.Sc/SCIEN/8824/2010-11

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL

AHMADU BELLO UNIVERSITY ZARIA

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

DEPARTMENT OF GEOLOGY

FACULTY OF SCIENCE

AHMADU BELLO UNIVERSITY, ZARIA

NIGERIA

OCTOBER,2015.

CERTIFICATION

This thesis entitled the **Hydrogeology of Kankara and Environs;Funtua sheet 78 NE** by Christiana OhwofasaAbusu meets the regulations and requirement governing the award of the degree of masters of Science Geology [Hydrogeology] of the Ahmadu Bello University Zaria and is approved for its contribution to knowledge and literary presentation.

_____ _____

Prof S.AAlagbe Date
Chairman Supervisory Committee

_____ _____

Dr A.E Ikpokonte Date
Member Supervisory Committee

_____ _____

Dr. H. Hamza Date
Head of Department

_____ _____

Prof.K.Bala Date
Dean School of Postgraduate Studies

DEDICATION

This work is dedicated to God Almighty and to my dearest daughterOhwofasa Ruth Onoriode.

ACKNOWLEDGEMENT

All praise is to the Almighty God for giving me his guidance and protection during the period of this work.

My sincere gratitude goes to my major supervisor Prof. S. A.Alagbe for supervising me in the field and making critical comments during the period of this work.

Thanks to Dr. A.E Ikpokonte the second supervisor to this project work. His frank comments have gone a long way in bringing this project work to a success. I am grateful to Prof. K. Schoeneich, the entire staff and non-staff of Geology Department,Ahmadu Bello University, Zaria, for their care and support in making this work successful. These include the Head of Department Dr..H.Hamza, Dr. M. L. Garba, Prof. P.O Ogunleye, Dr. T. Najime, Mr. S. S. Magaji,Jacob H,Mrs .F.Bamikunle,OluwafemiAdeyeye, Mr. Amedu Godwin,MrAmimashwun E, Mr. .S. Odugbo and Mr. J.Ayok.

My appreciation is directed to the following people who have contributed both financially and morally to the completion of this project. TheAbusu,s family Abusu Benjamin , Catherine Lucky,Ochuko,Emmannuel,Reacheal,Omonigho and Ovakpor,Mr. Muhammad Kana Abdullahi and Miss Ohwofasa Ruth Onoriode for her patience.

Any omission is unintentional and quiet regretful.

CHRISTIANA OHWOFASA ABUSU (2015)

ABSTRACT

Hydrogeological study of Kankara and the surrounding area was carried out. This involved locating rock outcrops on map to produce geological map, measurement of the static water level in hand-dug wells to produce groundwater configuration maps, and collection of water samples for physico-chemical analysis. Rock units in the study area are migmatite, granite-gneiss, and biotite granite.These rock units were located on the map with the help of a satellite navigator (GPS) and a compass clinometer. These rocks of the area have been subjected to various episodes of metamorphism and tectonism resulting to development of structural features favourable for groundwater accumulation. The major trends of fractures in the area are NNE-SSW and NNW-SSE directions. Groundwater level measurement was carried out in hand dug wells within the study area. This involves taking measurements of water level in the hand dug wells as well as the elevations and the coordinates of these wells. Groundwater level fluctuation in the water table (phreatic) aquifer and direction of groundwater flow directions were determined.

Eleven water samples were collected and analysed for their physic-chemical constituents. Water budget for the study area was prepared. This entails the water demand and available water resources of the area. The current water demand is 8,600 m^3/d or 3,139,302 m^3/a for the estimated population of 122,869 people in the study area. The future water demand in 30 years from the last population census is 21,154 m^3/d or 7,721,414 m^3/a at the growth rate of 3 % of people of the study area. The utilizable groundwater resources of the study area is 9,466,875 which is sufficient to meet the present as well as the future water demand of people in the study area.Aquifer characteristics obtained from pumping test data indicate yield ranges from 32.83 to 40.61 m3/day, Storativity ranges from 0.0147 to 0.0652 and transmissivity within the aquifers in the area range from 0.68 to 2.98 m^2/day corresponding to very low to low Transmissivity.

QUOTATION

I will look up to the hill, where will my help come from, my help will come from the Lord who made heaven and earth(Psalm 121:1-2)

TABLE OF CONTENTS

Page

Title Page i

Certification ii

Dedication iii

Acknowledgement iv

Abstract v

Quotation .. .. vi..

Table of Contents vii

List of Figures xi

List of Tables xiii

List of Plates xiv

List of Appendices xv

CHAPTER 1

INTRODUCTION **1**

1.1 Background 1

1.2 Aim and objectives of the Study 1

1.3 The Study Area 2

1.3.1 Location Extent and Accessibility 2

1.3.2 Topography and Drainage 4

1.3.3 Climate 4

1.3.4 Vegetation 8

1.3.5 People and Land Use 8

1.4 Previous Work 9

1.5 Scope Of The Study 12

CHAPTER 2

LITERATURE REVIEW **13**

2.1General Geology of the Northwestern Crystalline Hydrogeological Province of Nigeria.. 13

2.1.1Migmatite- Gneiss Complex 16

2.1.2Metasediments 16

2.1.3Older Granites 18

2.2Hydrogeology of North Western Nigeria 19

2.2.1Soft Overburden Aquifer 19

2.2.2Fractured Crystalline Aquifer 20

2.3 Water Quality of Northwestern Nigeria 20

CHAPTER 3

MATERIALS AND METHOD **22**

3.1 Introduction 22

3.2 Method of Investigation 22

3.3 Field work 23

3.3.1 Water Level Measurement 23

3.3.2 Coordinates 23

3.3.3 Water Sampling 24

3.4 Laboratory Work 24

3.4.1 Water Sample Analysis 24

3.5 Evaluation of Field Data 25

3.5.1 Groundwater Configuration Maps 25

3.5.2 Preparation of Hydrogeological Maps 25

3.6 Geological Mapping 25

CHAPTER 4

4 RESULTS AND DISCUSSION 27

4.1 Geology of the Study Area 27

4.1.1 Migmatites 27

4.1.2 Granite-Gneiss 28

4.1.3 Biotite Granite 28

4.2Relationship of Geology to Groundwater Occurrence 29

4.3Availability of Water Resources 38

4.3.1 Surface Water in the Study Area .. .. … 38

4.3.2 Groundwater in the Study Area 38

4.4Water Table Configuration and Directions of Groundwater Flow 38

4.5Aquifer Characteristics 39

4.6Water Resources Evaluation 39

4.7Dynamic Groundwater Resources of the Study Area 43

4.8Water Quality of the Study Area 43

4.8.1 Physical Properties of Water .. .. … 46

4.8.2 Chemical Quality of Groundwater 48

4.9Classification of Water Facies 50

4.10Chemistry and Usage of Water .. .. … 52

4.10.1Bicarbonate Hazard {meq/l = HCO_3 – (Ca + Mg)} 52

4.10.2Sodium Hazard 53

4.10.3Water Usage 54

4.11Water Budget for the Study Area.. 54

CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATION 57

5.1 Summary and Conclusion 57

5.2 Contribution to Knowledge 58

5.3 Recommendations 58

REFERENCES 59

APPENDICES 63

LIST OF FIGURES

1. Location Map of the Study Area 3
2. Drainage map of the study area 5
3. Map of Regional distribution of mean annual rainfall in Nigeria 6
4. Map of the date when rainy season starts … 7
5. Map of the date when rainy season ends 7
6. Generalized geological map of the Pan-African Belt 14
7. Generalized geological map of Nigeria 14
8. Geological map of the study area .. ..
9. Flow chart for automatic lineament extraction 30
10. Lineament map of the study area 31
11. Rose diagram of lineament for the study area 32
12. Rose diagram for biotitegranite 33
13. Rose diagram for granite gneiss 34
14. Rose diagram for migmatite .. … 35
15. Lineament density map of study area 36
16. Superimposition of lineament map on the drainage map 37
17. Groundwater configuration map of the study area at the peak of dry season 41
18. Groundwater configuration map of the study area at the end of rainy season 42

19. Geological map of Kankara area and its environs showing the sample points..

.. .. … .. ..

20. Wilcox plot for water samples from in and around kankara 47

21. Schoeller plot for water samples from the study area 51

22. Piper plot for water samples from the study area 51

LIST OF TABLES

page

1 Table 4.1 Summary of Aquifer Characteristics obtained from Pumping test data 39

2 Table 4.2 Standard for Transmissivity(T).. 39

3 Table 4.3Parameters measured insitu during field work in the study area 44

4Table 4.4Chemical parameters of water samples from the study area 45

5 Table 4.5Conversion factors from mg/l to meq/l 53

6 Table 4.6 Suitability of water for irrigation purposes in respect of Bicarbonate Hazard 53

7 Table 4.7 Water classification for irrigation purposes based on Sodium Absorption Ratio

... . 54

LIST OF PLATES

I. Migmatite in part of the study area 27

II. Granite-gneiss in part of the study area 28

III. Biotite granite in part of the study area 29

LISTS OF APPENDICES

1. Depth to water level in hand dug wells at the peak of dry season 63

2. Depth to water level in hand dug wells at the peak of rainy season 66

3. WHO 1993, standard permissible limit for physical parameters of water for drinking and domestic use. 69

4.Physical/Organoleptic parameters for drinking water(NIS 2007) 69

5. Chemical parameters for drinking water(Inorganic constituents(NIS 2007) .. 70

6. Pumping test data for GARAGE,NAGAMDA,TURARAand MABAI from Kankara (RUWASSA KASTINA STATE) 71

7. Pumping Test Data and Corresponding Drawdown-Time Graphs 75

ACRONYMS

DTWL - Depth to Water Level in Meter Below Ground Level.

GPS - Global Positioning System.

GL - Ground Level(masl).

GIS - Geographical Information System.

Km - Kilometer(s).

Km^2 - Square Kilometer(s).

Km^3 - Cubic Kilometer(s).

Liters/s/m – Liter per second per meter.

M - Meter(s)

M^2 - Square. Meter(s)

M^3 - Cubic Meter(s)

M^3/a - Cubic Meter(s) per annum

M^3/d - Cubic Meter(s) per day

M/year - Meter(s) per year

S.W.L - Static Water Level

T.D.D - Total Depth in Meters

L/s - Liters per second

BH _ Bicarbonate hazard.

SAR - Sodium absortion ratio/ Sodium hazard.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The study area falls within the crystalline hydrogeological province of the Nigeria. Water resources in this area areessentially groundwater. Groundwater accounts for over 95% of the earth's useable freshwater resources and plays an important role in maintaining soil moisture, stream flow and wetland (Freeze and Cherry, 1979).

Therefore,due to the water supply problems, study of the groundwater resources of sheet78 FuntuaNE located in semi-arid zone of Nigeria need to be carried, in order to avoid future supply deficit and to evolve adequate management strategies. This study seeks to establish the quality of groundwater, and to quantify groundwater resources of the area in order to aid its planning, development and management.

Major rivers which constitute the surface water in the area are Gagere and Petsa, otherminor river flowing northwest. These river systems contain water in their channels only during the rainy season and have little or no water in the dry season.

1.2 AIM ANDOBJECTIVES OF THE STUDY

The aim of this study is to investigate and assess the quality as well as the quantity of groundwater of the basement rocks ofsheet Funtua 78NE based on information derived from measurements of water levels in hand dug wells during the peak of dry season and the peak of rainy season. This study will also update the current level of knowledge of hydrogeology of the area and to serve as a database for future reference purposes. This study when completed will provide information about the geographical and geological features of the area, and provide

professional advice on how to design tube wells free of contaminated water.It also involve production of lineament map and calculation of water budget for the study area.

1.3THE STUDY AREA

The study area, sheet Funtua 78NE, geographically the area cuts across Kankara, Bakori, Malumfashi and Faskari Local Government areas in Katsina State, covering a total land area of approximately 748.02 km^2. Kankaratown is the largest town in the study area (Itie Mbotake Thompson, 1994).

1.3.1Location Extent and Accessibility

The study area is contained in the topographical map of Funtua sheet 78 NE, on a scale 1: 50,000. It covers an area of 748.02 km^2 and lies between latitudes $11^o45'$ N to $12^o00'$ N and longitudes $7^o15'$ E to $7^o30'$ E (Figure 1). Easy accessibility is provided mostly by a network of footpaths linking villages and the river banks. Seasonal motorable roads formimportant paths used by motorbikes. Two well tarred roads of trunk 'A' link the area from Maimashekari village on Sheme-Kankara road and the other one passes through Danmarke to Burdugau in the south east of the project area (Itie Mbotake Thompson,1994)

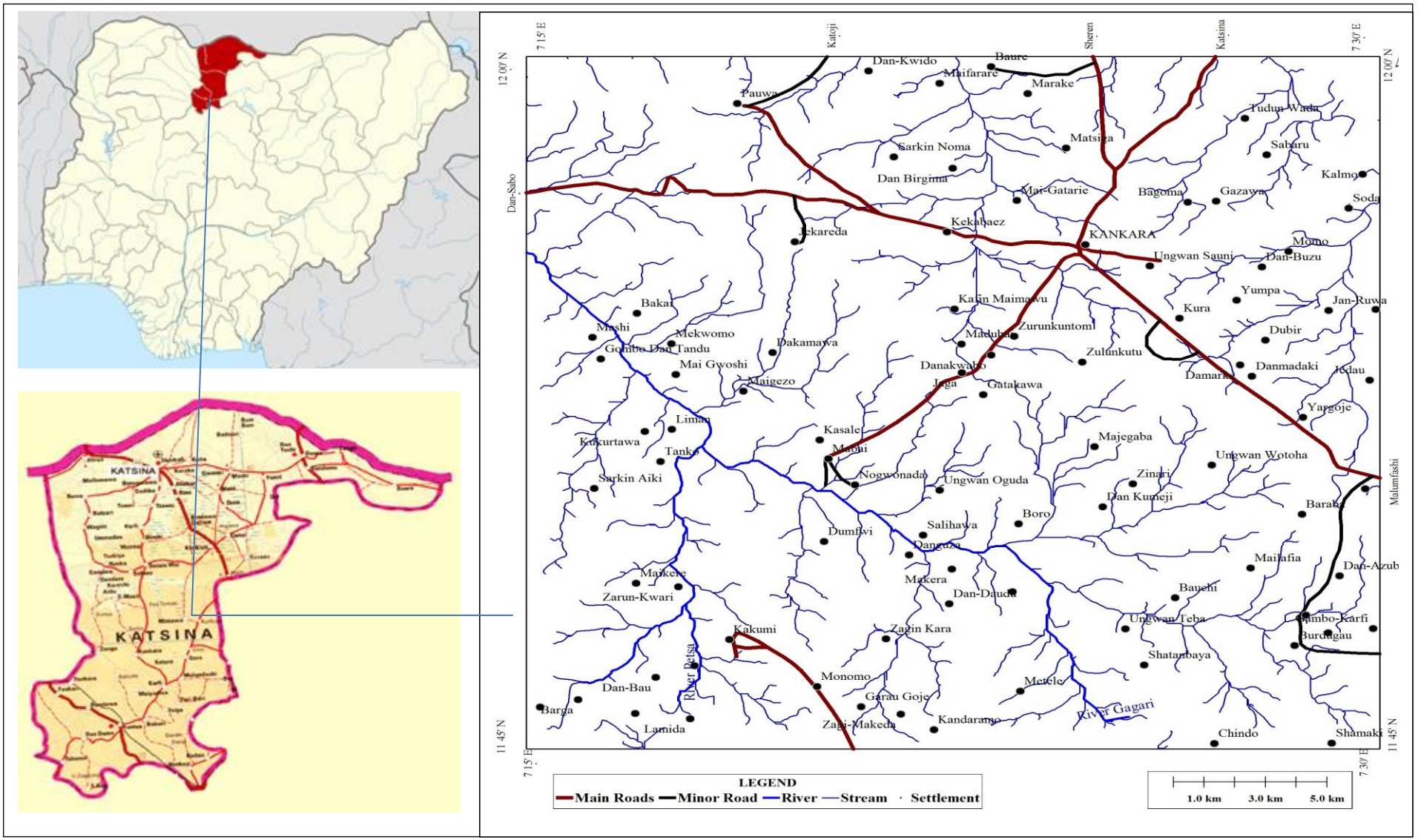


Figure 1: Location map of the study area,Federal Survey of Nigeria, 1967

1.3.2 Topography and Drainage

The topography of the area is that of gentle undulating landscape which reflects the underlying geology. The monotony is broking by the competent rocks like the quartzites and granites forming ridges and hills standing above the fairly flat incompetent matasediment. The most prominent physical features are formed by clusters of Older Granite hills in the west of the study area, where they form mainly isolated inselbergs ranging in height from 300 to 700 metres above the mean sea level. All rivers in the area are seasonal and contain water only during the rainy season. River Gagara and River Petsa are the largest rivers in the area.

Several drainage pattern, thought to be related to the underlying lithology, are observed through the area. The dendritic pattern is observed to be the dominant drainage pattern where there is moderate to thick alluvial cover (Figure 2). Radial drainage pattern characterizes hilly granitic areas while treallis drainage pattern occurs where the streams flow along rock foliations and joints consequently, there is some degree of structural control in the drainage patterns observed in the area.

1.3.3Climate

The study area has a tropical continental climate with mark wet and dry season. It has a average annual rainfall ranging from 800mm to 1000mm (Figure 3). Generally climate varies considerably according to months and seasons. The following are the season experienced in the study area which are: a cool dry (harmattan) season from

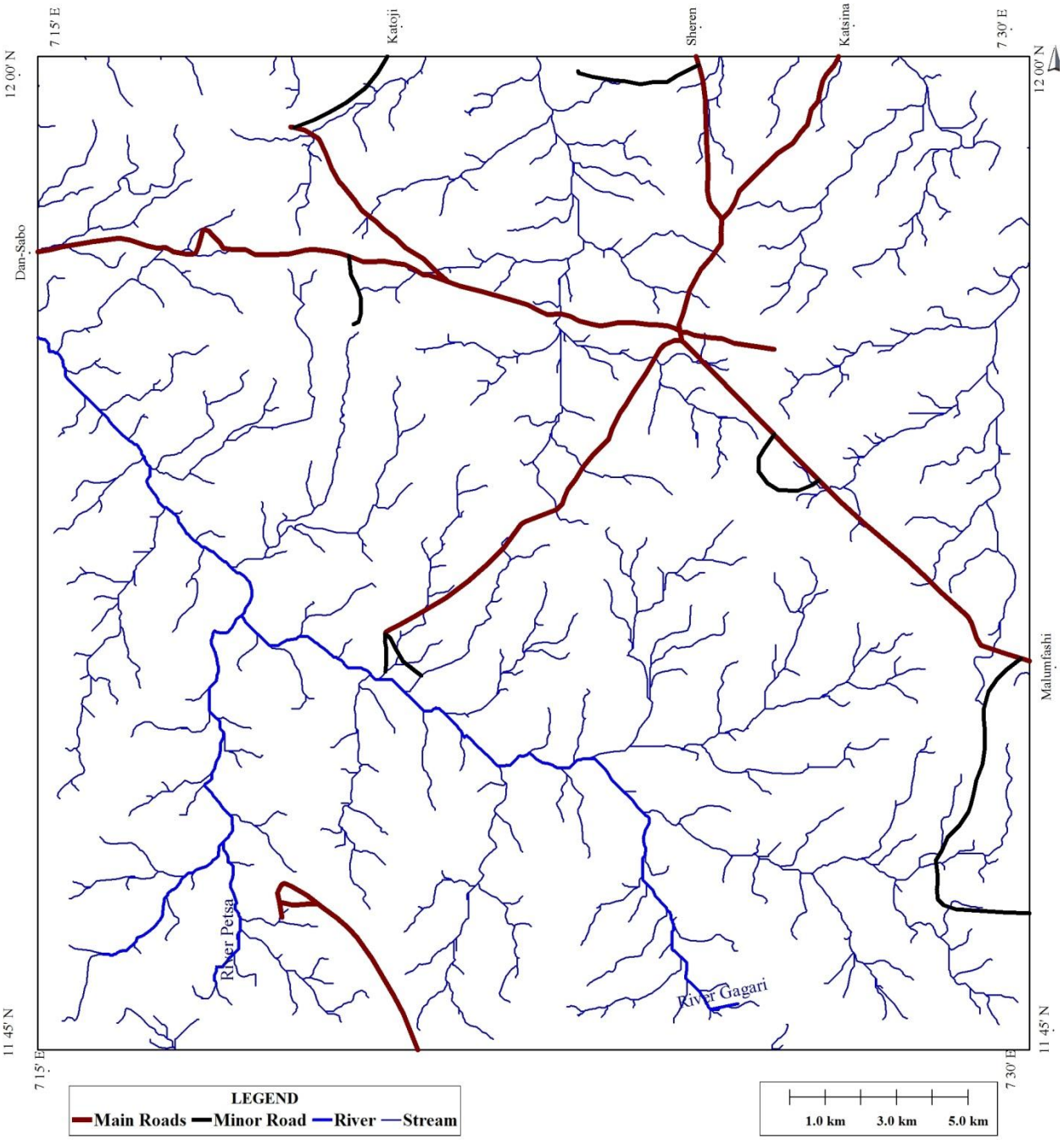


Figure 2: Drainage map of the study area,Federal Survey of Nigeria, 1967.

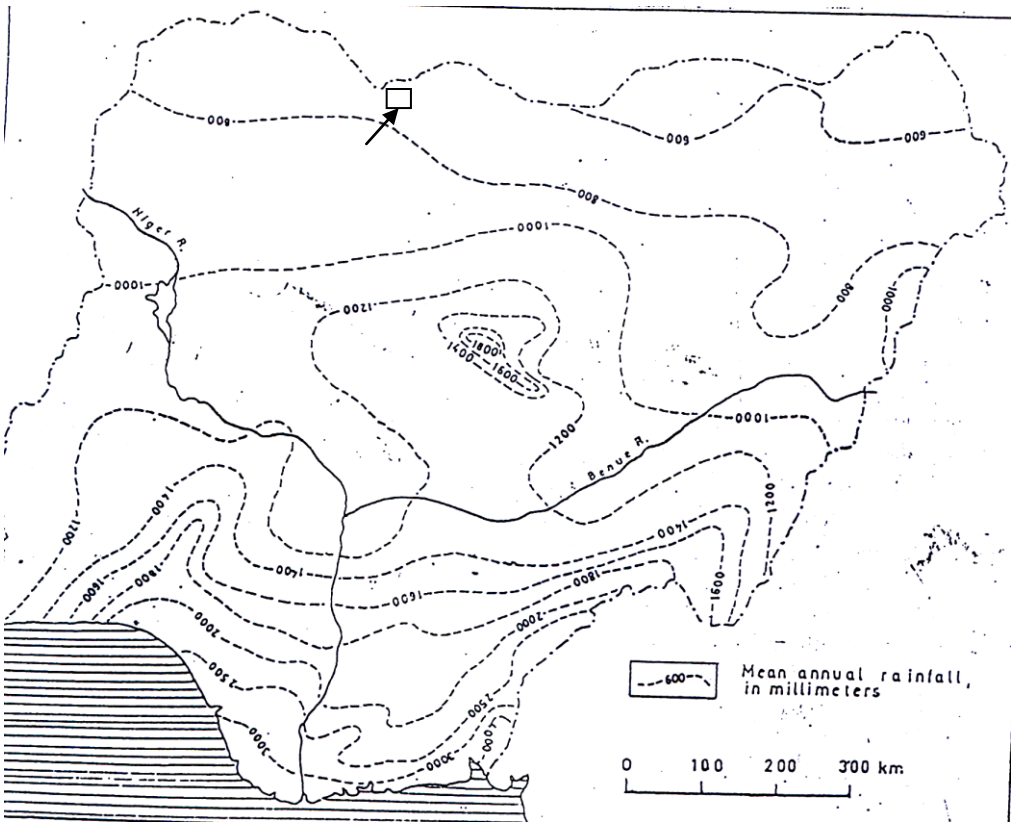


Figure 3: Map of regional distribution of mean annual rainfall in Nigeria, after Schoeneich, 2003. Study area is shown by an arrow.

March to May, a hot dry season from May to June, a warm wet season from June toOctober; and a less marked season after rains during the months of October to November and itis characterized by decreasing rainfall and gradual lowering of temperature.The fluctuations in temperatures varies from hot days to cool windy nights with average maximum temperature of about 45^{o}C and minimum of about 15^{o}C. The driest months are January/February in the area. Although downpour of rains could be recorded in March/April, the effective rainy season starts in June and last till mid-October (Figure 4 and 5). The rains are induced by the-northward movement of the southwest trade winds from Atlantic Ocean. Rainfall and evapotranspiration are the most important climatic parameter influencing the groundwater resources of the area. The amount of rainfall and the duration of rains are variable from year to year (Kachalla, 2011).

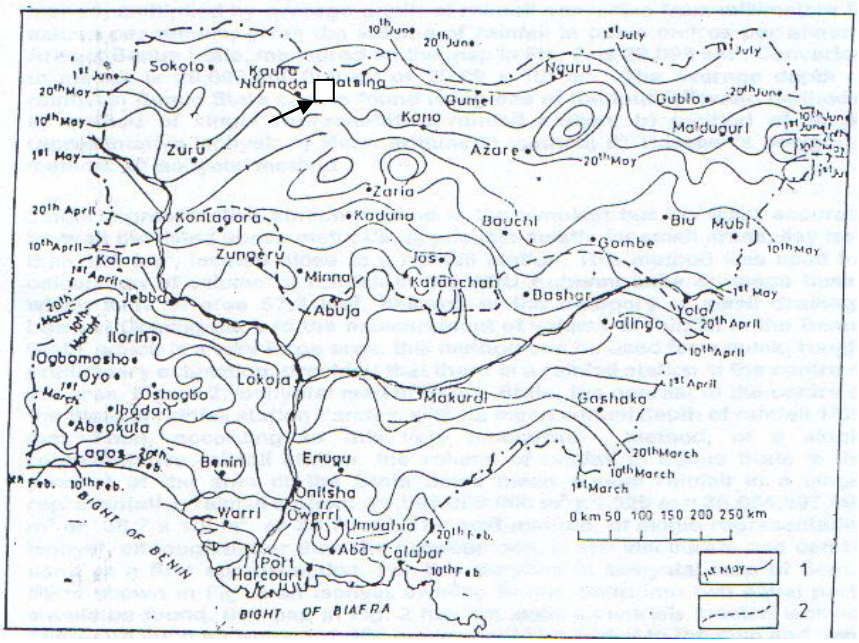


Figure 4: Map of the date when rainy season starts, Walter, 1977, in Schoeneich and Garba, 2010. Legend: 1-Isochrone of the start of rainy season; 2-Boundary between one-peak rainy season in the north and two-peak rainy season in the south. Study Area is shown by an arrow

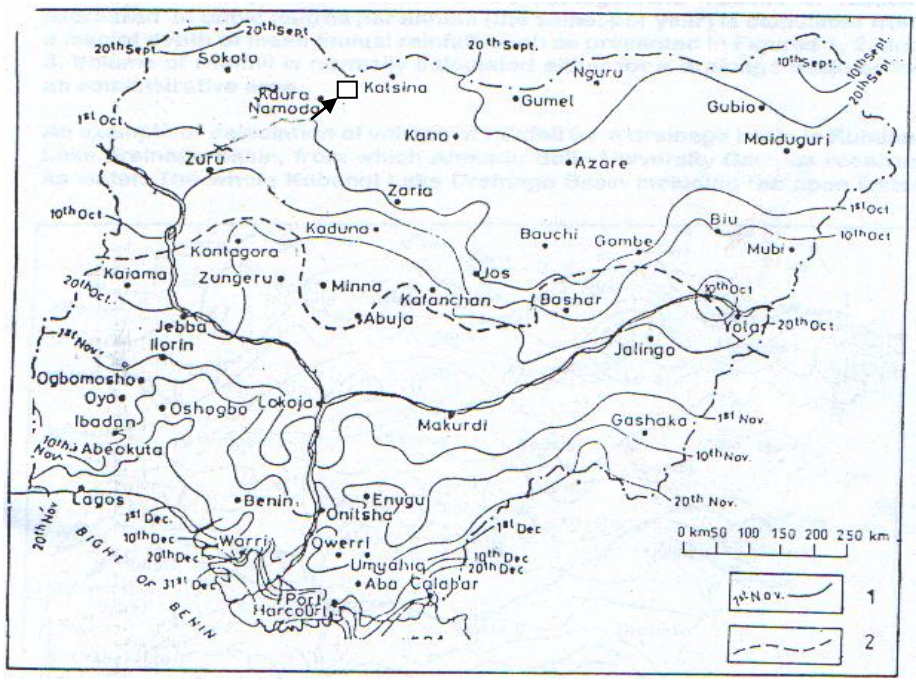


Figure 5: Maps of the date when rainy season ends, Walter, 1977, in Schoeneich and Garba, 2010. legend: 1-Isochrone of the end of rainy season; 2-Boundary between one-peak rainy season in the north and two-peak rainy season in the south. Study Area is shown by an arrow.

1.3.4 Vegetation

The study area belongs to the Sudan Savannah zone characterized by open woodland with abundant stunted trees, thorny bushes, shrubs and grasses interrupted by large isolated trees. The trees grow long tap roots and thick barks that make it possible for them to withstand the long dry season and bush fires. The grass cover has durable roots which remain underground after stalks are burnt away or wilted in the dry season only to germinate with the first rain. The existing vegetation is a function of many years of human interference and degradation. Exploitation of the vegetation has been largely for fuelwood, cultivation and grazing.

1.3.5 People, Land Use and Soil

The major ethnic groups in the study area are Hausa and Fulani; these are the indigenous ethnic groups, while Igbo and Yoruba are other ethnic groups leaving in the area. Most of the people in the study area are peasant farmers and petty traders. There are few civil servants and businessmen. Majority of the farmers are rearing animals like goats, sheep, local chickens and cattle. This increases greatly the economic viability of the people of the area.

The soils in the area belong to the generalized ferruginous Tropical soils, consisting of highly weathered red soils representing the zonal soil development under a climate regimewith a substantial but seasonal rainfall, where rock weathering has been intense. The soil texture varies from coarse sands to sandy clay loams and occasionally to sandy clays or clays. They are gravelly in nature due to the presence of included materials such as fragments of quartz, weathered rocks and iron concentrations.

These soils exhibit a marked differentiating horizon frequently with a surface layer rich in plant nutrients and subsoil in which clay mineral and iron oxide accumulated. Despite their lack of fertility, the soils are cultivated, since there is lack of more fertile soils. The soils found in

the lowland are termed “fadama” by local villagers and are completely different from the upland ferruginous tropical soils. The fadama soil consists mainly of heavy textural sandy clay loam to clay soils. Their relative high natural fertility and closeness to source of water combine to give the soils a high potential for increased crop production.

The two major economic activities within the area are farming and cattle rearing. The crops grown which includes millet, guinea corn, upland rice and maize for food as well as cash crops like cotton and groundnut. Guinea corn and millet are mostly cultivated due to their multiple functions to villagers as human food and fodders. Root crops like cassava and sweet potatoes on the other hand are cultivated along the fadama areas.

Shifting cultivation, overgrazing by cattle and periodic bush burning by the villagers results in disturbing the delicate seasonal balance between available moisture and vegetation cover (Thomas *et al.*, 1981) in semi-arid environment. This slight change in the balance leads to the top soil being readily washed off resulting to gully erosion, surface run-off and loss in soil moisture available for plant growth and groundwater recharge.

Therefore availability of potable water during the dry season is the most important environmental factor influencing location of most settlements within the area(Kachalla, 2011).

1.6 PREVIOUS WORK

Not much work has been done on the geology, water quality and hydrogeological investigation in this area. This is largely on a generalized study and either cover the entire Northern Nigeria Basement complex or cover the entire Northwestern Nigeria.

The earliest works done in northwestern Nigeria are those of Truswell and Cope (1963) who mapped the now classical Kusheriki area. They divided the metamorphic rocks of the area into three formations the Kusheriki, the Kushaka Schist and the Birnin Gwari Schist Formations.

Muotoh (1966) carried out geological mapping of the degree sheet 77 (Chafe). He delineated the various rocks into granite gneisses, migmatites, schists, quartzite, porphyritic biotite granite and hornblende biotite granite. He also carried out the petrographic description of each of the rock units withthe main component minerals of the granite gneiss to the microcline, quartz, biotite and normal accessories which include aplite, sphene, zircon and iron oxide. The general texture is allotrimorphic granular. And some sections show myrmekitic texture in interstices. The migmaties consist mainly of quartz, plagioclase, microcline, hornblende and biotite. Accessories minerals include apatite, zircon, sphene and allanite. Schists are commonly fine-grained with well-developed schistosity and common minerals are quartz, biotite flakes, hornblende and porphyroblastic microcline, perthite, andalusite and garnet are very common. The porphyritic biotite granite comprises large sponge's plates of microcline pathite, embedded in medium to coarse-grained matrix composed of grains of plagioclase feldspars, quartz and biotite. The hornblende biotite granite is coarse-grained rock consisting of mainly microcline, plagioclase, hornblende and quartz.

In McCurry (1976), in her work on a General Review of the Geology of the Precambrian to Lower Paleozoic Rocks of Northern Nigeria divided the Paleozoic and Precambrian rocks of northern Nigeria into four major groups. These are the Basement Complex rocks which includemetasediment of high metamorphic grade such as paragneiss, basic and calcareous schist, marble and quartzite, as well as orthogneiss and possibly Early Eburnian granites; the Younger Metasediments which include rocks ranging from psammitic to pelitic sediments of low metamorphic grade, with occasional conglomeratic facies and interbedded lavas; the Older Granite Series which include rocks intruded during the Pan-African orogeny cycle like the basic and the intermediate intrusive small, irregular bodies of quartz and pyroxene diorite, and gabbro;

and the Volcanic rocks which belong to the post-Older Granite episode of high-level magmatic activities.

Ajibade*et al.*,(1989) divided the Nigerian basement into two provinces in their work on the Proterozoic Crustal Development in the Pan-African Regime of Nigeria. These provinces are the Western province characterized by narrow, sediment-dominated, N-S trending, low-grade schist belts in a predominantly migmatite-gneiss 'older' basement, and the whole is intruded by Pan-African granitic plutons; and the Eastern province, which comprises mainly a migmatite-gneiss complex intruded by larger volume of Pan-African granites and the Mesozoic Ring Complexes of Central Nigeria.

Du Preeze and Barber (1965) worked on the groundwater distribution in Northern Nigeria and described that the hydrogeological properties of the Basement complex is either in weathered mantle or in joints and fractures are present in the fresh rocks. They also emphasized, however, that the Basement complex taken as a whole, forms a very poor source of groundwater. The weathered mantle is often too thin to harbor large quantities of water and is usually too clayey to be highly permeable. The thickness of the weathered mantle varies widely reaching a maximum of 50 m with an average of 15 to 20 m. The joints are normally poorly developed to compensate for the inadequacy of the zone of weathering overlying them. Finally, the water is said to be chemically suitable for all purposes.

Kankara (2013) worked on groundwater quality in Funtua Northeast, Northwestern Nigeria where he analyzed some chemical parameters of cations, anions and trace elements in groundwater and surface water of the area.In his findings he discovered that the major cations are Calcium (Ca^{2+}) and magnesium (Mg^{2+}), while anions are the carbonate. Minor cations are the alkali (K and Na), while the anions are Sulphate (SO_4^{2-}), Chloride (Cl^-) and Nitrates (NO_3^-). The

most predominant Trace Elements in wells are manganese (Mn^{2+}), copper (Cu^{2+}) and Fluoride (F^{-}). While Phosphates and Nitrates are the minor anions.

1.7 SCOPE OF THE STUDY

Scope of the present study includesboth general geology and hydrogeological mapping which entailed:

- ✓ Mapping and locating of rock outcrops and sampled wells on the base map;
- ✓ sampling and analysis (physico-chemical) of the groundwater of the study area to determine/ establish its suitability for drinking and other domestic use; and
- ✓ Production of the watertable map, and updating the geological map of the area.
- ✓ Identification of lineaments in relation to groundwater In the study area.
- ✓ Calculation of water budget of the study area.

CHAPTER 2

LITERATURE REVIEW

2.1 GEOLOGICAL FRAME WORK OF THE NORTHWESTERN CRYSTALLINE HYDROGEOLOGICAL PROVINCE OF NIGERIA

Nigeria lies in the extensive region east of the West African craton and northwest of the Congo Craton which was affected by the Pan-African orogeny about 600 Ma ago. The Nigerian basement lies to the south of the Tuareg Shield (Figure 6). Nigeria is divided into three broad geological provinces: the Precambrian to Lower Paleozoic rocks of Crystalline Basement Complex; the Jurassic Younger Granite and Tertiary to Quaternary Volcanics; and the Cretaceous to Recent sediments (Figure 7).Almost 50% of Nigeria is covered by the crystalline rocks and 90% of this belongs to the Nigerian Basement Complex which is thought to be mostly Precambrian in age (Falconer, 1911). In 1963, Truswell and Cope observed that the dominant rock types in the crystalline Basement Complex of Nigeria are migmatites and granites.

McCurry (1976) divided the Palaeozoic and Precambrian rocks of northern Nigeria (Northwestern Nigeria inclusive) into four major groups:

Basement Complex (SensuStricto), underlies the entire area and includes all rocks older than the late Proterozoic metasediments of high metamorphic grade such as paragneiss, basic and calcareous schist, marble and quartzite, as well as orthogneiss and possible early (Eburnian) granite. The whole Basement Complex has been through at least two tectono-metamorphic cycles, and consequent metamorphism, migmatisation and granitisation has extensively modified the original rocks so that they generally occur as relict raft and xenoliths in migmatites and granites. More extensive areas of gneiss and ancient metasediments occur in north-west Nigeria.

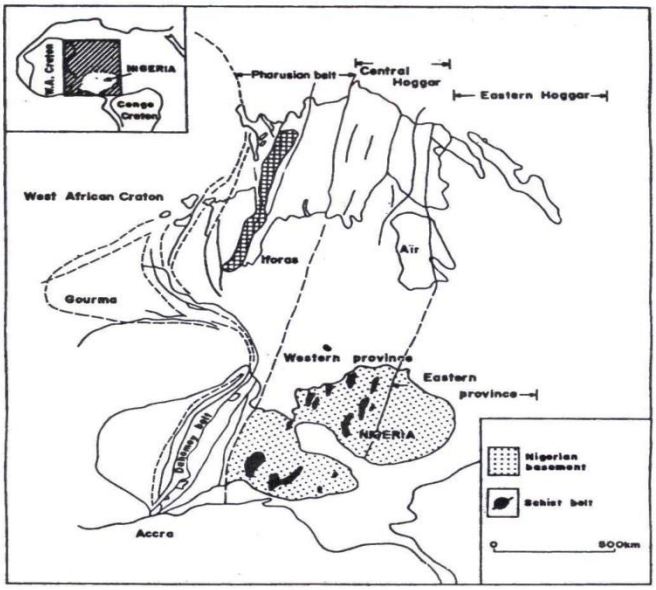


Figure 6: Generalized geological map of the Pan-African Belt east of the West African Craton showing the relative positions of the Nigerian Basement and the Tuareg Shield (after Caby*et al.*, 1981).

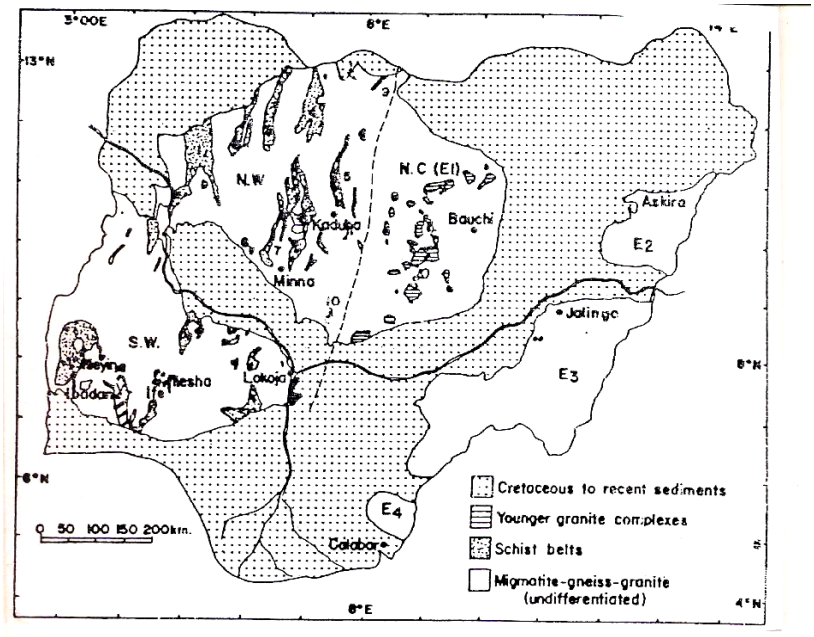


Figure 7: Generalized geological map of Nigeria,after Ajibade, 1976.

The metasediments recognized within the Basement Complex are believed to be relict of old supracrustal sediments which are known as the Younger Metasediments.

Younger Metasediments, these are extensively developed in north-western Nigeria they are well-defined and has approximately north-south trending belts. The rock types are varied, ranging from psemmatic to politic sediments of low metamorphic grade, with occasional conglomeratic facies and interbedded lava.They have been steeply folded along with the Basement Complex during the Pan-African orogeny, so that they now occur in synclinorial keels in a sea of a granitic material, resembling the greenstone-migmatite association of cratonic regions (Wright and McCurry 1970)

Older Granite Seriesinclude rocks intruded during the Pan-African orogeny cycle. The earliest rocks appear to be basic and intermediate intrusive represented by small, irregular bodies of quartz and pyroxene diorite, and gabbro. In the North-west, such basic have been extensively intruded by later acid rocks so that they now form part of an acid-basic complex. Granitisation on an extensive scale profoundly modified earlier rocks and resulted in widespread suit of syn-to late-tectonic granites, granodiorites and syenites.

Volcanic Rocksare the youngest rocks in the north-western Nigeria. They belong to the post-Older Granite episode of high level magmatic activity. Preliminary age determinations suggest that these rocks were intruded during epirogenic uplift and fracturing in the final stages of the Pan-African orogeny. For this reason, they are included in the description of the 'basement' rocks and not with the other volcanic rocks of Nigeria.

The first detailed work in northwest Nigeria was carried out by Truswell and Cope (1963) who mapped the now classical Kusheriki area. They were so impressed by the parallel structures and transitional contacts between the different metamorphic units in the area and concluded that

the gneissic complex, the schist formations and the Older Granites in the area were formed during a single orogenic event.The north-western hydrogeological province part of Nigeria is underlain by the Precambrian-crystalline rocks which include the migmatite-gneiss complex, metasediments and Older Granite.

2.1.1 Migmatite- Gneiss Complex

The Migmatite – Gneiss Complex is generally considered as the basement complex sensustricto(Rahaman, 1988; Dada, 2006) and it is the most widespread of the component units in the Nigerian basement. It has a heterogeneous assemblage comprising migmatites, orthogneises, paragneisses, and a series of basic and ultrabasic metamorphosed rocks. Petrographic evidence indicates that the Pan-African reworking led to recrystallization of many of the constituent minerals of the Migmatite–Gneiss Complex by partial melting with majority of the rock types displaying medium to upper amphibolite facies metamorphism. The Migmatite–Gneiss Complex has ages ranging from Pan-African to Eburnean.

We have two major types of gneiss; biotite gneiss and banded gneiss. The biotite gneiss is normally fine to medium grained to coarse porphyroblastic with strong foliationcaused by the parallel arrangement of alternating dark and light coloured minerals, which exhibit intricate gneiss folding of their bands and sometimes have variable joint directions with quartz mineralization. The bands are composed essentially of feldspar, quartz and biotite. The Migmatite – Gneiss Complex is the oldest basement rock dated as Birimian (about 2500 Ma).

2.1.2Metasediments

The Older Matesediments underwent prolonged repeated metamorphism, and now occur as quartzite (ancient sandstones) which mostly occurs as ridges, marble (ancient limestones) and

other calcareous and relics of highly altered clayey sediments and igneous rocks. There are also some slightly metamorphosed ancient Precambrian sedimentary and volcanic rocks known as the Younger Metasediments. The major rock types are ancient shaly rocks which are now referred to as quartz-biotite-muscovite schist. These change laterally into coarse-grained feldspar bearing micaceous schist.Schists with graphite, phyllites and chlorite are common. Ferruginous quartzites and talc schists also occur. The Younger Metasediments contain most of the gold deposits in Nigeria in the northwest around Maru and Anka, and at Zuru, Birnin Gwari near Kaduna and also Ilesha in southwestern Nigeria. They are popularly called schist belt by most writers.

The Schist Belts comprise low grade, metasediment-dominated belts trending N–S which are best developed in the western half of Nigeria. These belts are considered to be Upper Proterozoic supracrustal rocks which have been infolded into the migmatite-gneiss-quartzite complex. The lithological variations of the schist belts include coarse to fine grained clastics, peliticschists, phyllites, banded iron formation, carbonate rocks (marbles/dolomitic marbles) and mafic metavolcanics(amphibolites). Some may include fragments of ocean floor material from small back-arc basins. Rahaman (1976) and Grant (1978) for example suggest that there were several basins of deposition whereas Oyawoye (1972) and McCurry (1976) considered the schists belts as relicts of a single supracrustal cover. Olade and Elueze(1979) considered the schist belts to be fault-controlled rift-like structures. Grant(1978), Holt (1982) and Turner (1983), based on structural and lithological associations, suggest that there are different ages of sediments. However, Ajibade*et al.*,(1979) disagree with this conclusion and show that both series contained identical deformational histories. The structural relationships between the schist belts

and the basement were considered by Truswell and Cope (1963) to be conformable metamorphic fronts and it was Ajibade*et al.* (1979) who first mapped a structural break.

2.1.3Older Granites

The term "Older Granite" was introduced by Falconer (1911) to distinguish the deep-seated, often concordant or semi-concordant granites of the Basement Complex from the high-level, highly discordant tin-bearing granites of Northern Nigeria. The Older Granites are believed to be pre-, syn- and post-tectonic rocks which cut both the migmatite-gneiss-quartzite complex and the schist belts. They range widely in age (750–450 Ma) and composition. They represent a varied and long lasting (750–450 Ma) magmatic cycle associated with the Pan-African orogeny. The rocks of this suite range in composition from tonalites and diorites through granodioritesto true granites and syenites. Charnockites form an important rock group emplaced during this period. They are generally high level intrusions and anataxis has playedan important role (Rahaman, 1981). The Older Granites suite is notable for its general lack of associated mineralization although the thermal effects may play a role in the remobilization of mineralizing fluids.

The Older Granites are the most obvious manifestation of the Pan-African orogeny and represent significant additions of materials (up to 70% in some places) to the crust (Rahaman, 1988). Attempt to classify the Older Granites with respect to timing during an orogenic event are valid over only short distances. Contact features between members of the Older Granites suite suggest the coexistence of several magmas. Dada (2006) was of the opinion that the term "Pan African Granitoids" be used for the Older Granites not only on the merit of age which was not available at the time they were named Older Granites, but because it covers several important

petrologic groups formed at the same time.The granitoids which outcrop with the schist belts in northwestern Nigeria include biotite granites, biotite muscovite granites, syenites, chanockites, serpentinites and anorthosites.

Older Granites are the magmatic products of the Pan-African Orogeny. They are widespread throughout the Basement Complex and occur as large circular masses within the schists and the Older Migmatite-Gneiss Complexes (McCurry, 1976;Ajibade and Fitches, 1988). The Older Granites vary extensively in composition. They are composed of quartz, feldspar and biotite. They are weakly foliated and massive when fresh they are greyish blue due to the prominence of biotite and when weathered they exhibit brownish coloration because of leaching of other elements leaving iron which oxidizes giving it a brownish colour.

2.2HYDROGEOLOGY OF NORTHWESTERN NIGERIA

Two major aquifers are distinguished in the Crystalline Hydrogeological Province of North Western Nigeria and these are regolith aquifer and fractured crystalline aquifer.The regolith aquifer is a readily accessible source of water to the local population through hand dug wells. Below it is the fractured crystalline aquifer, extending maximum to 70 m beyond as proved by Tahir 2014 below the ground surface, which can only be exploited through boreholes. The regolith aquifer varies in thickness from 0 m to 30 m, depending on local geology, topography, and climate of the area (Adanu, 1987; Baba, 2007).

2.2.1Soft Overburden Aquifer

This is found within the weathered material overlying the fresh bedrock unit. The zone of weathering is generally only a few tens of meters deep, but in area of low relief, this can reach up the depth of between 30-40m. Such zone is characterized by the presence of reddish brown

materials. Soft overburden aquifer is generally shallow in depth. Consequently, its groundwater is usually susceptible to pollution and their yield is subjected to seasonal fluctuations.

2.2.2 Fractured Crystalline Aquifer

Fractured crystalline aquifer is directly underlying the soft overburden aquifer. However, some fractured aquifers are highly prolific, especially when these fractures are extensively interconnected with one another and linked to the surface for recharge. According to Du Preeze and Barber (1965), fractures in the crystalline basement of northern Nigeria, extend to a depth of not more than 90m. However more recent research (Eduvie, 1991, and Bala*et al*., 2011) shows that depth of boreholes drilled into the migmatite gneiss and porphyritic granite fall within the same range (25.0 m to 77.10 m for those within the migmatite gneiss and 29.0 m to 79.50 m for boreholes taping the porphyritic granite).

2.3WATER QUALITY OF NORTHWESTERN NIGERIA

The quality of groundwater supply depends on its purpose and these vary widely: the need for drinking, industrial, irrigation and recreation (Tijani, 1994 and Schoeneich, 2001). The quality and type of mineral matters dissolved depend on the chemical composition and physical structure of the rocks as well as the hydrogenion concentration (pH) and redox potential (Eh) of the water (Black and Hanshaw, 1965). Appello and Potma (2005) states that standard groundwater chemical analysis will,at the minimum, comprise values for temperature, electrical conductivity (EC), pH major cations (Na^{+}, K^{+}, Mg^{2+}, Ca^{2+}) and major anions (Cl^{-}, HCO^{-}_{3}, SO^{2-}_{4} and NO_3^{2-}). Eduvie (1991) also states, Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, HCO_3^{-}, SO_4^{2-} and Cl^{-} are present in important quantities as major ions even though determination of $NO^{2}_{3}{}^{-}$, $Fe^{+}$and phosphate ion would enhance a better assessment of chemical quality of water. The chemical composition of

groundwater depends on the mineralogy of the aquifer and the chemical character of water is modified by the ionic exchange reaction during infiltration of the water and anthropogenic influence of man (Abimbola*et al.*, 2002). The enrichment of groundwater in these constituents depends on the rock type in which the water is found, residence time of water in the rock, andwater circulation process which takes place in the rock including evaporation and transpiration (Adanu, 1989).

The pH of basement rock groundwater is generally within 4 to 9. In granite terrains the chloride content in groundwater is about 6 mg (Wright and Burgess, 1992). The hydrochemicalfacies for basins in northwest Nigeria appear to be influenced aside from the lithology, by rainfall and their proximity to the sea. In the Basement Complex of northwestern Nigeria in general, no single cation-anion pair exceeds 50%, hence an appreciable percentage of the groundwater in the northwestern Nigeria areas is of the non-dominant type. Within the overburden aquifer of the Basement Complex, with limited regional flow, a rainfall of about 1150 mm per annum is arbitrarily set as the boundary between alkaline and saline groundwater (Raji and Alagbe, 1997). They calculated values in percentage for the anion and cation facies, computed on the basis of equivalent per million and write that the hydrochemicalfacies of waters from Shika drainage basin are generally $CaMgPHCO_3$ (secondary alkalinity) in composition while waters from the Kangimi drainage basin are mainly $NaKPHCO_3$ (primary alkalinity) in composition. Appendix iii shows WHO (1999) standard for drinking water quality while Appendix iv shows NIS (2007) standard for drinking water quality.

CHAPTER 3

MATERIALS AND METHODS

3.1 INTRODUCTION

The study involves collection of topographical map of the study area, water sampling for physico-chemical analysis and mapping of rock outcrops for the production of geological map. The topographical map was collected from Geography Department Ahmadu Bello University, Zaria. About 59 wells were studied out of which 10 were chosen for physico-chemical analysis. Many wells were sampled to enable easy and accurate production of groundwater configuration map, as well as the co-ordinatesof each sampled locations were taken using satellite navigator. Depth to water level in hand dug wells at the peak of dry season and at the end of raining season where measured and located on the topographical maps. The water level values were subtracted from the values of the elevation of wells and plotted on the topographical map. All these data plotted on the topographic map were used for the preparation of water table configuration maps both for dry season and wet season. Water table map of the area and direction of groundwater flow was determined.

3.2 METHOD OF INVESTIGATION

Hydrogeological studies were carried out in three stages and these are field work, laboratory work, and evaluation of both the field and the laboratory data. A total of eleven water samples from ten hand dug wells across the study area were collected and analyzed for chemical contents and qualities of groundwater of the study area. Measurements for both peaks of dry and rainy seasons were carried out during March/April and August/September 2012 respectively.

During the measurement, depth to water level, elevation of wells, and coordinates of each well was taken using metric tape and satellite navigator (GPS).

3.3 FIELD WORK

3.3.1 Water Level Measurement

Water level in hand dug wells were measured using metric tape for fifty nine hand dug wells in the study area. The result obtained is shown in Appendix 1. This is done by lowering the metric tape into wells. The eyes as a guide when it reached the surface, it indicate a wave or ripple on the surface of the water. Readings were taken from the reference mark. Value of depth to water levelin hand dug wells where subtracted from the values of their elevations.

During the collection of the samples physical parameters such as temperature, conductivity, PH and the total dissolved solids were obtained during the field work with the aid of the four-in-one meter (PH/EC/TDS/Temperature-model Mi 806 combined meter). This instrument beeps a sound when the tip of the lowered probe touches the water in the plastic rubber, and readings were taken.

3.3.2 Coordinates

Coordinates and elevations of each well were recorded using Garmin satellite navigator (GPS). The satellite navigator was calibrated to ensure accuracy in reading and was used to measure the exact locations of wells by recording their coordinates and elevations. The values obtained were used to plot water table configuration maps of the peak of dry season and peak of raining season by subtracting the water level measured in a well from the elevation of that same well.

3.3.3 WATER SAMPLING

During the field work, water was sampled from ten selected hand dug wells for chemical analysis. Twenty two containers of one litter each was washed before taking to the field. Two separate samples were collected from each water point, one for the determination of anions and the second one for the determination of cations. The sample for the cations was acidified with concentrated nitric acid (HNO_3) to a pH of approximately two and was firmly capped. This is done in other to reduce the absorption of ions from the solution and the formation of bonds between the containers and the ions. Thereafter the sample was preserved in the deep freezer before taken to the laboratory for analysis.

3.4 LABORATORY WORK

3.4.1 Water Sample Analysis

During sampling, eleven water samples from ten different wells locations where collectedandbrought from the field where taken foranalysis for both majorcations and anions in the Department of Soil Science Laboratory Ahmadu Bello University, Zaria. Concentrations of major cations (magnesium, calcium, sodium and potassium) and major anions (bicarbonate, sulphate, nitrate and chloride) were measured using Atomic Absorption Spectrophotometer, Flame Photometer and Titration. Flame Photometer was used for sodium, calcium and potassium; titrimetric method was used for bicarbonate, sulphate and chloride; and Atomic Absorption Spectrophotometer was used for magnesium and iron figure19.

3.5 EVALUATION OF FIELD DATA

3.5.1 Groundwater Configuration Maps

Base map of the study area (Sheet 78 Funtua NE on the scale of 1: 50,000) was obtained from Geography Department, Ahmadu Bello University, Zaria. Locations of hand dug wells on the base map were plotted based on their field coordinates. The groundwater configuration maps were produced using conventional method as well as using GIS (Global Mapper 13.0) method of maps production. The contour maps plotted were for the aquifer tapped by the hand dug wells in the study area. Fifty ninehand dug wells were measured in the entire study area.

3.5.2 Preparation of Hydrogeological Maps

Values of depth to water level measured in hand dug wells were subtracted from the values of their elevations. The resultant values were used to plot the maps manually which produced points of equal water table elevation and was letter digitized (water table contour lines or isohypes). The map was used in studying the configuration of the water table and directions of groundwater flow figure 17and18.

3.6 GEOLOGICAL MAPPING

Geological mapping of the study area was done on a scale of 1:50,000 using the following field materials such as:Hammer, Camera, Masking tape, GPS, and Bags. Traverses were made either by footpaths and available roads. During the traverse any outcrop seen is being identified and mapped, located on the base map. Features observed on rock outcrops were shape (include the size), structure, texture, colour (whether the rock is light or dark in colour) and the minerals content. GPS was used to get the co-ordinate, camera was used to take photograph of

outcrops, and fresh samples were collected and labeled with a masking tape. In the study area, threelithologies were identified and mapped.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 GEOLOGY OF THE STUDY AREA

Rocks identified during the field work in Kankara and its environs include thefollowings: migmatite, granite gneiss and biotite granite(Figure 8).

4.1.1Migmatite

The migmatite is found in the southwest and southeast part of the study area. In the field the rock may occur as the flat lying medium size domes or ridges, whaleback or as high rising escarpment. Texturally themigmatites are medium to coarse grained which are light coloured alternating with the paleosome (dark coloured component). The banding may be almost microscopic or very coarse and vary in size. The main minerals are quartz, feldspar and biotite, small scale joints and fractures (Plate1). The migmatite mostly made up of metamorphosed granite as their dominant component.They are generally poorly foliated with albitic and pegmatitic veins commonly cutting across the rock units.

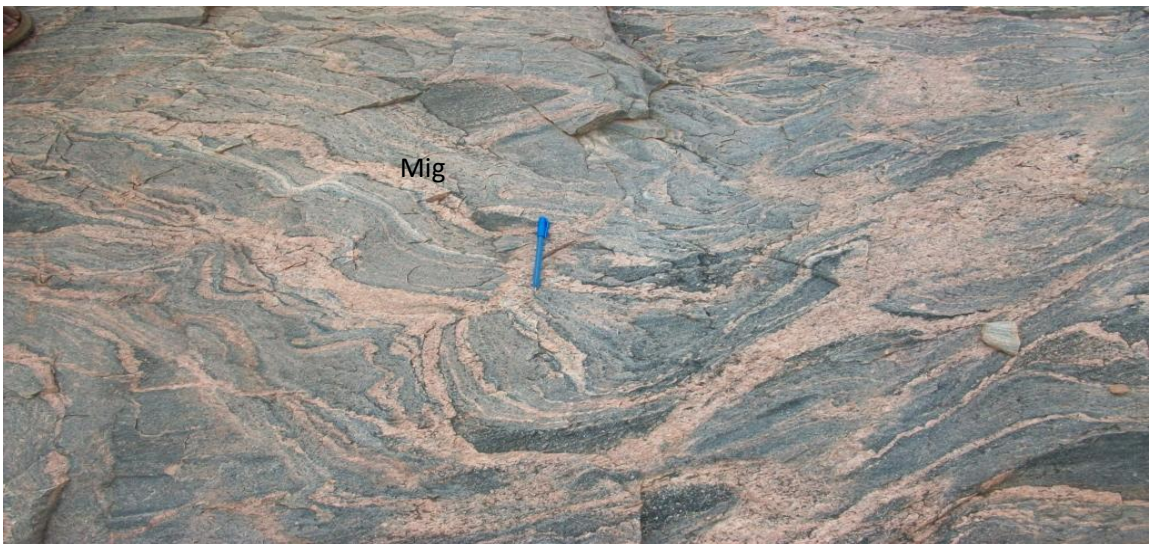


Plate I: Migmatite in part of the study area (11^{o}51’ N; 7^{o}20’ E)

4.1.2 Granite-Gneiss

This rock type outcrops from Pauwa down to ZaginMakeda in the northern to southern parts of the study area (Plate II).In the field the rock occurs as ridges and more dykes, fractures and faults. They are fine to medium grained foliated Biotite-rich Granitic rocks, pinkish in colour but whitish in most out crop due to weathering. The visible minerals are biotite, feldspar, and quartz. They are mediumgrained, fairly uniform in texture, weakly foliated and massive. Exposures occurring within the river channels are highly weathered.

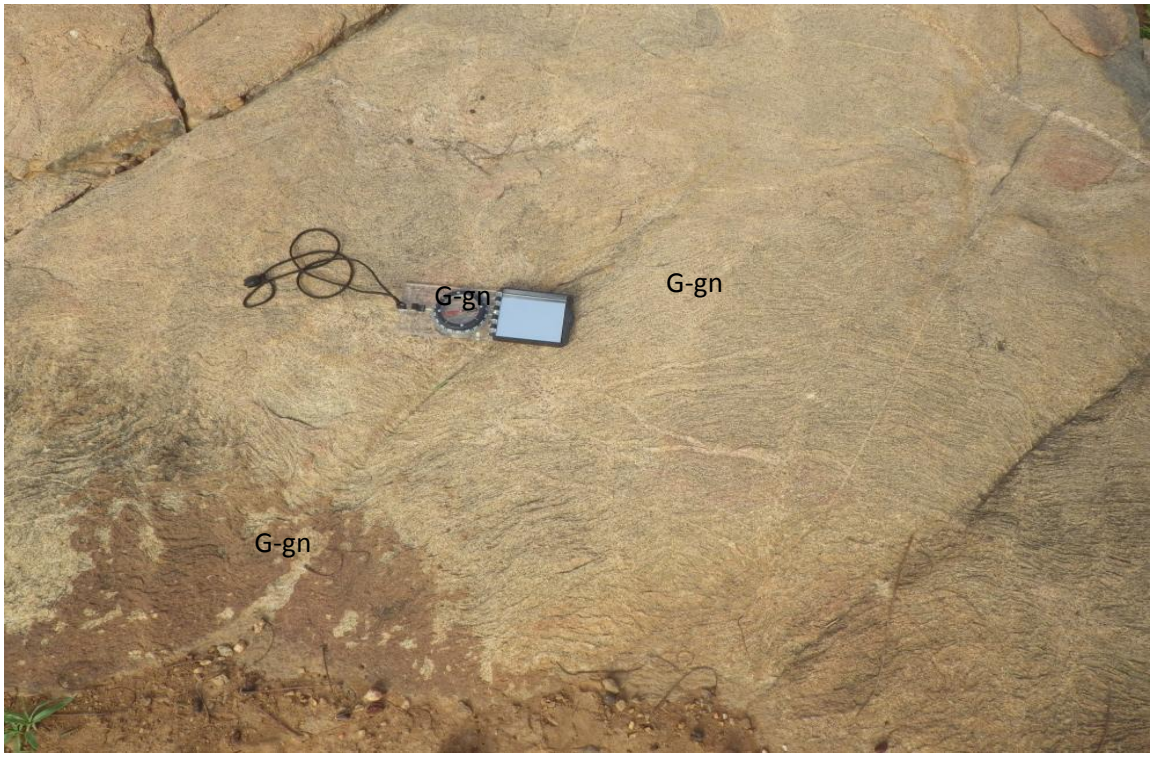


Plate II: Granite-gneiss in part of the study area ($11^{o}54'$ N; $7^{o}22'$ E)

4.1.3Biotite Granite

Biotite granite is found in the North - West part of the study area in the field.The rock may occur as massive, Inselberg. They are highly jointed and fractures withabundant of veins.

Major minerals found in the rock arebiotite, feldspar and quartz. It is greyish blue in colour due to the prominence of Biotite and when weathered they exhibit brownish colouration because of leaching of otherelement leaving iron which oxidizes giving it a brownish colour(plate III). Biotitegranite is magmatic in origin. It has abundance of large feldspar set in groundmass rich in quartz, biotite and hornblende.



Plate III: Biotite granite in part of the study area ($11^{o}56'N$; $7^{o}16'E$)

4.2RELATIONSHIP OF GEOLOGY TO GROUNDWATER OCCURRENCE

The basement rocks of the area have been subjected to various episodes of metamorphism and tectonism (McCurry, 1976) resulting to development of structural features favourable to groun+dwater accumulation. Foliation development in the gneiss and the jointing, fracturing in all basement rock produced by tectonism are expected to aid in rock weathering and thus favour groundwater accumulation. Joints and fractures are found on the major rocks of the area. Lineament of the studyarea were extracted using (PCL geomatica).Lineament were then

exported as shape files from PCL geomatica,then imported into Arc map (Arc GIS) software where statistical analysis was performed. Lineament information from Arc GIS was exported and imported into rock work software where orientation was performed to construct a rose diagram and determine their dominant direction.(Figure 9,10 and 11).Superimposing the lineament map on the drainage map,it shows that there is some degree of structural control in the drainage patterns observed in the area(Figure 16).The major trends are NW, NNE-SSW and NNW-SSE.

The major trend in the biotite granite is in NE-SW direction. Figure 12.The major trend in the granite gneiss is in NS,NW–SE.Figure 13. While for the migmatite the major trend is in E-W direction. Figure 14.

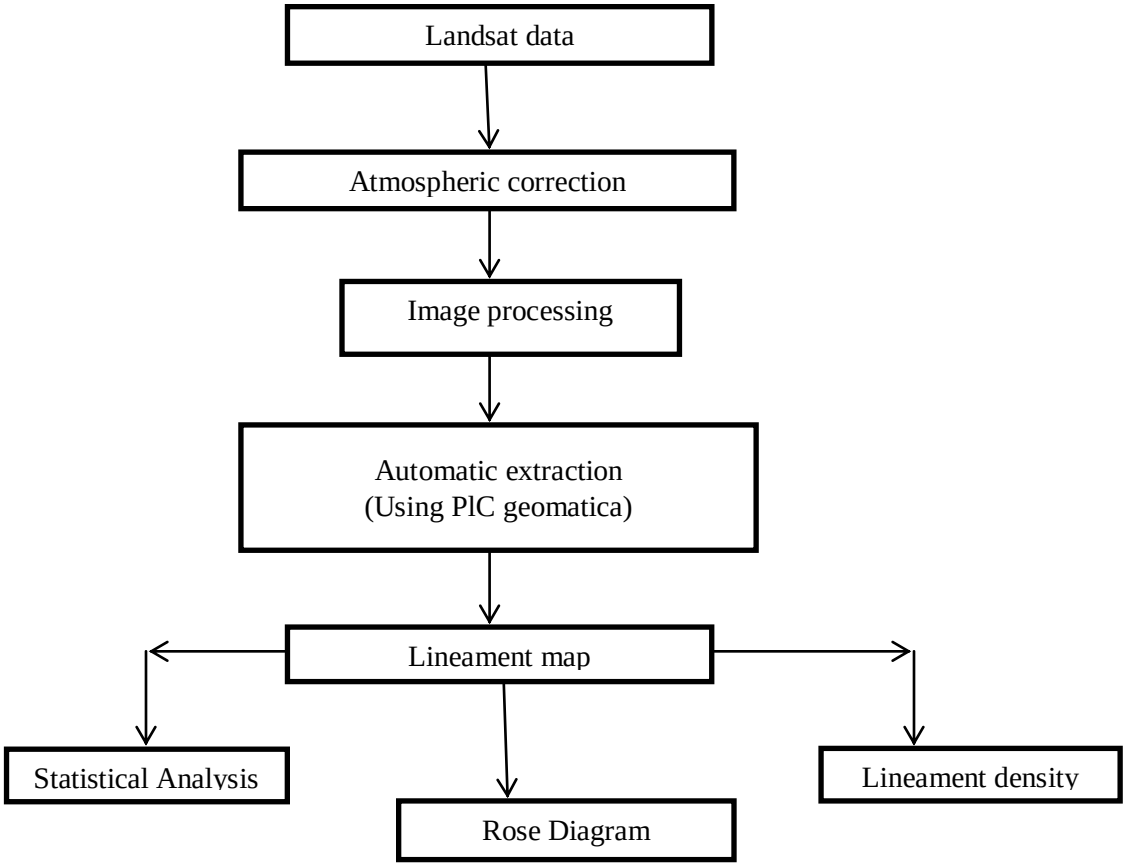


Figure 9: Flow chart for automatic lineament extraction.

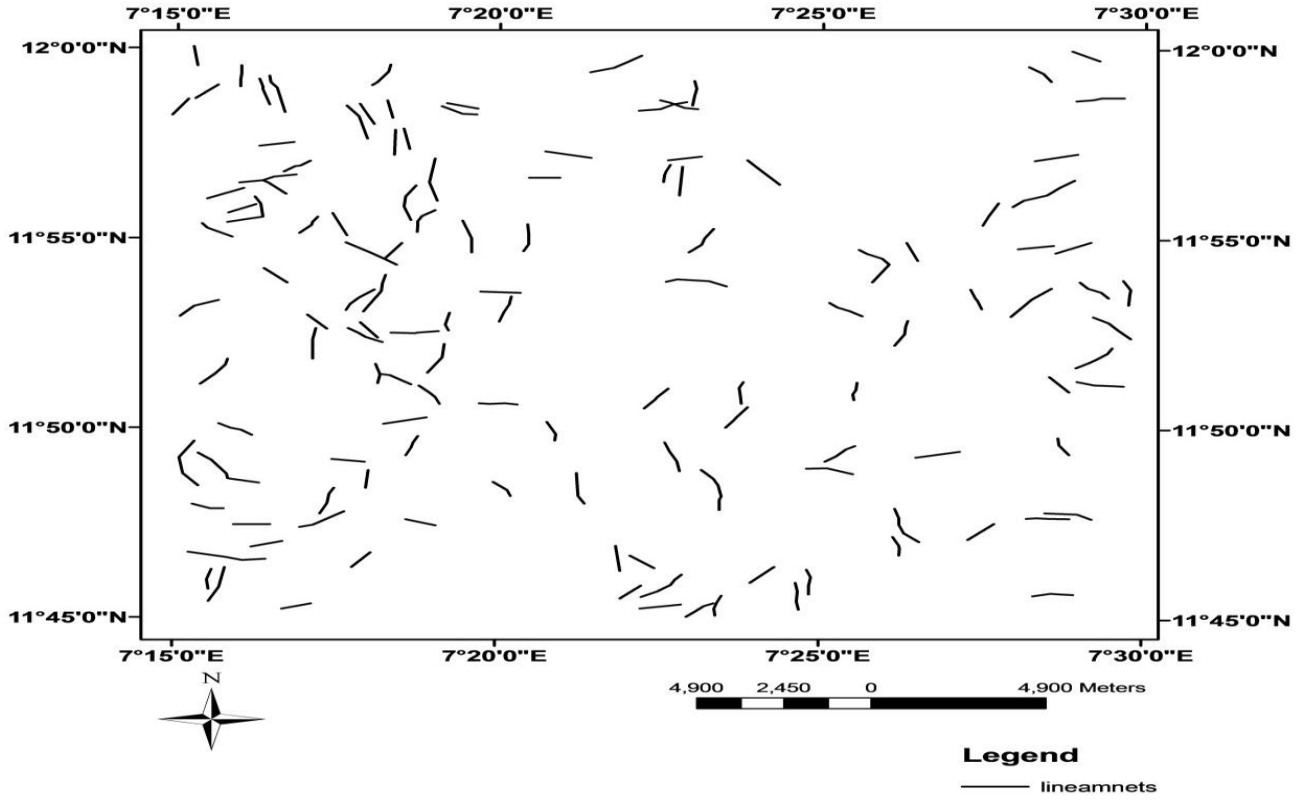


Figure 10:Lineament map of the study area

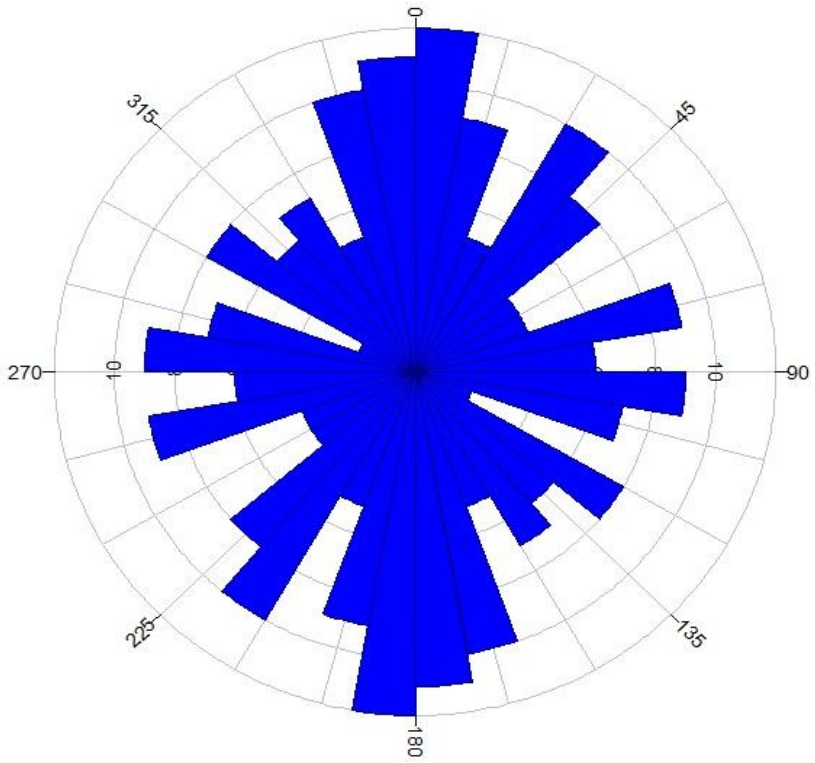


Figure 11: Rose diagram of lineaments in the study area

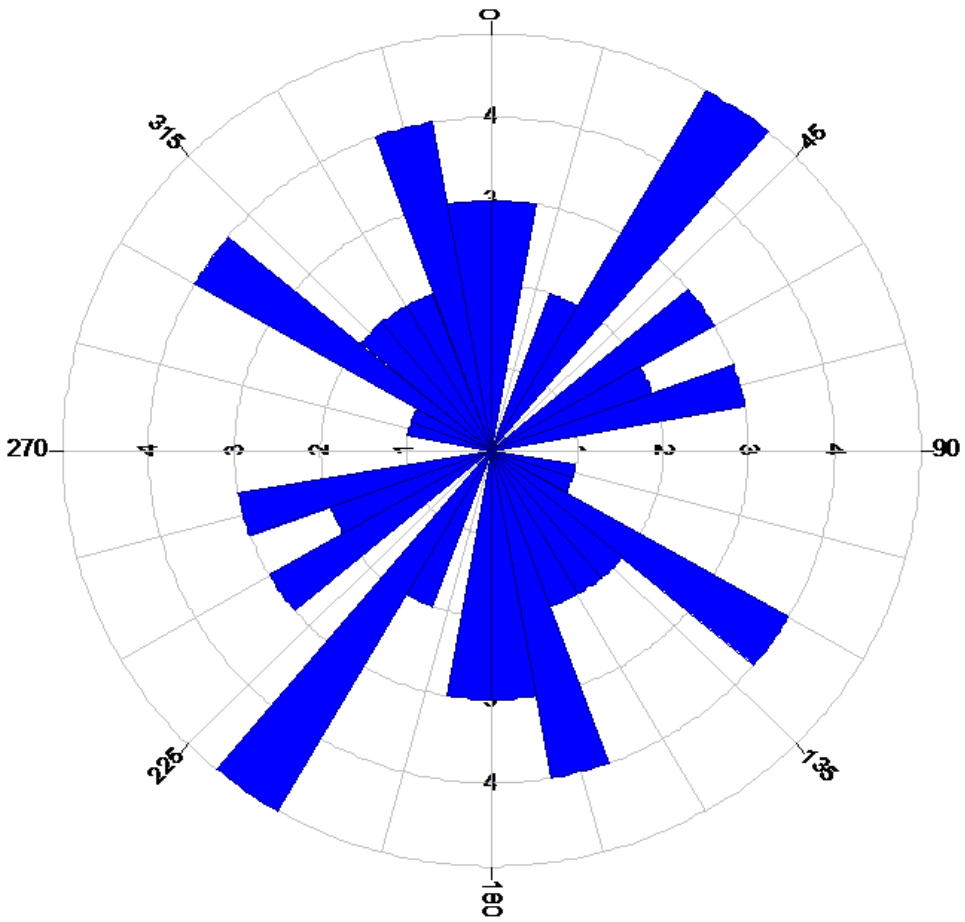


Figure: 12 Rose diagram for biotite granite

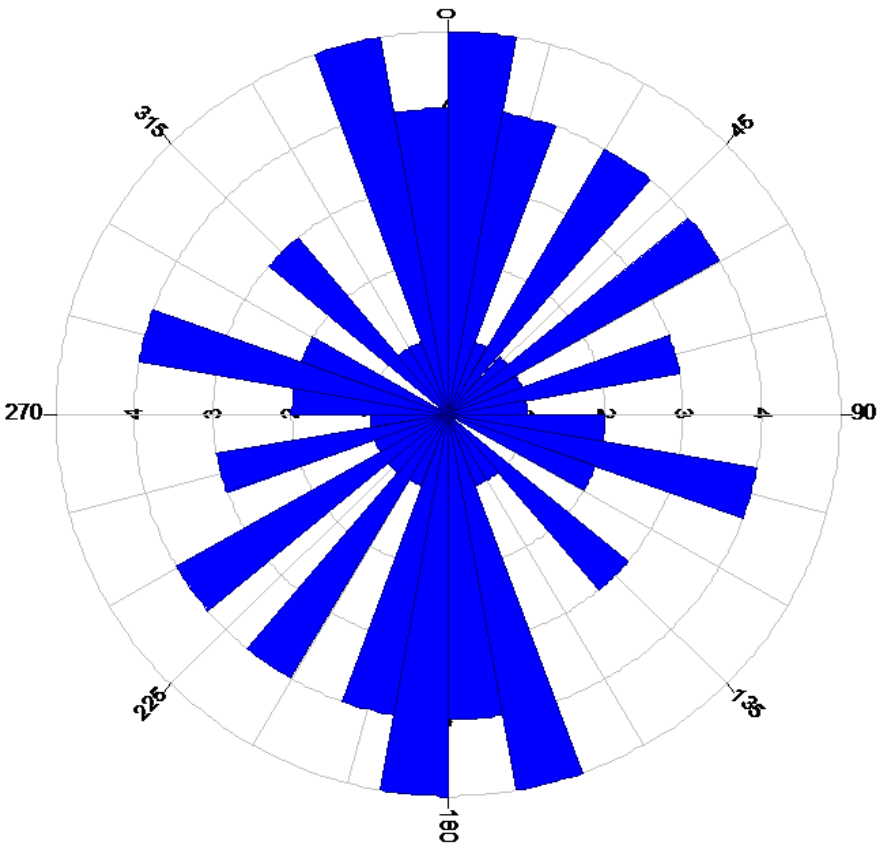


Figure: 13 Rose diagram for granite gneiss

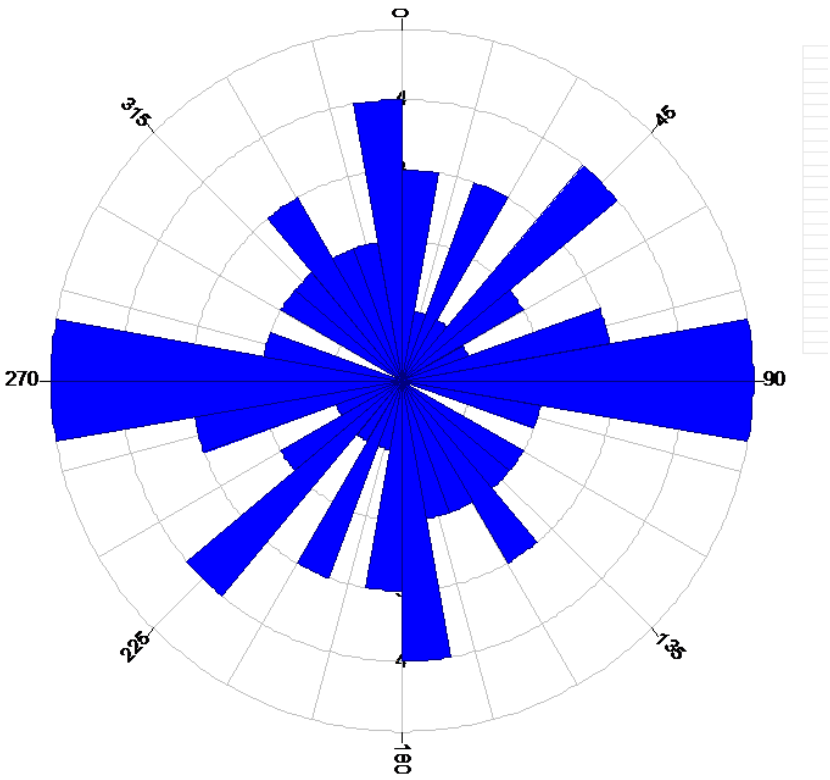


Figure: 14 Rose diagram for migmatite

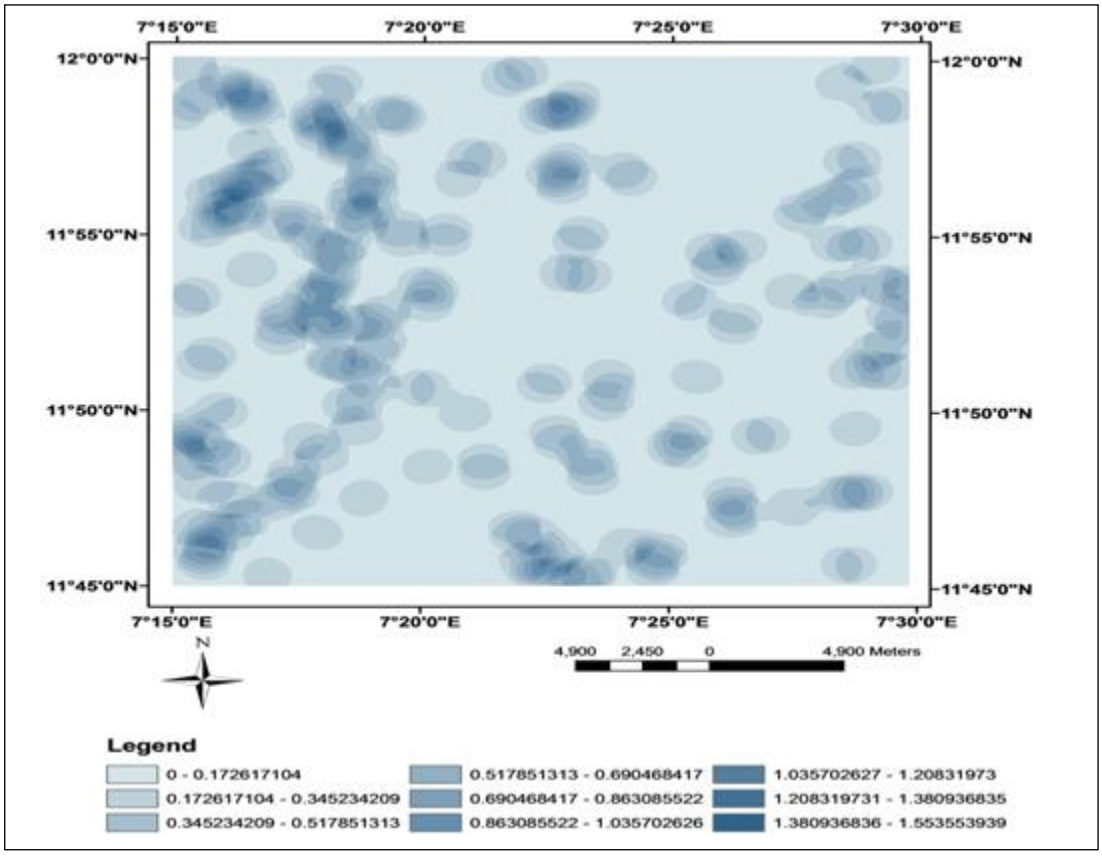


Figure 15: Lineament density map of the study area

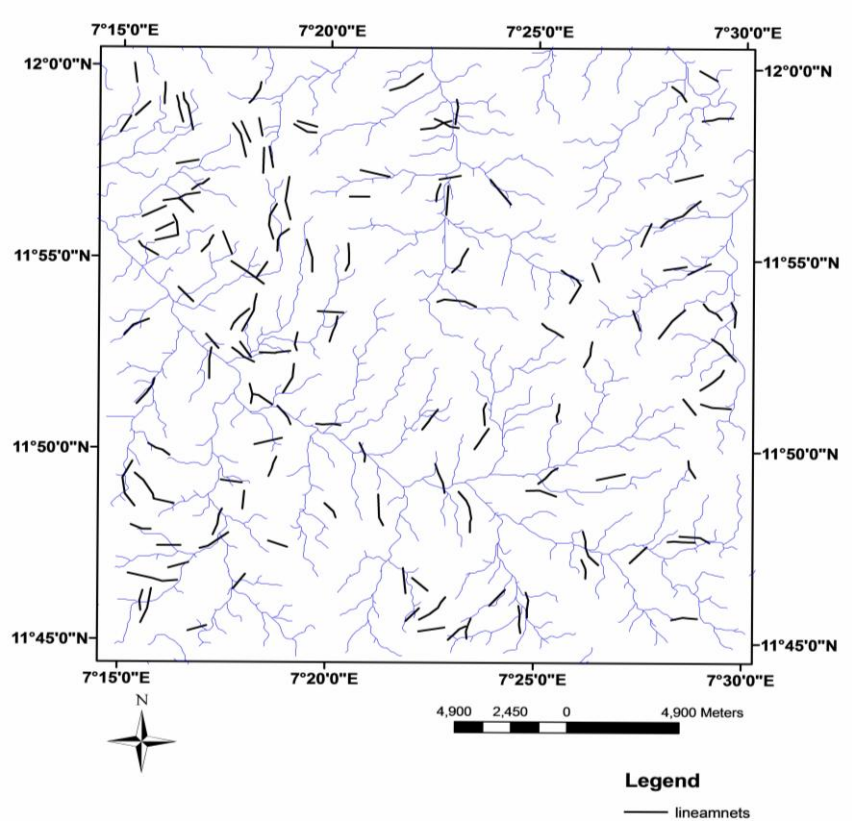


Figure 16: Superimposition of lineament map on the drainage map

The study area is found to have a number of crisscrossed lineaments. The intersection of lineaments is considered as good occurrence of groundwater potential zones. For analysis purpose, lineament density have been prepared and categorized in three classes: low, medium and high (Figure 15). Higher density of lineament is very favourable zones for groundwater recharge than lesser ones. In the lineament density map, the western part of the map has the highest lineament density in the biotite granite rock type; the eastern part which is made up of migmatite has the medium lineament density while the central part which is made of granite gneiss has the lowest lineament density.The highest fractures are found in the biotite granite in the study area.

4.3AVAILABILITY OF WATER RESOURCES

4.3.1 Surface Water in the Study Area

Mean annual depth of rainfall in the study area (Funtua sheet 78NE) from map of mean annual rainfall in Nigeria by Schoeneich (2003) is 850 mm/a. Volume of rainfall over the study area has been calculated as follows: study area as calculated is 748,500,000 m^2. Therefore, the volume of rainfall is 850 mm/a x 748,500,000 m^2 = 0.85 x 748,500,000 m^2 = 631,125,000 m^3/a. Major rivers in the area are Gagare and Petsa rivers and other smaller streams. However, allthese river systems contain water in their channels only during the rainy season and have little or no water in the dry season. There is no single artificial dam in the study area.

4.3.2 Groundwater in the Study Area

Groundwater within the study area occurs in weathered overburden and fractured crystalline aquifers, weathered overburden aquifer in the study area is very thick and this is because the dominant rock types in the area are metamorphic rocks.

4.4 WATER TABLE CONFIGURATION AND DIRECTIONS OF GROUNDWATER FLOW

Measurement of the groundwater table was done at the peak of dry season and raining season(April and August) 2012. Because of the nature of the area (semi-arid zone), there is less rainfall, thick overburden and so wells in the area are deep as well as the water table from the ground surface. The average depth to water table at the peak of dry season was 12.26 meter below the ground surface while that of raining season was 8.68meters. The groundwater that form recharge flows laterally towards streams and river channels as indicated by arrows drawn perpendicular to equipotential lines and tends to diverge from the recharge areas and coverage towards the drainage channels (Figure 17 and 18).

4.5 AQUIFER PROPERTIES

Aquifer characteristics obtained from pumping test data show that yield ranges from 32.83 to 40.61 m^3/day, Storativity ranges from 0.0147 to 0.0652 while transmisivity within the aquifers in the area range from 0.68 to 2.98 m^2/day corresponding to very low to low transmissivity after Krasny (1993) (Table4.1and 4.2) thus implying that aquifers in the area are suitable for small withdrawals for local water supply (Krasny, 1993). Appendix VI.

Table4.1 : Summary of Aquifer Characteristics obtained from Pumping Test Data

S/No.	Area	Yield (m^3/day)	Transmissivity, T (m^2/day)	Storativity, S
1.	Garagi	40.61	2.98	0.0652
2.	Nagamala	32.83	0.60	0.0476
3.	Turare	32.83	1.62	0.0147
4.	Mabai	35.42	1.56	0.0374

Table4.2: Standard for Transmissivity (T) Krasny (1993)

T (m^2 /day)	Designation of transmissivity	Groundwater Supply Potential
1000	Very high	Withdrawal of great regional importance
100	High	Withdrawal of lesser regional importance
10	Intermidiate	Withdrawal for local water supply (small community plants etc)
1	Low	Small withdrawals for local water supply (Private consumption etc).
0.1	Very law	Small withdrawals for local water supply with limited consumption.
	Impermeable	Sources for local water supply are difficult if possible to ensure.

4.6 WATER RESOURCES EVALUATION

An estimation of the total groundwater reserve and recharge based on the overall water balance is necessary for the effective management of the groundwater resources in the area. The

main source of replenishment of the groundwater is rainfall. The unreliability and the erratic nature of the rainfall combine with the high surface runoff and evapotranspiration causes scarcity of surface water. This has resulted in over dependence on the groundwater resource in order for the inhabitants to meet their domestic water needs.

A basic groundwater equation which will permit an approach to a qualitative estimate of the groundwater availability can be established for the hydrologic cycle which has a direct effect on the flow and storage of groundwater. Thus:

$Ie=P-(Et + Rs)$ (Itie Mbotake Thompson, 1994).

Where Ie = effective infiltration (recharge), P = precipitation, Et = evapotranspiration, Rs = surface run-off.

All the functions except Ie can be measured, while Ie is the amount of groundwater recharge in the aquifers during the study period. This concept is applied to groundwater basins. Within the basin the groundwater is recharged by rainfall infiltration, seepage from stream beds, and inflow from upstream of the aquifers and leakage from other aquifers.

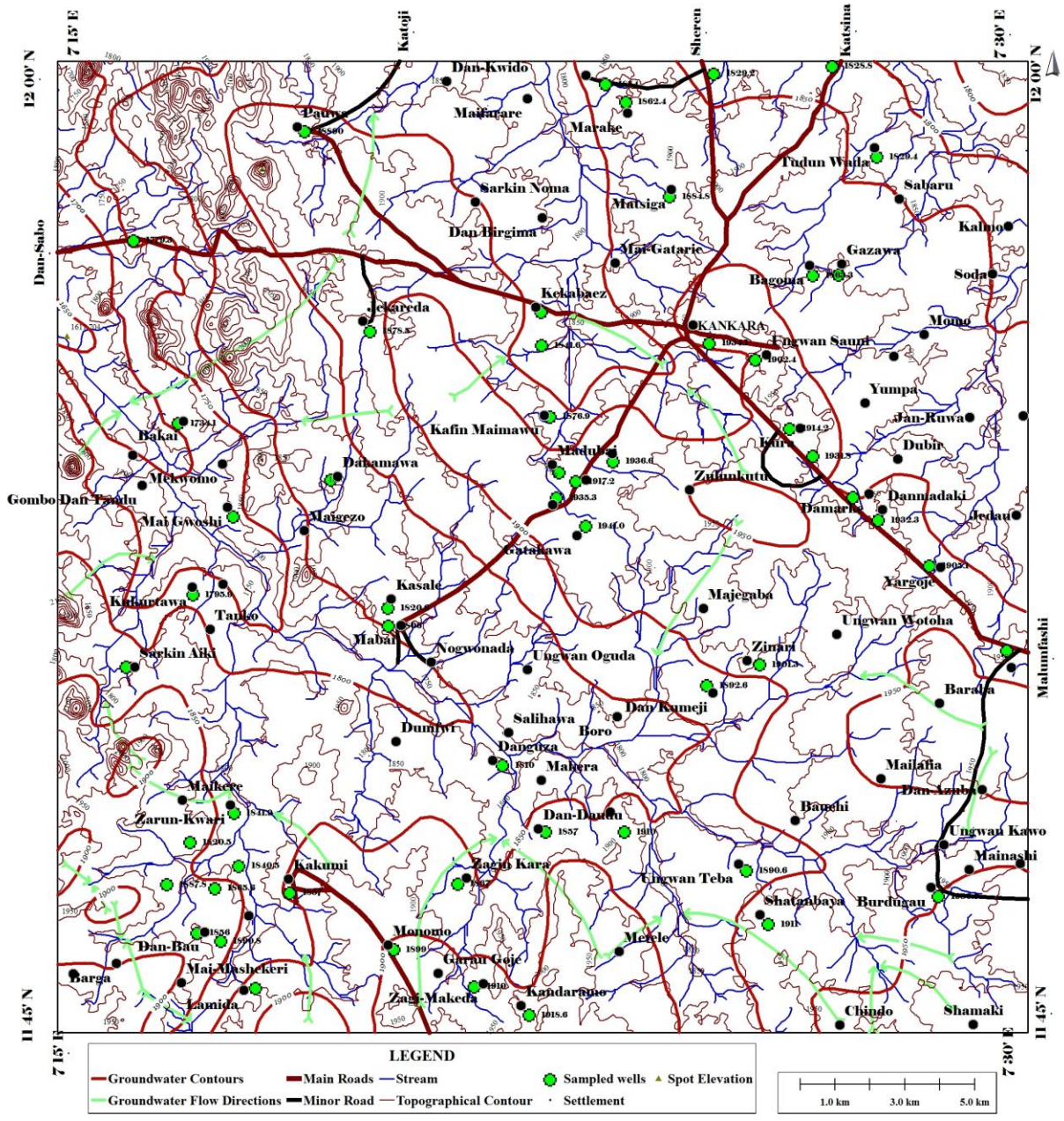


Figure 17: Ground Water configuration Map of the study area at the peak of dry season

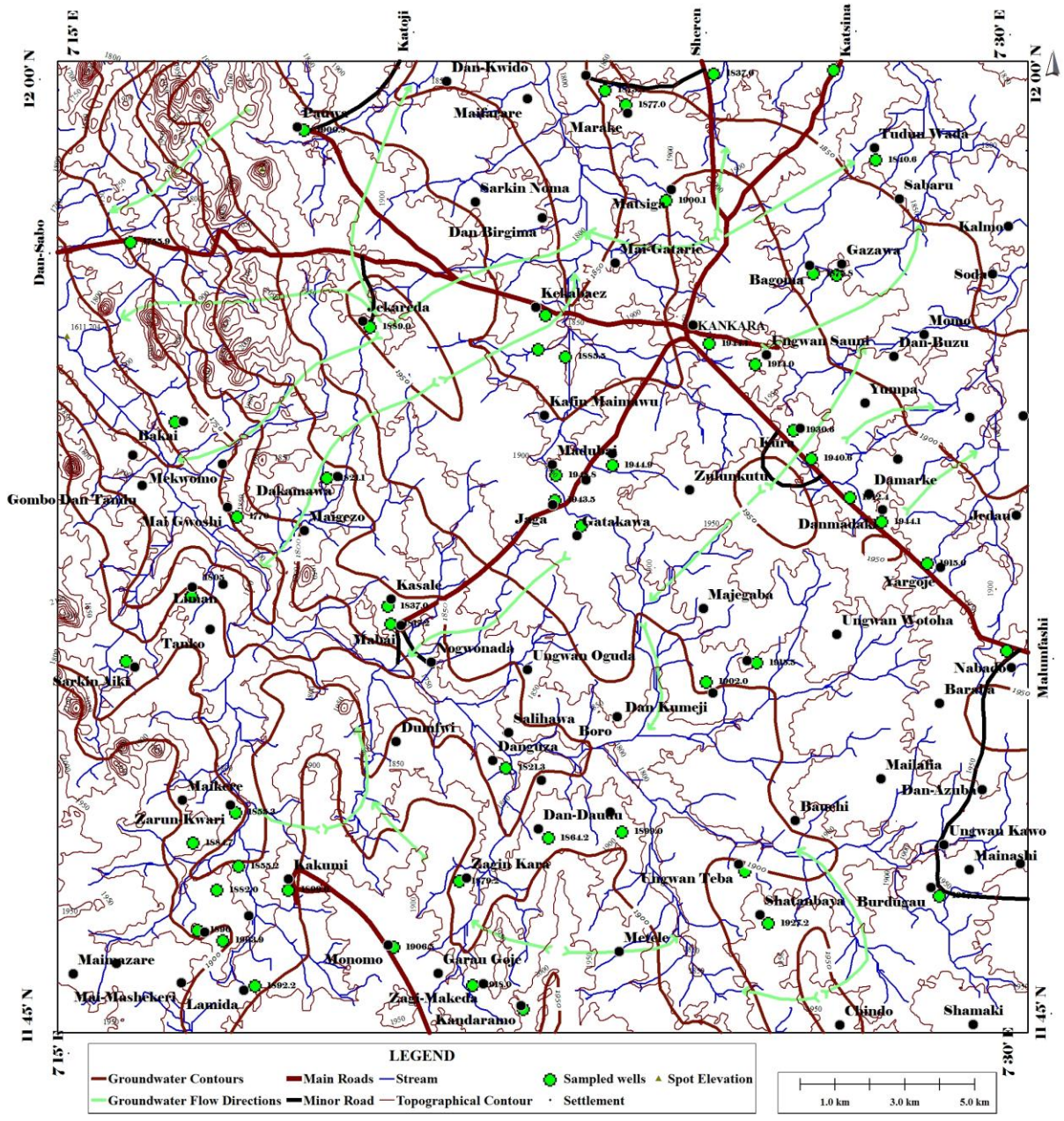


Figure 18:Ground Water configuration Map of the study area at the end of rainy season

4.7 DYNAMIC GROUNDWATER RESOURCES OF THE STUDY AREA

Total area covered by Funtua sheet 78NE is 748.02km^2. The mean annual depth of rainfall over the area is 850mm/a (Schoeneich and Garba2010). Base flow coefficient corresponding to the depth of rainfall 850mm/a, is 0.03. Therefore, the volume of rainfall is 748,500,000m^3 x 0.85m/a=631,125,000m^3/a. Then the recharge is 631,125,000m^3/a x 0.03=18,933,750m^3/a, as total dynamic groundwater resources of the area.

Utilizable dynamic groundwater resources is 50% of the total dynamic groundwater resource of the area, which is 18,933,750m^3/a x 50% = 9,466,875m^3/a.

4.8WATER QUALITY OF THE STUDY AREA

A total of tenhand-dug wells were sampled for physico-chemical analysis(Figure 19). Temperature, pH, total dissolved solid and conductivity were determined on the spotin the field (Table 4.3). The cationsanalyzed include Na^+, K^+, Ca^{2+}, $Mg^{2+}$and Fe^{2+}, while the anions include HCO^-_3, SO_4^{2-}, Cl^- and NO^-_3 and their concentrations expressed in milligrams per liter (Table 4.4). The concentration in most of the cations an anions are below and within the expected limit of the international standard for drinking water by WHO (1993) and Nigeria Industrial Standard (2007).

Table4.3 :Parameters measured insitu during field work in the study area.

S/N	Location	Coordinates	PH	TDS (Ppm)	Conductivity µS/cm	Temp (^{o}C)
5	Dan-nakwabo	11^{o} 53’ 31.0” N, 07^{o} 23’ 03.3” E	6.10	80.4	120	28.0
2	Kukumi	11^{o} 47’11.8” N, 07^{o} 18’ 32.8” E	7.24	67	100	27.9
3	Dandaudu	11^{o} 48’ 02.6” N, 07^{o} 22’ 23.7” E	7.24	174.2	260	29.2
4	Dankumeji	11^{o} 50’ 22.3” N, 07^{o} 25’ 03.3” E	7.24	314.9	470	28.5
5	Yargoje	11^{o} 52’ 15.3” N, 07^{o} 28’ 20.8” E	7.24	160.8	240	29.3
6	Burdugau	11^{o} 47’ 08.9” N, 07^{o} 28’ 39.2” E	7.24	160.8	240	29.1
7	KuyanGizo	11^{o} 55’ 43.4” N, 07^{o} 25’ 12.6” E	7.24	361.8	540	27.5
8	Pauwan	11^{o} 58’ 53.2” N, 07^{o} 18’ 48.8” E	7.24	281.4	420	30.1
9	Dakamawa	11^{o} 53’ 34.6” N, 07^{o} 19’ 09.7” E	7.24	361.8	540	28.6
10	Tudunwada	11^{o} 58’ 53.2” N, 07^{o} 27’ 39.9” E	6.55	361.8	540	28.7
10	Tudunwada	11^{o} 58’ 53.2” N, 07^{o} 27’ 39.9” E	6.55	361.8	540	28.7

Table 4.4: Chemical properties of water samples from the study area (Soil science laboratory, Ahmadu Bello University, Zaria)

S/No.	Location	Coordinates	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Fe^{2+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	NO_3^{-}	BH	SAR	WaterFacies
1	Dan-nakwabo	11° 53' 31.0" N, 07° 23' 03.3" E	4.28	13.09	2.00	9.10	0.34	1.40	0.36	160	0.35	1.20	0.49	Mg-HCO_3
2	Kukumi	11° 47'11.8" N, 07° 18' 32.8" E	6.64	32.03	2.50	19.00	2.66	1.10	3.02	230	0.32	0.80	0.68	Mg-Na-HCO_3
3	Dandaudu	11° 48' 02.6" N, 07° 22' 23.7" E	12.51	21.69	3.10	22.00	0.65	1.00	0.30	370	0.21	3.03	0.87	Mg-Na-HCO_3
4	Dankumeji	11° 50' 22.3" N, 07° 25' 03.3" E	28.48	24.78	4.20	31.00	0.30	2.00	0.36	830	0.28	10.14	1.03	Mg-HCO_3
5	Yargoje	11° 52' 15.3" N, 07° 28' 20.8" E	11.84	36.46	2.70	18.00	0.23	2.10	0.30	410	0.21	3.13	0.58	Mg-HCO_3
6	Burdugau	11° 47' 08.9" N, 07° 28' 39.2" E	10.34	27.34	3.00	20.00	0.43	1.20	0.24	320	0.21	2.50	0.67	Mg-HCO_3
7	KuyanGizo	11° 55' 43.4" N, 07° 25' 12.6" E	44.56	22.17	2.00	11.00	0.31	2.00	0.97	770	0.18	8.57	0.03	Ca-Mg-HCO_3
8	Pauwan	11° 58' 53.2" N, 07° 18' 48.8" E	33.47	36.24	3.30	38.00	0.31	1.20	0.48	550	0.18	4.36	1.08	Mg-Ca-HCO_3
9	Dakamawa	11° 53' 34.6" N, 07° 19' 09.7" E	41.92	16.88	2.50	37..00	0.42	1.30	0.12	640	0.25	7.01	1.22	Ca-Na-HCO_3
10	Tudunwada	11° 58' 53.2" N, 07° 27' 39.9" E	22.67	17.28	4.60	22.00	0.41	3.50	0.24	300	0.46	2.36	0.85	Mg-Ca-Na-HCO_3
11	Tudunwada	11° 58' 53.2" N, 07° 27' 39.9" E	22.67	46.95	4.50	22.00	0.44	1.00	0.42	340	0.18	0.58	0.61	Mg-HCO_3

4.8.1 Physical Properties of Water

Temperature: Temperatures of the water measured in-situ vary from 27.5^{o}C to 30.1^{o}C with an average of 28.6^{o}C. The temperature is within the permissible limits of WHO (1999) standard for drinking water and for other domestic use.

Hydrogen-Ion Concentration (pH): This is a measure of the acid and base concentration and the values of pH in the water samples of the study area ranges from 6.10 to 7.24with an average of 7.01. This falls within the recommended limit of WHO (1999) of drinking water quality. pH is usually controlled by the carbondioxide-bicarbonate-carbonate equilibrium.

Total Dissolve Solid: Total Dissolved Solids of groundwater in the hand-dug wells of the study area range from 67mg/l to 361.8 mg/l with an average of 244.2 mg/l. The total dissolves solid in a water sample can be represented by the sum of the ionic concentration of the major constituents (Ca^{2+}, K^{+}, Na^{+}, Cl^{-} and HCO^{3-}). The TDS can also be divided bya factor of 0.7 (Davis and Dewest, 1960).

Conductivity: Conductivity was measured at the spot of samples collection. Conductivity is measured in micro-Siemens/cm in water at the temperature of 20^{0}C. In the study area, conductivity values range from 100 µS/cm to 540 µS/cm,with an average of 364.5 µS/cm.Based on the conductivity of the water samples, seven of the samples are excellent for irrigation (conductivity < 250 µS/cm); the remaining four of the samples are good for irrigation (conductivity between 250-750 µS/cm).This is shown in Wilcox plot (Figure 20) which determines the suitability of water for irrigation purposes. It is a plot of Sodium Hazard (SAR) vs. Salinity Hazard (Conductivity). Wilcox plot has the following sections; Conductivity (µS/cm) C1: Low (0-249), C2: Medium (250-749), C3: High (750-2249), C4: Very High (2250-5000).

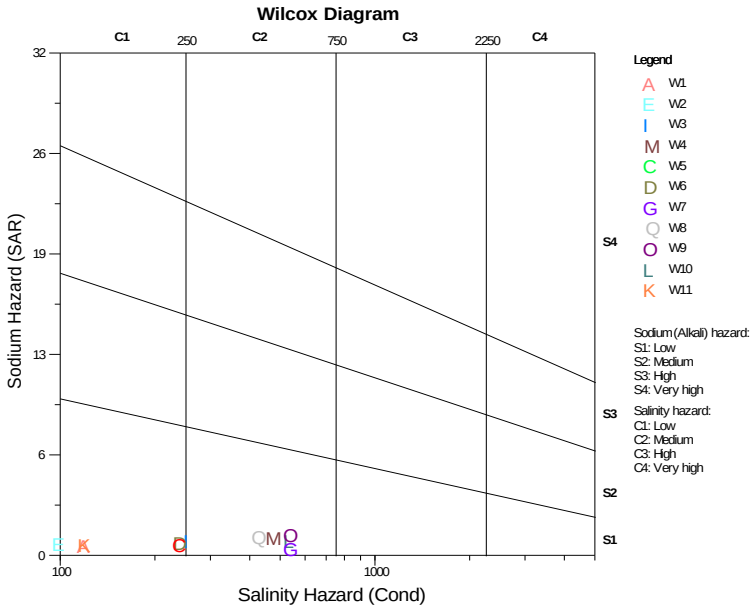


Figure 20: Wilcox plot for water samples from in and around Kankara

Hydrogen Ion Exponent (pH)

The pH of water is a measure of its acid-base equilibrium and is usually controlled by the carbon dioxide picked up from atmosphere as rain falls, presence of acids of peaty origin, decaying vegetation, and presence of sulphate. These factors cause low pH of water. Low pH may also be caused by precipitation of ions in a stored water sample before testing, especially if several days elapsed between sampling and testing. On the other hand, high pH results from the presence of magnesium, potassium and sodium in high concentration. In 2001, Schoeneich states that temperature slightly affects pH also, especially low mineralized water. In pure water, a decrease in pH of about 0.4 leads to temperature rise by 25^{o}C. On the bases of pH, water is described as neutral if 6.8 < pH < 7.2, weakly alkaline if 7.2 < pH < 7.8. The water is weakly acidic if 6.8 > pH > 6.0 and acidic if 6.0 > pH > 4.5. The pH of groundwater in the study area ranges from 6.10 to 7.24 indicating weakly acidic to neutral.

4.8.2Chemical Quality of Groundwater

Sodium (Na^+): Sodium concentration ranges from 9.10 mg/l to 38.00 mg/l, on average 22.64mg/l which is typical of the water in igneous and metamorphicterrain with moderate to high rainfall. The main source of sodium in groundwater is from the release of soluble products during the weathering of plagioclase feldspar (Davis and Dewest, 1960). Its occasional predominance over the other cations depends on the nature of the feldspar found at the location. Some parts of it could have been derived from clay minerals as exchangeable sodium.

Calcium (Ca^{2+}): Calcium ion concentration in the water sampled within the area of study is found to range from the values of 4.28mg/l to 44.56 mg/l, on average 21.76mg/lis the second most dominant cations in the water samples analyzed.The calcium may have been released from weathering of calcium-rich minerals in migmatites e.g. plagioclase feldspar, amphibole and pyroxene. Other good sources of Ca^{2+} are from fertilizers and atmospheric precipitation.

Magnesium (Mg^{2+}): Magnesium (Mg^{2+}) in the hand dug wells of the study area range from 13.09 mg/l to 46.95 mg/l, on average 26.81mg/l. It falls within the recommended limit of WHO (1999) standard for drinking water. Magnesium can be obtained in the solution by the weathering of igneous and metamorphic rocks,€ containing feldspars, mica (biotite) and pyroxene. The magnesium concentration in the water analyzed is safe for all purposes.

Potassium(K^+):is released to water by weathering of orthoclase and microcline (Schoeneich, 2001). In table 4 above, Potassium ranges from 2.0 – 4.6 mg/l, on average 3.12 mg/l, on average 3.12mg/l. Potassium is unimportant in drinking water.

Iron (Fe^{2+}): The concentration of dissolved iron in groundwater in the study area rages between 0.23 mg/l to 2.66 mg/l, on average 0.59mg/l.The principal minerals containing iron is an essential component includes the pyroxenes, amphiboles, biotite and magnetite.Iron

concentration is higherthan the permissible limit of WHO (1999) standard of the drinking water most especially in location 2 of the study area.

Thehigh concentration of iron in the aluminum aquifer of Kankara may be due to a large amount of iron released from the silicates which are completely hydrolyzed (Millot, 1970). The iron is transported by rivers in the form of ferric oxide, hydroxide stabilized by colloidal organic substances and absorbed in clay minerals. The possible source of iron in the study area is from weathered biotite. The impact of iron on both plants and animals include:

Brownish colouration on laundry clothes,brownish deposit in water,growth of iron bacteria, and affects the taste of drinking water as well as beverages.The solution to high iron content in water is to expose the water to oxygen by fetching water in an open container to allow for precipitation of iron.Two valent iron is oxidized to less soluble three valent iron and precipitated.

Chloride (Cl^-): The concentration of Cl^- in groundwater in the study area ranged from 1.00 mg/l to 3.50mg/l, on average 1.61mg/l. In the Basements Complex generally, some of the chloride in crystalline areas, are from minerals which contains chlorine as essential constituents. Another source of chloride is from fertilizers. The values fall below the permissible limit of WHO (1999) standard of drinking water quality.

Sulphate (SO_4): Sulphate in the study area ranges from 0.12 mg/l to 3.02 mg/l, on average 0.61mg/l. Sulphate is probably derived from oxidation of sulphides in igneous rocks. The values falls within desirable concentration limit of WHO (1999) standard of drinking water.

Bicarbonate (HCO_3^-): The concentration of bicarbonate varies from 160 mg/l to 830 mg/l, on average 447.27mg/l. Most bicarbonate ions in groundwater are derived from the carbon dioxide in the atmosphere, carbon dioxide in the soil and respiration of plants in the zone (Adanu, 1989).

Nitrates (NO_3^-): The nitrates concentration ranges from 0.18 mg/l to 0.46 mg/l, 0.25mg/l.Most nitrates in natural water come from organic sources or from industrial and agriculturalchemicals. These values are below the recommended limited by WHO(1999).

4.9Classification of Water Facies

Based on the results of the chemical analysis, the water faciesis predominantly Ca-Mg-HCO_3; and the dominant anion is HCO_3^-while the least is Cl^-, from the major cations and anions based on Schoeller diagram (Figure 21).

Piper plot is useful for showing multiple sample and trends in major ions. In this plots, major ions are plotted as cation and anion percentages of milliequivalents in two base triangles. The total cations in Meq/l, and the total anions in Meq/l, are set equal to 100 %. The data points in the two triangles are then projected onto the diamond grid. The projection reveals certain useful properties of the total-ion relationships. Every sample is represented by three data points; one in each triangle and one in the diamond grid. 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 toshow clustering of samples (Figure 22).It divides water into types according to their placementnear the four corners of the diamond triangle. Water that plots at the top of the diamond is highin Ca^{2+} + Mg^{2+} and $HCO_3^-$and is the region of waters with temporary hardness. Water plotted at the lower corner of the diamond is composed primarily of Na^+ + Cl and HCO_3^-.

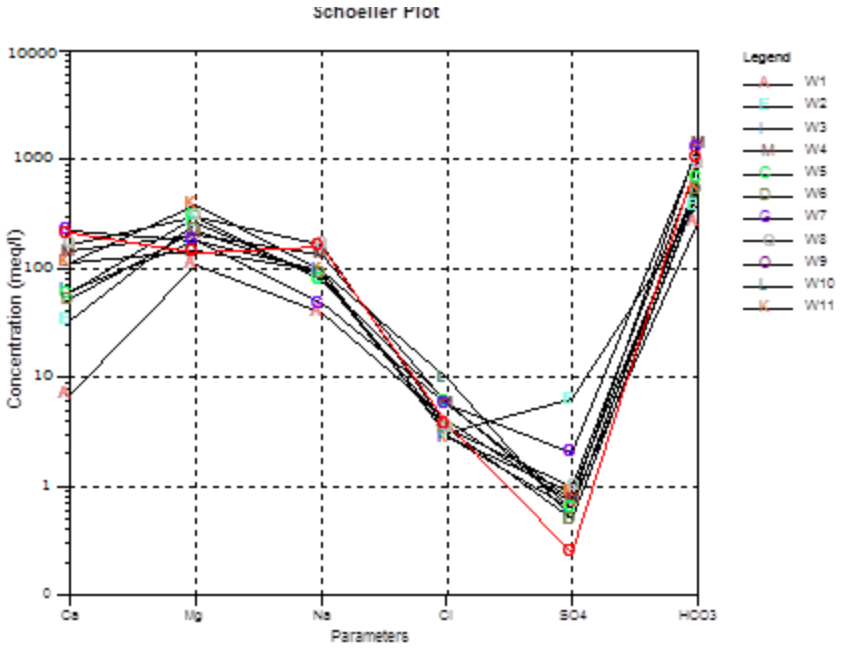


Figure 21: Schoeller plot for water samples from the study area

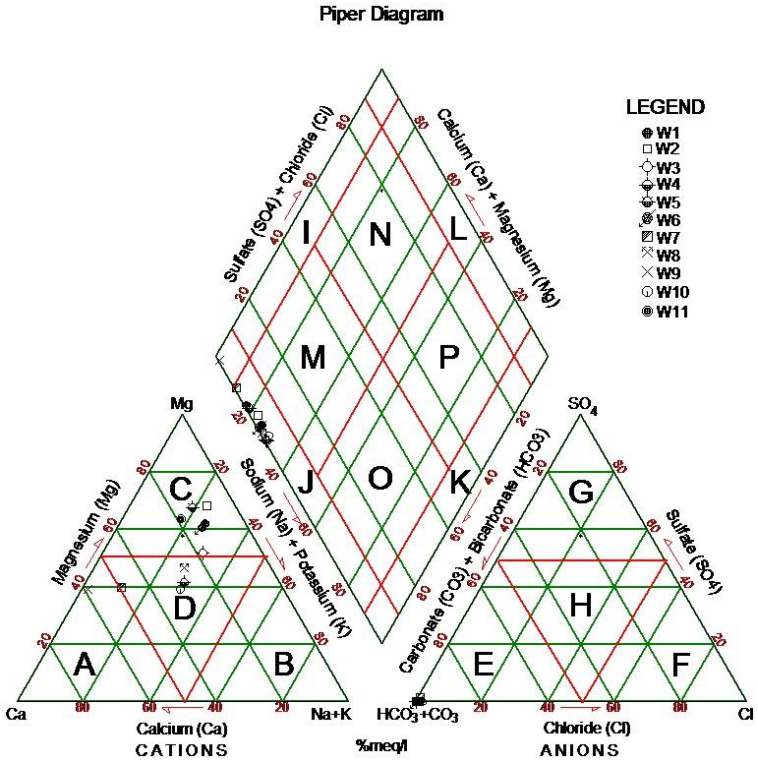


Figure 22: Type classificationfor water samples from Kankara and environs using the Piper trilinear diagram(Back and Hanshaw 1965).A = Calcium type,B = sodium orpotassium type,C = magnesiumtype, D = no dominanttype,E = bicarbonate type,F = chloride type,G = sulfate type,H = no dominant type I=Ca+Mgtype, J =HCO3+CO3type,K=Na+K type,L=Cl+SO4typeM =Ca(Mg) HCO3type,N=Ca(Mg) Cl SO4type,O=Na(K) HCO3type,P=Na(K) Cl(SO4) type

4.10 CHEMISTRY AND USAGE OF WATER

Chemical and biological characteristic of water determine its usefulness for domestic, industrial and agricultural purposes. In 1991, Eduvie states that water chemistry can give important clues of the geological history of an area, the direction of water movement and a probable presence of hidden ore deposits. The amount of dissolve minerals in groundwater depends on a large number of factors such as the type of soil or rock through which it passes, the time taken for the water to pass through various geological terrain, temperature, pressure and materials already in solution. Water chemistry of the study area is determined to evaluate the water for domestic use especially for drinking and for other use such as agriculture and industry.

4.10.1 Bicarbonate Hazard {meq/l = HCO_3 – (Ca + Mg)}

This refers to the excess of bicarbonate over calcium, all expressed in milliequivalents per liter (meq/l). Values of Bicarbonate Hazard from 0.00 to 1.25 meq/l, are considered safe for irrigation purposes, from 1.25 to 2.50 meq/l marginal, and above 2.50 meq/l unsuitable. Negative values are not recorded but are shown as zero (Schoeneich, 2001). Water with bicarbonate hazard greater than1.25 meq/l, should not be applied for irrigation except on very sandy highly permeable soils, or in conjunction with chemical soil amendments, like gypsum. To calculate for the bicarbonate hazard, all elements must be converted from mg/l or ppm to meq/l (Table4.5). Bicarbonate Hazard calculated for the groundwater in the study area ranges between 0.00 and 10.14meq/l. Three of the values fall within the 0.00 meq/l and 1.25 meq/l, two of the values fall within 1.25 to 2.50 meq/l, while the remaining ones are above 2.50 meq/l which indicate that water in some places within the study area is safe for irrigation purposes while in some places is not safe for irrigation.

Table4.5: Conversion factors from mg/l to meq/l values of mg/l are to be multiplied by conversion factors

S/N	CATIONS (in mg/l or ppm)	Conversion Factors	ANIONS (in mg/l or ppm)	Conversion Factors
1.	Calcium, Ca	0.04990	Bicarbonate, HCO_3	0.01639
2.	Sodium, Na	0.04350	Carbonate, CO_3	0.03333
3.	Potassium, K	0.02557	Chloride, Cl	0.02821
4.	Magnesium, Mg	0.08228	Nitrate, NO_3	0.01613
5.	Ammonium, NH_4	0.05544	Nitrite, NO_2	0.02174
6.	Iron, F^{++}	0.03364	Phosphate, PO_4	0.03159
7.	Iron, F^{+++}	0.08371	Sulphate, SO_4	0.02083

Table 4.6: Suitability of water for irrigation purposes in respect of Bicarbonate Hazard (meq/l) (Source: Schoeneich, 2001)

Bicarbonate, meq/l		
0.00 meq/l	**1.25 meq/l**	**2.50 meq/l**
Water safe for irrigation	Water marginal for irrigation	Water unsuitable for irrigation

4.10.2 Sodium Hazard

Low sodium hazard in water shows that the water is suitable for irrigation purposes while medium or high sodium hazard shows that the water is not suitable for irrigation activities especially on clayey impermeable soil types, unless gypsum or other chemical amendments are applied to the soil to neutralize the hazard.

Sodium hazard is calculated according to the following formulae:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$

Interaction of mineral components of sub-surface rock units with groundwater under confining pressure and temperature leads to hydrolysis; it results in the breaking up of feldspars into their component metals and consequently the formation of clay minerals with the released of

metals becoming soluble cations.This process is responsible for the presence of Ca, Mg, Na, and K in water samples especially groundwater. High sodium content in some groundwater can be attributed to the weathering of sodium dominated feldspars found in the rock units which are in direct contact with the groundwater (Olatunji*et al.*, 2001).

The calculated values of sodium hazard of the groundwater in the study area falls within the excellent category for irrigation activities (0.03 to 1.22), based on the classification by Hem (1959).

Table4.7: Water classification for irrigation purposes based on Sodium Absorption Ratio (SAR) After Hem (1959)

SAR	WATER CLASS	QUALITY
0 – 10	Excellent	Low sodium
10 – 18	Good	Medium sodium
18 – 26	Fair	High sodium
26 – 100	Poor	Very high sodium

4.10.3 Water Usage

From the whole analysis, groundwater in the study area is good for drinking and domestic use. The cations and the anions fall within permissible limit of World Health Organization (WHO) standard for drinking water (1999) and the Nigerian Standard for Drinking Water (NIS, 2007).

The groundwater in the study area is also good for irrigation purposes because of its low bicarbonate hazard, low sodium hazard and low salinity hazard.

4.11 WATER BUDGET FOR THE STUDY AREA

Water budget is basically water demand versus available water resources. In 2002, Offodile states that proper management practice is necessary to highlight the need and to

quantify the available water resources through a well-coordinated water resources study. In planning water budget of any given area, population of water consumers has to be taken into consideration. The population of Kankara L.G.A in the last population census is 245,739 people. The National Bureau of Statistics put the national growth rate of Katsina State based on the 2006 census at 3 %. Since the study did not cover the entire Kankara Local Government, the population of the study area will be at least half of the population of the entire local government because the study had cover the major towns of the local government including Kankara town, the headquarters of the local government. Half of the population of the local government is about 122,869 people. A viable water resources management plan of an area has a planning horizon of 30 years. Therefore the population of the study area can be estimated for the next 30 years using the formula $P\ \ell^{rn}$(Kpedekpo, 1982), where P is the present population, ℓ is the exponential, r is the population growth rate, and n is the projected year. Population of the study area from the last census (2006) will be $122{,}869\ \ell^{0.03 \times 30} = 122{,}869\ \ell^{0.9} = 302{,}208$ people

In the study area, current water consumption is below the current water demand. Water consumption within the study area is mainly for domestic use (urban residential water consumption). In Nigeria, the average, daily, domestic water demand is estimated to range from about 70 l/p/h in the rural areas to 150 l/p/d in the urban areas and semi urban towns (Offodile 2002).In 2007, Schoeneich in his work on water resources management in Nigeria gave 50 l/p/d for urban dwellers and 15 l/p/d for rural dwellers. In 2009, Ochenemi in his study on water supply situation in Lokoja town measured unit water demand in Lokoja and got 63 l/p/d. For the sake of uniformity, 70 l/p/h will be used in this research because most of the area mapped is rural except Kankara town and this town is not up to 40 % of the study area. Therefore, 122,869 x 70 l/p/h (0.07 m^3/d) = 8,600 m^3/d or 3,139,302 m^3/a as the current water demand of the study area.

In 30 years from the last population census (2006), the water demand will be 302,208 people x 70 l/p/h (0.07 m^3/d) = 21,154 m^3/d or 7,721,414 m^3/a.

The current water demand of the study area is 8,600 m^3/d or 3,139,302 m^3/a, while the estimated future water demand in 30 years from 2006 population census is 21,154 m^3/d or 7,721,414 m^3/a.The utilizable groundwater resources of the study area is 9,466,875 m^3/a. Comparing the current water demand of the study area with the utilizable water resources, current water demand is about 35 % of the utilizable water resources, while comparing with the future water demand with the utilizable water resources, the future water demand is about 90 % of the utilizable water resources of the study area and there will still be excess deposits of 1,745,460 m^3/a.

CHAPTER5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSION

The study area (Funtua sheet 78 NE) has an area coverage of 748,500km^2 with mean annual rainfall of 850 mm/a. Volume of rainfall over the study area is 631,125,000 m^3/a. Total dynamic groundwater resources of the area is 18,933,750 m^3/a with base flow coefficient corresponding to the depth of rainfall 850 mm/a, is 0.03. Utilizable dynamic groundwater resources is 50% of the total dynamic groundwater resource of the area, which is 9,466,875 m^3/a.The study area receives it recharge by precipitation which directly infiltrates and replenishes the aquifer in the area, this was observed from increase in static water levels recorded for hand dug wells during the wet season compared to decline in levels measured during the dry season period. However, discharge from the aquifer system in the area is either through natural means which include discharge from springs, evaporation and streams. While artificial discharge is mainly through abstraction from boreholes and hand dug wells.

Assessment of groundwater in hand dug wells of the area was carried out. The quality of groundwater in general in the study area with reference to analysis made for their physico-chemical parameters compared with the standards set by both the World Health Organizations (1999) and the Nigerian Industrial Standards (2007) show that most of the ions falls within the standard limit of drinking water and other domestic use. The water quality for other uses especially irrigation based on Sodium Absorption Ratio and Bicarbonate Hazard calculated, indicate that the groundwater in the study area is suitable for irrigation purposes. Water facies of the area were also established with the help of Aquachem 4.0 software. Water of the study area is

of temporary hardness as revealed in the results of the analyzed chemical parameters and their placement on piper diagram that was produced from Aquachem 4.0 software.

5.2 CONTRIBUTION TO KNOWLEDGE

Hydrogeological map of the study area for both peak of dry and rainy seasons were produced; Geological map of the area was updated; Structural map was superimposed on both the geology and the drainage map and found that the flow of water in the area is structurally controlled; Lineament density map of the area revealed three areas of low, medium and high density, was produced; water budget for the study area was produced; Water quality of the area was determined and evaluated.

5.3 RECOMMENDATIONS

With the awareness of these problems of acute potable water supply faced by the people of Kankara and environs, there is need for the government of the state to join hands with the Federal Government of Nigeria to design a programme that will help in making water available throughout the year in the study area.

A lot of challenges were encountered during the field work ranging from lack of motorable roads linking villages and the rugged terrain of the area, for this I recommend that in future study if is on this kind of area, the area should not be as large as a quarter sheets.

REFERENCES

Abimbola, A.F. Odukoya, A.M and Olatunji, A.Z (2002).Influence of Basement on Hydrochemical characteristics of Ground water in northern part of Ibadan metropolo S.W. Nigeria Journal of Nig Ass. Of Hydrogeology. Vol. 13, p1-6.

Adanu, A.E (1987). Some Hydrogeological Characteristics of Shallow Basement Aquifers in Zaria – Kaduna Area of Nigeria. In: Current Research in African Earth Sciences. Matheis and Schandemeier (eds). Belkam, Rotterdam.

Adanu, A.E (1989). "Hydrogeologyical of the Basement complex. Terrain in the zaria Kaduna Area of Nigeria" Berliner GeoloissenschaftincheAbhanlungen. Reihe A. Band 113. Berlin.

Ajibade A. C., Fitches W. R., Wright J. B. (1979). The Zungerumylonites, Nigeria: recognition of a major unit. Rev de Geol GeogPhys 21:359–363.

Ajibede A.C. (1976). Provisional classification and correlation of the achiest Belt in North Western Nigeria. In: Kogbe, C.A (ED) Elizabethan pet. Co. Lagos, P85-90.

Ajibade, A.C. And Fitches, W.R. (1988).The Nigeria Precambrian and the pan African progeny in pre Cambrian Geology of Nigeria. A Publication of the Geological Survey of Nigeria.

Ajibade A. C., Rahaman M. A., Woakes M. (1989). Proterozoic crustal development in the Pan-African Regime of Nigeria. ILP Working Group 3 Mid-term Report.

Appello, C,A. and Potma, D. (2005). Geochemistry groundwater and pollution 2nd, Edition. Ma Grow 11 higher, Education= NJ, P35-60.

Baba, A. (2007). Surface and Groundwater Availability in Ahmadu Bello University Main Campus, Samaru, Zaria. Unpublished Master's Thesis Submitted to the Department of Geology, Ahmadu Bello University, Zaria.

Bala, A. E., Eduvie, O. M. and Byami, J. (2011). Borehole Depth and Regolith Aquifer Hydraulic Characteristics of Bedrock Types in Kano Area, Northern Nigeria. African Journal of Environmental Science and Technology Vol. 5(3), P 228-237.

Black, W. and Hanshaw, B. B. (1965). Chemical Geohydrology Adv. Hydro. Sci. (2) pp 49-109.

Caby, R, Beatrand, J. M.L, and Black, R. (1981). Pan Africa Ocean closure and continental collision in the Hogger. Ifores segment`, centeralsahara in precanbrian plate tectonics, kroner A. (E.D) Amesterdarn, p 407-434.

Dada, S. S. (2006). Proterozoic evolution of Nigeria. In: Oshi O (ed.).The basement complex of Nigeria and its mineral resources (A Tribute to Prof. M. A. O. Rahaman). Akin Jinad& Co. Ibadan, pp 29–44.

Davis and Dewest (1960).Hydrology, John Wirley and sons, Inc. New York. London Sydney pp.60.

Du Preez and Barber, J.W. (1965). The Distribution and chemical quality of groundwater in northern Nigeria. Bull. Geolosurv. 36, p12-20.

Eduvie, M.O (1991). Groundwater Investment Assessment and Borhole Design and completion in the Basement Complex Area, Kaduna State, sheet 123 SE, Unpubl. M.sc Thesis Department of Geology, A.B.U Zaria.

Falconer, J.D. (1911). The Geology and Geography of Northern Nigeria MacMillan London, P.295.

Federal Survey of Nigeria (1967). Topographical map of Funtua Sheet 78 NE. Published by the Office of the Surveyor General of the Federation, Abuja, Nigeria.

Freeze, R. A.; Cherry, J. A. (1979). Groundwater. Prentice Hall Inc. 304p.

Grant, N. K. (1978). Structural distinction between a metasedimentary cover and an underlying base-ment in the 600 my old Pan-African domain of Northwestern Nigeria. Geol Soc Am Bull 89:50–58.

Hem, J. D., (1959). In; Du Preez, J. W. and Barber, W., (1965. The Distribution and Chemical Quality of Groundwater in Northern Nigera. Geol. Surv. Bull. (36); 93p. Kogbe, C. A.; Schoeneich, K. and Ebah, E. I. (1992), Hydrogeological Framework of Maiduguri Metropolis in the Chad Basin, NE, Nigeria. Paper presented at the 5th Conference of the Nigerian Association of Hydrogeologists, Shiroro Hotel, Minna, Nigeria.

Holt, R. W. (1982).The Geotectonic Evolution of the Anka Belt in the Precambrian Basement Com-plex of N.W. Nigeria. Unpublished Ph.D. Thesis, The Open University.

Itie Mbotake Thompson, (1994).Groundwater Resources of the Upper Gagere River Basin in SokotoKatsina States Northwestern Nigeria. Pp. 44.

Kachalla, Musa (2011). Groundwatër occurrence in Damaturu and its environs Yobe State, NorthenEasthern Nigeria. Pp. 7.

Kankara, A. I. (2013). Groundwater Quality in Funtua North East, Northwestern Nigeria. International Journal of Environmental Engineering and Management Volume 4, Number 3 pp. 171-176.

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

Krasny, J. (1993). Classification of Transmissivity Magnitude and Variation. Available at: https://info.ngwa.org/GWOL/pdf/931057849.PDF

McCurry (1976). The Geology of the Precambrian to Lower Paleozoic rock of Northern Nigeria. A review, in Geology of Nigeria Edited by Kogbe Published by Elizabeth co Lagos pp.15-40.

Millot, G. (1970). Geology of Clays, Springerverlag. New York, pp 127-139.

Muotoh, E. O. G. (1966). Notes on the Geology of 1: 100,000 Sheet 77 (Chafe). Geol. Surv. of Nigeria Rept. No. 1506.

National Bureau of Statistics (2006).The 2006 National Population Census of Nigeria. National Bureau of Statistics Headquarters Abuja, Nigeria.

NIS (Nigerian Industrial Standard 554) (2007). Nigerian Standard for Drinking Water Quality.

Ochenemi, K. M. (2009). Water Supply Situation in Lokoja, Problems and Prospects. Unpublished M. Sc. Thesis, Geology, A. B. U. Zaria, Nigeria.

Offodile, M. E. (2002). Groundwater Supply and Development in Nigeria. Nigeria 2nd Ed. Macon Geology and Engineering Services Ltd. In: Kogbe, C. A. (Ed), *Geology of Nigeria.* Elizabethan Publication, RD, Minna.

Olade, M. A., Elueze AA (1979).Petrochemistry of the Ilesha amphibolite and Precambrian crustal Evolution in the Pan-African domain of SW Nigeria. Precambrian Res 8:303–318.

Olatunji, A. S., Tijani, M. N., Abimbola, A. F. and Oteri, A. U. (2001). Water Resources Journal of Nigerian Association of Hydrogeologists, p 81.

Oyawoye, M. O. (1972). The basement complex of Nigeria. In: Dessauvagie TFJ, Whiteman AJ (eds) African geology. Ibadan University Press, pp 66–102.

Rahaman, M. A. (1976).Review of the basement geology of South-Western Nigeria. In: KogbeC.A (ed) Geology of Nigeria, 2nd edn, Elizabethan Publishers, Lagos, pp 41–58.

Rahaman, M. A. (1981). Recent advances in the study of the basement complex of Nigeria. Abstract,1st Symposium on the Precambrian Geology of Nigeria.

Rahaman, M. A. (1988).Recent advances in the study of the basement complex of Nigeria. In: Geological Survey of Nigeria (ed) Precambrian Geol Nigeria, pp 11–43.

Raji, B.A. andAlagbe, S.A. (1997).Hydrochemicalfacies in Parts of Nigeria Basement Complex Environmental Geology 29 (1/2):7 Springer Vol.1.

RUWASSA (2014). Rural Water Supply and Sanitation Agency, Katsina State.

Schoeneich, K. (2001). Water Quality. Unpublished Postgraduate Lecture Notes, Ahmadu Bello University, Zaria.

Schoenich K. (2003).Water Budget for Basin Development Authorities (Abbreviated Version) pre-prints of the 29th WEDC Conference towards the Millennium Development Goals-Action for Water and Environmental Sanitation held at the Conference Centre of Sheraton Hotels and Towers in Abuja from 22nd -26th September 2003 pp.1-4.

Schoeneich, K., (2007).Water Resources Management in Nigeria. *Borno Journal of Geology* 4(2): P 39-63.

Schoeneich K and Garba M.L. (2010). Hydrogeology (Geol 405). Unpublished Lecture Notes, Ahmadu Bello University, Zaria.

Tijani, N. N. (1994).Hydrchemical Assessment of Groundwater in Moro Area, Kwara States, Nigeria, Nigeria Environs Geol. 24. 194-202.

Truswell, J.F. and Cope, R.N. (1963). The Geology of Parts of Nigeria and Zaria Provinces, Northern Nigeria. G.S.N Bulletin No.29, pp.20.

Thomas, B. D., Edwards, K. A., Barba, K. C. and Hogg, I. C. G. (1981). Run-off, Erosion and Conservation in a Representative Catchment in Marchakos District Kenya. In: Tropical Agricultural Hydrology, John Wiley.

Turner, D. C. (1983). Upper Proterozoic schist belts in the Nigerian sector of the Pan-African Provinceof West Africa Precambrian Res 21:55–79.

WHO (1999). Guideline for Drinking Water Quality Fourth Edition. A Publication of the World Health Organisation, Gutenberg. PP 468-475.

Wright. J. B., and McCurry, P. (1970). A Reappraisal of Some Aspects of Precambrian Shield Geology. Discussion in Geology Society of American Bulletin, 81, 3491-106.

Wright, E.P and Burgess (1992). The Hydrogeology of Crystalline Basement Aquifers in Africa. Geological Society Special Publication, London. Pp.163-169.

APPENDICES

Appendix I: Depth to water level in hand dug wells at the peak of dry season in the study area; the last two columns were used for construction of map, while column five is presented for record purpose

S/N	Location	Coordinates	Accuracy (masl, ftasl)	Elevation of Wells from GPS (masl, ftasl)	Depth to Water Table (masl, ftasl)	Elevation of Water Table (masl, ftasl)	Elevation of Wells from Map (masl, ftasl)	Elevation of Water Table from Map (masl, ftasl)
1	Masanawa	11° 55' 41.9" N 07° 25' 08.3" E	10	589 1932.4	4.85 15.91	584.15 1916.50	594.4 1950.0	589.5 1934.1
2	KuyanGizo	11° 55' 43.4" N 07° 25' 12.6" E	11	585 1919.3	7.30 23.95	577.70 1895.34	584.97 1919.2	577.7 1895.3
3	Tsauni	11° 55' 22.5" N 07° 25' 49.2" E	10	601 1971.8	14.50 47.57	586.50 1924.21	594.4 1950.0	579.9 1902.4
4	Kura	11° 54' 24.0" N 07° 26' 21.1" E	10	597 1958.7	17.00 55.77	580.00 1902.89	600.5 1970	583.4 1914.2
5	SabonGida	11° 53' 55.1" N 07° 26' 32.7" E	11	603 1978.3	14.7 48.23	588.30 1930.11	603.5 1980	588.8 1931.8
6	Damarke	11° 53' 17.3" N 07° 17' 15.8" E	10	598 1961.9	18.00 59.06	580.00 1902.89	597.4 1960	579.4 1900.9
7	GidanDaudu	11° 52' 52.7" N 07° 27' 42.8" E	10	599 1965.2	17.60 57.74	582.00 1909.45	606.6 1990	589.0 1932.3
8	Yargoje	11° 52' 15.3" N 07° 28' 20.8" E	14	612 2007.9	15.20 49.87	596.80 1958.01	595.90 1955	580.7 1905.1
9	Bagoma	11° 56' 46.6" N 07° 26' 42.7" E	14	581 1906.2	18.80 61.68	562.20 1844.45	586.7 1925	567.9 1863.3
10	Gazawa	11° 56' 42.1" N 07° 27' 00.0" E	9	588 1929.1	11.50 37.73	576.50 1891.40	586.7 1925	575.2 1887.3
11	Tudun Wada	11° 58' 53.2" N 07° 27' 39.9" E	9	565 1853.7	14.80 48.56	550.20 1805.12	571.5 1875	556.7 1826.4
12	TsamiyanSarki	11° 59' 54.2" N 07° 27' 00.1" E	9	562 1843.8	9.50 31.17	552.50 1812.66	566.9 1860	557.4 1828.8
13	KadaBoki	11° 59' 47.5" N 07° 25' 08.4" E	10	568 1863.5	9.40 30.84	558.60 1832.67	566.9 1860	557.5 1829.2
14	Baure	11° 59' 39.8" N 07° 23' 28.7" E	8	559 1834.0	6.40 21.00	552.20 1811.68	571.5 1875	565.1 1854.0
15	Marake	11° 59' 20.3" N 07° 23' 48.7" E	10	570 1870.1	11.45 37.57	558.50 1832.25	579.1 1900	567.7 1862.4
16	Matsiga	11° 57' 55.7" N 07° 24' 27.8" E	9	580 1902.9	5.50 18.04	574.50 1884.84	580.6 1905	575.2 1887.0

17	Kaikabayaz	11° 56’ 09.2” N 07° 22’ 28.6” E	14	562 1843.8			562.0 1843.8	
18	Pauwa	11° 58’ 53.2” N 07° 18’ 48.8” E	14	601 1971.8	18.30 60.04	582.70 1911.75	594.4 1950.0	576.1 1890
19	Zango	11° 57’ 14.3” N 07° 16’ 09.5” E	14	556 1824.1	6.30 20.67	549.70 1803.48	548.6 1800	542.3 1779.3
20	Bakai	11° 54’ 26.1” N 07° 16’ 49.6” E	8	528 1732.3	7.90 25.92	520.10 1706.36	536.4 1760.0	528.6 1734.1
21	Maigwoshi	11° 52’ 58.0” N 07° 17’ 22.1” E	8	536 1758.5	4.80 15.75	531.20 1742.78	541.0 1775	536.2 1759.3
22	Dakamawa	11° 53’ 34.6” N 07° 19’ 09.7” E	9	564 1850.4	12.75 41.83	551.20 1808.40	563.9 1850	551.1 1808.2
23	Jekaiarede	11° 55’ 56.2” N 07° 19’ 46.1” E	14	606 1988.2	21.80 71.52	584.20 1916.67	594.5 1950	572.6 1878.5
24	Kapi	11° 55’ 39.2” N 07° 22’ 29.6” E	14	583 1912.7	17.80 58.40	565.20 1854.33	579.1 1900	561.3 1841.6
25	KapinMaiyawu	11° 55’ 31.0” N 07° 22’ 51.3” E	9	567 1860.2	10.10 33.14	556.90 1827.10	582.2 1910	572.1 1876.9
26	Zurunkuku	11° 53’ 50.6” N 07° 23’ 35.7” E	7	596 1955.4	5.70 18.70	590.30 1936.68	595.9 1955	590.2 1936.3
27	Danakwabo	11° 53’ 31.0” N 07° 23’ 03.3” E	15	582 1909.4	10.00 32.81	572.0 1876.64	594.4 1950	584.4 1917.2
28	Madubai	11° 53’ 41.1” N 07° 22’ 52.3” E	14	537 1761.8	6.30 20.67	530.7 1741.14	595.9 1955	589.6 1934.3
29	Jaga	11° 53’ 12.5” N 07° 22’ 44.2” E	10	587 1925.9	6.00 19.69	581.0 1906.17	595.9 1955	589.9 1935.3
30	Gatakawa	11° 52’ 50.3” N 07° 23’ 03.9” E	8	594 1948.8	5.80 19.03	588.2 1929.79	597.4 1960	591.6 1941.0
31	Dankumeji	11° 50’ 22.3” N 07° 25’ 03.3” E	12	585 1919.3	8.10 26.57	576.9 1892.72	585.2 1920	585.2 1920.0
32	UngwanTofa	11° 50’ 43.6” N 07° 25’ 18.9” E	8	581 1906.2	11.80 38.71	574.2 1883.85	591.3 1940	579.5 1901.3
33	KwakareNabado	11° 50’ 50.6” N 07° 29’ 48.3” E	10	581 1906.2	17.60 57.74	563.4 1848.43	608.1 1995	590.5 1937.3
34	Nasaru	11° 49’ 40.2” N 07° 31’ 52.7” E	9	627 2057.1	10.80 35.43	616.2 2021.65	627.0 2057.0	
35	Maikawo	11° 48’ 46.0” N 07° 31’ 00.1” E	9	626 2053.8	11.40 37.40	614.6 2016.40	626.0 2053.8	
36	Ung. Kuka	11° 48’ 23.7” N 07° 30’ 54.5” E	6	615 2017.7	8.80 28.87	606.2 1988.85	615.0 2017.7	
37	Burdugau	11° 47’ 08.9” N 07° 28’ 39.2” E	13	612 2007.9	9.00 29.53	603.0 1978.35	603.5 1980	594.5 1950.5
38	Gidan Kure	11° 46’ 42.5” N 07° 26’ 02.2” E	10	592 1942.3	14.70 48.23	577.3 1894.02	597.4 1960	582.5 1911.0
39	Ung. Teba	11° 47’ 29.0” N 07° 25’ 22.6” E	13	587 1925.9	10.50 34.45	576.5 1891.40	586.7 1925	576.3 1890.6

40	Ung. Dangizo	11° 48’ 07.1” N 07° 23’ 44.6” E	14	542 1778.2	11.80 38.71	530.2 1739.50	586.7 1925	582.2 1910.0
41	Dan Daudu	11° 48’ 02.6” N 07° 22’ 23.7” E	8	587 1925.9	19.10 62.66	567.9 1863.19	585.2 1920	585.2 1920.0
42	Danguza	11° 49’ 07.4” N 07° 21’ 51.5” E	11	565 1853.7	15.10 49.54	549.9 1804.13	567.0 1860	551.7 1810.0
43	Mabai	11° 51’ 18.0” N 07° 20’ 06.6” E	11	571 1873.4	13.40 43.96	557.6 1829.40	563.9 1850	550.5 1806.0
44	Katsale	11° 51’ 39.6” N 07° 20’ 07.6” E	14	573 1879.9	10.50 34.45	562.5 1845.47	565.4 1855	554.9 1820.6
45	Lamida	11° 45’ 43.3” N 07° 18’ 01.3” E	13	578 1896.3	14.20 46.59	563.8 1849.74	586.7 1925	572.4 1878.0
46	Kakumi	11° 47’ 11.8” N 07° 18’ 32.8” E	12	571 1873.4	13.00 42.65	558.0 1830.70	579.1 1900	566.0 1857.0
47	GarauGoje	11° 46’ 18.2” N 07° 20’ 06.0” E	9	598 1961.9	18.60 61.02	579.4 1900.92	597.4 1960	578.8 1899.0
48	ZagiKaru	11° 47’ 20.9” N 07° 21’ 11.8” E	11	581 1906.2	14.10 46.26	566.9 1859.91	582.2 1910	568.1 1864.0
49	ZagiMakeda	11° 45’ 48.2” N 07° 21’ 20.9” E	7	591 1939.0	9.10 29.86	581.9 1909.12	591.3 1940	582.2 1910.0
50	Kandarawa	11° 45’ 18.4” N 07° 22’ 16.2” E	9	590 1935.7	24.80 81.36	565.2 1854.33	609.6 2000	584.8 1918.6
51	Dan Ban B	11° 47’ 14.4” N 07° 17’ 25.0” E	9	573 1879.9	12.00 39.37	561.0 1840.55	580.6 1905	568.6 1865.6
52	Dan Bawo A	11° 46’ 34.0” N 07° 17’ 09.8” E	10	564 1850.4	21.00 68.90	543.0 1781.50	586.7 1925	565.7 1856.0
53	Dan Bawo B	11° 46’ 27.6” N 07° 17’ 31.8” E	7	584 1916.0	15.00 49.21	569.0 1866.80	591.3 1940	576.3 1890.8
54	Zari Mai Ang.	11° 47’ 18.9” N 07° 16’ 40.3” E	11	583 1912.7	15.90 52.17	567.1 1860.56	591.3 1940	575.4 1887.8
55	Zari	11° 47’ 57.0” N 07° 17’ 01.6” E	13	572 1876.6	17.10 56.10	554.9 1820.54	588.3 1930	568.1 1864.0
56	ZarinKwari	11° 48’ 25.3” N 07° 17’ 40.9” E	14	570 1870.1	10.10 33.14	559.9 1836.94	571.5 1875	561.4 1841.9
57	Dan Bau A	11° 47’ 35.7” N 07° 17’ 46.6” E	7	568 1863.5	7.00 22.97	561.0 1840.55	570.0 1870	
58	Mununu	11° 50’ 52.8” N 07° 16’ 00.8” E	8	560 1837.3			560.0 1837.2	
59	Kukurtawa Marafa	11° 51’ 44.0” N 07° 17’ 03.9” E	8	549 1801.2	4.30 14.11	544.7 1786.99	551.7 1810	547.4 1795.9

AppendixII:Depth to water level in hand dug wells at the peak of rainy season in the study area; the last two columns were used for construction of map, while column five is presented for record purpose

S/N	Location	Coordinates	Accuracy (masl, ftasl)	Elevation of Wells from GPS (masl, ftasl)	Depth to Water Table (masl, ftasl)	Elevation of Water Table (masl, ftasl)	Elevation of Wells from Map (masl, ftasl)	Elevation of Water Table from Map (masl, ftasl)
1	Masanawa	11° 55' 41.9" N 07° 25' 08.3" E	10	589 1932.4	1.8 5.9	587.2 1926.5	594.4 1950.0	592.6 1944.1
2	KuyanGizo	11° 55' 43.4" N 07° 25' 12.6" E	11	585 1919.3	1.5 4.92	583.5 1914.4	584.97 1919.2	583.47 1914.28
3	Tsauni	11° 55' 22.5" N 07° 25' 49.2" E	10	601 1971.8	10.0 32.80	591.0 1939.0	594.4 1950.0	584.4 1917.2
4	Kura	11° 54' 24.0" N 07° 26' 21.1" E	10	597 1958.7	12.0 39.37	585.0 1919.3	600.5 1970	588.5 1930.63
5	SabonGida	11° 53' 55.1" N 07° 26' 32.7" E	11	603 1978.3	12.0 39.37	591.0 1938.9	603.5 1980	691.5 1940.63
6	Damarke	11° 53' 17.3" N 07° 17' 15.8" E	10	598 1961.9	14.5 47.57	583.5 1914.3	597.4 1960	582.9 1912.43
7	GidanDaudu	11° 52' 52.7" N 07° 27' 42.8" E	10	599 1965.2	14.0 45.93	585.0 1919.3	606.6 1990	592.6 1944.07
8	Yargoje	11° 52' 15.3" N 07° 28' 20.8" E	14	612 2007.9	12.0 39.37	600.0 1968.4	595.90 1955	583.9 1915.63
9	Bagoma	11° 56' 46.6" N 07° 26' 42.7" E	14	581 1906.2	15.0 49.21	566.0 1857.0	586.7 1925	571.7 1875.79
10	Gazawa	11° 56' 42.1" N 07° 27' 00.0" E	9	588 1929.1	8.0 26.25	580.0 1902.9	586.7 1925	578.7 1898.75
11	Tudun Wada	11° 58' 53.2" N 07° 27' 39.9" E	9	565 1853.7	10.5 34.45	554.5 1819.3	571.5 1875	561.0 1840.55
12	TsamiyanSarki	11° 59' 54.2" N 07° 27' 00.1" E	9	562 1843.8	7.2 23.62	554.8 1820.2	566.9 1860	559.7 1836.38
13	KadaBoki	11° 59' 47.5" N 07° 25' 08.4" E	10	568 1863.5	7.0 22.97	561.0 1840.5	566.9 1860	559.9 1837.03
14	Baure	11° 59' 39.8" N 07° 23' 28.7" E	8	559 1834.0	0.5 1.64	558.5 1832.3	571.5 1875	571.0 1873.36
15	Marake	11° 59' 20.3" N 07° 23' 48.7" E	10	570 1870.1	7.0 22.97	563.0 1863.1	579.1 1900	572.1 1877.03
16	Matsiga	11° 57' 55.7" N 07° 24' 27.8" E	9	580 1902.9	1.5 4.92	578.5 1861.8	580.6 1905	579.1 1900.08
17	Kaikabayaz	11° 56' 09.2" N 07° 22' 28.6" E	14	562 1843.8			562.0 1843.8	

18	Pauwa	11° 58’ 53.2” N 07° 18’ 48.8” E	14	601 1971.8	15.0 49.21	586.0 1922.6	594.4 1950.0	579.4 1900.79
19	Zango	11° 57’ 14.3” N 07° 16’ 09.5” E	14	556 1824.1	4.3 14.11	551.7 1810.0	548.6 1800	544.3 1785.89
20	Bakai	11° 54’ 26.1” N 07° 16’ 49.6” E	8	528 1732.3	4.6 15.09	523.4 1717.2	536.4 1760.0	531.8 1744.91
21	Maigwoshi	11° 52’ 58.0” N 07° 17’ 22.1” E	8	536 1758.5	1.5 4.92	534.5 1753.6	541.0 1775	539.5 1770.08
22	Dakamawa	11° 53’ 34.6” N 07° 19’ 09.7” E	9	564 1850.4	8.8 28.87	555.2 1821.5	563.9 1850	555.1 1821.13
23	Jekaiarede	11° 55’ 56.2” N 07° 19’ 46.1” E	14	606 1988.2	18.6 61.02	587.4 1927.2	594.5 1950	575.9 1888.98
24	Kapi	11° 55’ 39.2” N 07° 22’ 29.6” E	14	583 1912.7	15.0 49.21	568.0 1863.5	579.1 1900	564.1 1850.79
25	KapinMaiyawu	11° 55’ 31.0” N 07° 22’ 51.3” E	9	567 1860.2	7.5 24.50	559.5 1835.6	582.2 1910	574.7 1885.5
26	Zurunkuku	11° 53’ 50.6” N 07° 23’ 35.7” E	7	596 1955.4	3.5 10.08	592.5 1945.3	595.9 1955	592.4 1944.92
27	Danakwabo	11° 53’ 31.0” N 07° 23’ 03.3” E	15	582 1909.4	5.5 18.04	576.5 1891.4	594.4 1950	588.9 1931.92
28	Madubai	11° 53’ 41.1” N 07° 22’ 52.3” E	14	537 1761.8	2.8 9.19	534.2 1752.6	595.9 1955	593.1 1945.81
29	Jaga	11° 53’ 12.5” N 07° 22’ 44.2” E	10	587 1925.9	3.5 11.48	583.5 1914.4	595.9 1955	592.4 1935.3
30	Gatakawa	11° 52’ 50.3” N 07° 23’ 03.9” E	8	594 1948.8	3.5 11.48	590.5 1937.3	597.4 1960	593.9 1948.52
31	Dankumeji	11° 50’ 22.3” N 07° 25’ 03.3” E	12	585 1919.3	5.5 18.04	579.5 1901.3	585.2 1920	579.7 1901.96
32	UngwanTofa	11° 50’ 43.6” N 07° 25’ 18.9” E	8	581 1906.2	7.5 24.5	578.5 1898.1	591.3 1940	583.8 1915.5
33	KwakareNabado	11° 50’ 50.6” N 07° 29’ 48.3” E	10	581 1906.2	15.5 50.85	565.5 1855.4	608.1 1995	592.6 1944.15
34	Nasaru	11° 49’ 40.2” N 07° 31’ 52.7” E	9	627 2057.1	7.5 24.50	619.5 2032.6	627.0 2057.0	
35	Maikawo	11° 48’ 46.0” N 07° 31’ 00.1” E	9	626 2053.8	9.0 29.53	617.0 2024.3	626.0 2053.8	
36	Ung. Kuka	11° 48’ 23.7” N 07° 30’ 54.5” E	6	615 2017.7	5.5 18.04	597.0 1999.7	615.0 2017.7	
37	Burdugau	11° 47’ 08.9” N 07° 28’ 39.2” E	13	612 2007.9	6.8 22.31	605.2 1985.6	603.5 1980	596.7 1957.69
38	Gidan Kure	11° 46’ 42.5” N 07° 26’ 02.2” E	10	592 1942.3	10.0 32.81	582.0 1909.5	597.4 1960	587.4 1927.19
39	Ung. Teba	11° 47’ 29.0” N 07° 25’ 22.6” E	13	587 1925.9	7.0 22.97	580.0 1902.9	586.7 1925	579.7 1902.03
40	Ung. Dangizo	11° 48’ 07.1” N 07° 23’ 44.6” E	14	542 1778.2	7.9 25.92	534.1 1752.3	586.7 1925	578.8 1899.08

41	Dan Daudu	11° 48’ 02.6” N 07° 22’ 23.7” E	8	587 1925.9	17.0 55.77	570.0 1870.1	585.2 1920	568.2 1864.23
42	Danguza	11° 49’ 07.4” N 07° 21’ 51.5” E	11	565 1853.7	11.8 38.71	553.2 1814.9	567.0 1860	555.2 1821.23
43	Mabai	11° 51’ 18.0” N 07° 20’ 06.6” E	11	571 1873.4	10.0 32.81	561.0 1840.5	563.9 1850	553.9 1817.19
44	Katsale	11° 51’ 39.6” N 07° 20’ 07.6” E	14	573 1879.9	5.5 18.04	567.5 1861.9	565.4 1855	559.9 1836.96
45	Lamida	11° 45’ 43.3” N 07° 18’ 01.3” E	13	578 1896.3	10.0 32.81	568.0 1863.5	586.7 1925	576.7 1892.19
46	Kakumi	11° 47’ 11.8” N 07° 18’ 32.8” E	12	571 1873.4	9.8 35.15	561.2 1838.2	579.1 1900	569.3 1864.85
47	GarauGoje	11° 46’ 18.2” N 07° 20’ 06.0” E	9	598 1961.9	16.3 53.48	581.7 1908.4	597.4 1960	581.1 1906.52
48	ZagiKaru	11° 47’ 20.9” N 07° 21’ 11.8” E	11	581 1906.2	9.4 30.84	571.6 1875.5	582.2 1910	572.8 1879.16
49	ZagiMakeda	11° 45’ 48.2” N 07° 21’ 20.9” E	7	591 1939.0	6.7 21.98	584.3 1914.0	591.3 1940	584.6 1918.02
50	Kandarawa	11° 45’ 18.4” N 07° 22’ 16.2” E	9	590 1935.7	20.0 65.60	570.0 1870.1	609.6 2000	589.6 1934.4
51	Dan Ban B	11° 47’ 14.4” N 07° 17’ 25.0” E	9	573 1879.9	7.0 22.97	566.0 1856.9	580.6 1905	573.6 1882.03
52	Dan Bawo A	11° 46’ 34.0” N 07° 17’ 09.8” E	10	564 1850.4	12.2 40.03	545.2 1888.7	586.7 1925	574.5 1884.97
53	Dan Bawo B	11° 46’ 27.6” N 07° 17’ 31.8” E	7	584 1916.0	11.0 36.09	573.0 1879.9	591.3 1940	580.3 1903.91
54	Zari Mai Ang.	11° 47’ 18.9” N 07°16’ 40.3” E	11	583 1912.7	11.2 36.75	571.8 1876.0	591.3 1940	580.1 1903.25
55	Zari	11° 47’ 57.0” N 07° 17’ 01.6” E	13	572 1876.6	13.8 45.28	558.2 1831.3	588.3 1930	574.5 1884.72
56	ZarinKwari	11° 48’ 25.3” N 07° 17’ 40.9” E	14	570 1870.1	6.0 19.69	564.0 1850.4	571.5 1875	565.5 1855.31
57	Dan Bau A	11° 47’ 35.7” N 07° 17’ 46.6” E	7	568 1863.5	4.5 14.76	563.5 1848.8	570.0 1870	
58	Mununu	11° 50’ 52.8” N 07° 16’ 00.8” E	8	560 1837.3			560.0 1837.2	
59	Kukurtawa Marafa	11° 51’ 44.0” N 07° 17’ 03.9” E	8	549 1801.2	1.5 4.92	547.5 1796.3	551.7 1810	550.2 1805.08

AppendixIII: WHO 1999, Standard Permissible Limit for Physical and Chemical Parameters of Water for Drinking and Domestic Use

Water Quality Standard	Unit Measurement	WHO STANDARD	
		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
-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
Sodium, Na	Mg/l	< 120	< 400
Calcium, Ca	Mg/l	< 75	< 200
Magnesium, Mg	Mg/l	< 125	< 125
Iron, Fe, Total	Mg/l	< 0.1	< 1.0
Manganess, Mn	Mg/l	0.01	< 0.5
Sulphate, SO_4	Mg/l	< 200	< 400
Nitrate, NO_3	Mg/l	< 10	< 45
Nitrite, NO_2	Mg/l	< 10	< 2.0
Fluoride, F	Mg/l	0.7-1.2	1.2-2.4
Cadmium, Cd	Mg/l	< 0.01	< 0.01
Lead, Pb	Mg/l	< 0.020	< 0.050
Copper, Cu	Mg/l	< 0.05	< 1.0
Zinc, Zn	Mg/l	< 0.5	< 5.0
Chromium, Cr	Mg/l	< 0.05	< 0.1
Selenium, Se	Mg/l	< 0.01	< 0.01
Antimony, Sb	Mg/l	< 0.05	< 0.05
Arsenic, As	Mg/l	< 0.01	< 0.05

Appendix IV: physical / Organoleptic Parameters for drinking water (NIS, 2007)

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

Appendix V: Chemical Parameters for drinking water (Inorganic constituents- NIS 2007)

Parameter	Unit	Maximum permitted levels	Health impact
Aluminum (Al)	mg/l	0.2	Potential neuro-degenerative disorders
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

AppendixVl: PUMPING TEST DATA FOR GARAGE FROM KANKAR (RUWASSA KATSINA STATE)

TIME	DWL	DRAW DOWN	PUMPING RATE	TIME	DWL	DRAW DOWN	PUMPING RATE
0				0	21.10	2.10	
1	18.70	0.45		1	21.52	2.82	
2	19.20	0.50		2	21.70	3.00	
3	19.70	0.50		3	21.80	3.10	0.74/s
4	19.90	0250		4	21.90	3.20	
5	20.20	1.50		5	21.97	3.27	
6	20.40	1.70		6		3.27	
7	20.53	1.85		7	21.98	3.28	
8	20.70	2.0		8	22.00	3.30	
9	20.70	2.00		9	22.01	3.31	
10	20.80	2.10		10	22.02	3.32	
12	20.90	2.20		12	22.03	3.33	
14	20.93	2.23		14	22.05	3.38	
16	20.95	2.25		16	22.07	3.37	
18	20.97	2.27	0.47/s	18	22.08	3.38	0.74/s
20	21.00	2.30		20	22.10	3.40	
25	21.03	2.33		25	22.14	3.44	
30	21.05	2.35		30	22.19	3.49	
35	21.06	2.35		35	22.20	3.50	
40	21.07	2.37		40	22.25	3.55	
45	21.08	2.27		45	22.30	3.60	
50	21.10	2.38		50	22.38	3.68	
60	21.10	2.40		60	22.45	3.75	
70	21.10	2.40		70	22.52	3.82	
80	21.10	2.40	0.47/S	80	22.63	3.92	0.74/s
90	21.10	2.40		90	22.82	4.12	
100	21.10	2.40		100	22.90	4.20	

PUMPING TEST DATA FOR NAGAMDA FROM KANKARA (RUWASSA, KATSINA STATE)

TIME	DWL	DRAW DOWN	PUMPING RATE	TIME	DWL	DRAW DOWN	PUMPING RATE
0	5.70			0	14.58	8.88	
1	6.70	1.00		1	15.70	10.00	
2	6.90	1.20		2	15.97	10.20	
3	7.37	1.67		3	16.26	11.06	0.58/s
4	7.90	2.20	0.38/s	4	17.98	12.28	
5	8.20	2.50		5	18.54	12.84	
6	8.65	2.95		6	18.80	13.10	
7	8.90	3.20		7	19.23	13.53	
8	9.03	3.33		8	19.70	14.00	
9	9.20	3.50		9	20.06	14.36	
10	9.40	3.70		10	20.47	14.77	
12	9.80	4.10		12	21.05	15.35	
14	10.70	5.00		14	21.70	16.00	
16	11.45	5.25		16	22.06	16.36	
18	12.03	6.33		18	22.52	16.82	
20	12.47	6.77		20	22.79	17.09	
25	13.40	7.70		25	23.19	17.49	0.58/s
30	13.95	8.25	0.38/s	30	23.56	17.86	
35	14.09	8.39		35	23.82	18.12	
40	14.23	8.53		40	24.16	18.46	
45	14.30	8.60		45	24.69	18.99	
50	14.38	9.68		50	24.88	19.18	
60	14.43	8.73		60	25.33	19.63	
70	14.88	9.10		70	25.30	21.89	
80	14.88	9.10		80	22.23	21.38	
90	14.58	8.88		90	28.26	22.52	
100	14.88	9.18		100	30.02	24.32	0.58/s
120				120	33.09	27.39	
140				140	37.44	31.74	

PUMPING TEST FOR TURARA FROM KANKARA (RUWASSA KATSINA STATE)

TIME	DWL	DRAW DOWN	PUMPING RATE	TIME	DWL	DRAW DOWN	PUMPING RATE

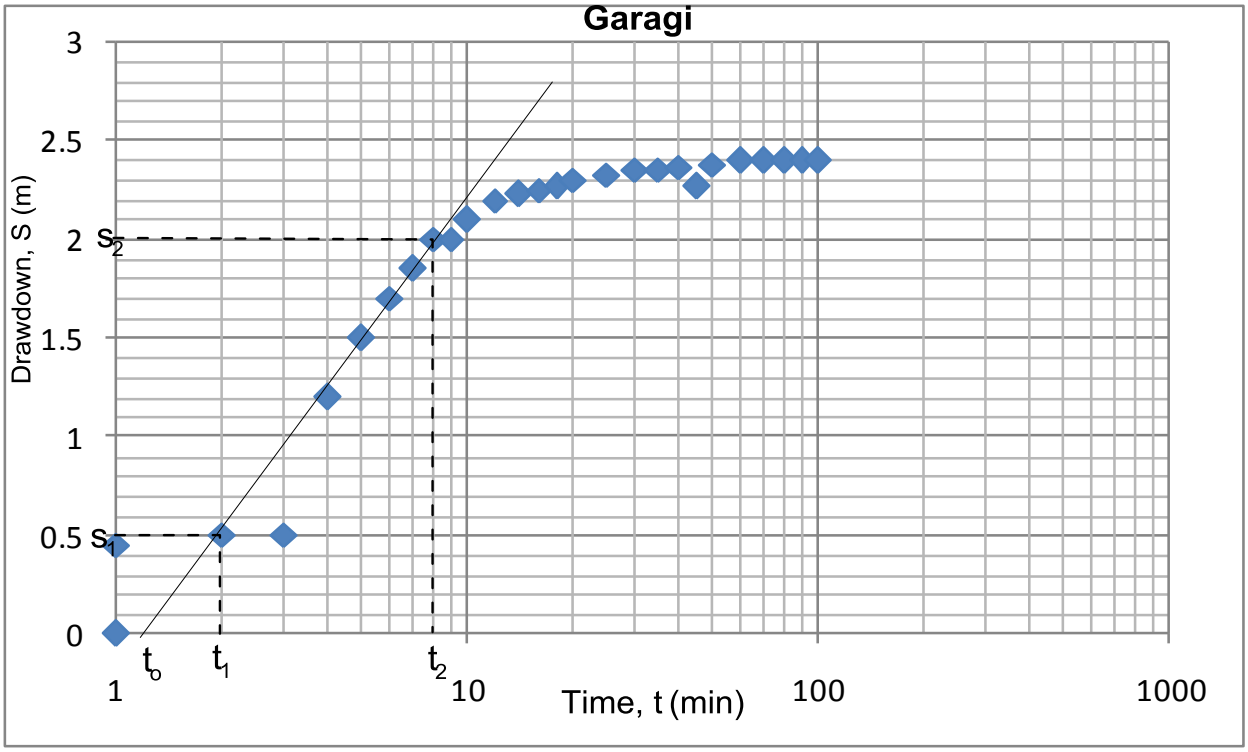
0	13.10			0	19.05	5.95	
1	14.20	1.00		1	20.20	7.10	
2	14.50	1.40	0.38/s	2	20.98	7.88	
3	16.55	3.05		3	21.20	8.10	
4	16.70	3.60		4	21.55	8.45	0.85/s
5	17.15	4.05		5	21.55	8.45	
6	17.55	4.45		6	21.60	8.30	
7	17.80	4.70		7	21.30	8.70	
8	17.92	4.82		8	21.92	8.82	
9	18.5	4.95		9	22.03	8.93	
10	18.10	5.00		10	22.20	9.10	
12	18.05	4.95		12	22.25	9.35	
14	18.00	4.90		14	22.30	9.20	
16	18.20	5.02		16	22.52	9.42	
18	18.20	5.70		18	22.50	9.40	
20	18.40	5.30		20	22.50	9.40	
25	18.50	5.60	0.38/s	25	22.40	9.40	0.80/s
30	18.80	5.70		30	22.30	9.30	
35	18.90	5.80		35	22.32	9.20	
40	18.66	5.88		40	22.32	9.22	
45	18.88	5.88		45	22.34	9.22	
50	18.98	5.88		50	22.35	9.26	
60	19.01	5.91		60	22.36	9.26	
70	19.03	5.93		70	22.37	9.27	
80	19.04	5.94		80	2.37	9.27	
90	19.05	5.95	0.38/s	90	22.37	9.27	
100	19.05	5.95		100	22.37	9.27	
120	19.05	5.95		120			

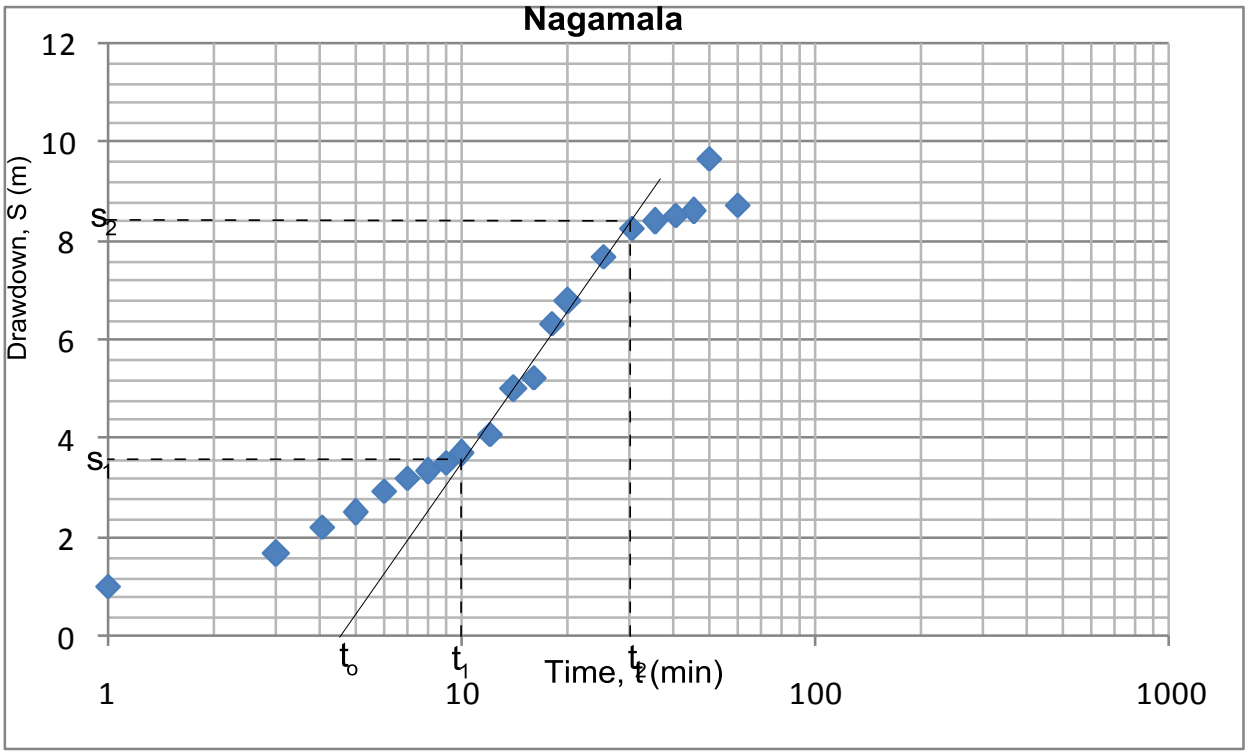
PUMPING TEST DATA FOR MABAI FROM KENKARA (RUWASSA KATSINA STATE)

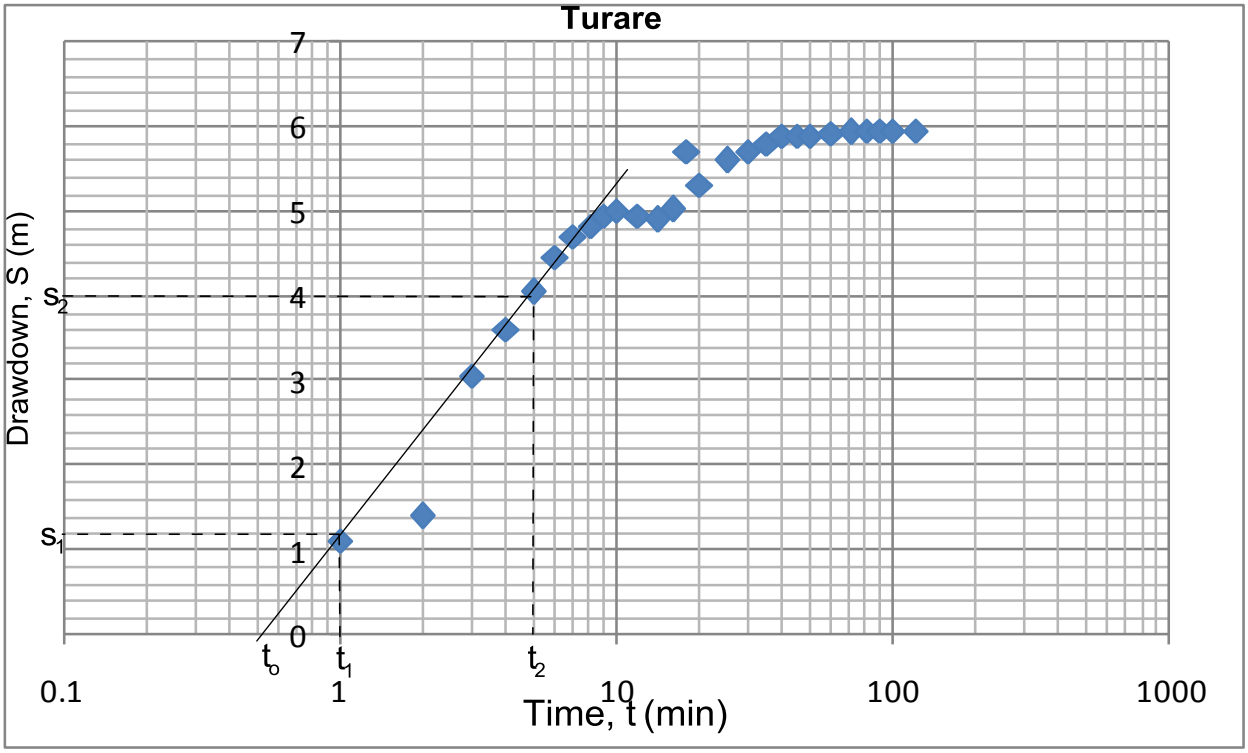
TIME	**DWL**	**DRAW DOWN**	**PUMPING RATE**	**TIME**	**DWL**	**DRAW DOWN**	**PUMPING RATE**
0	12.15			0	15.78	3.63	
1	12.88	0.73		1	12.20	5.05	0.60/s

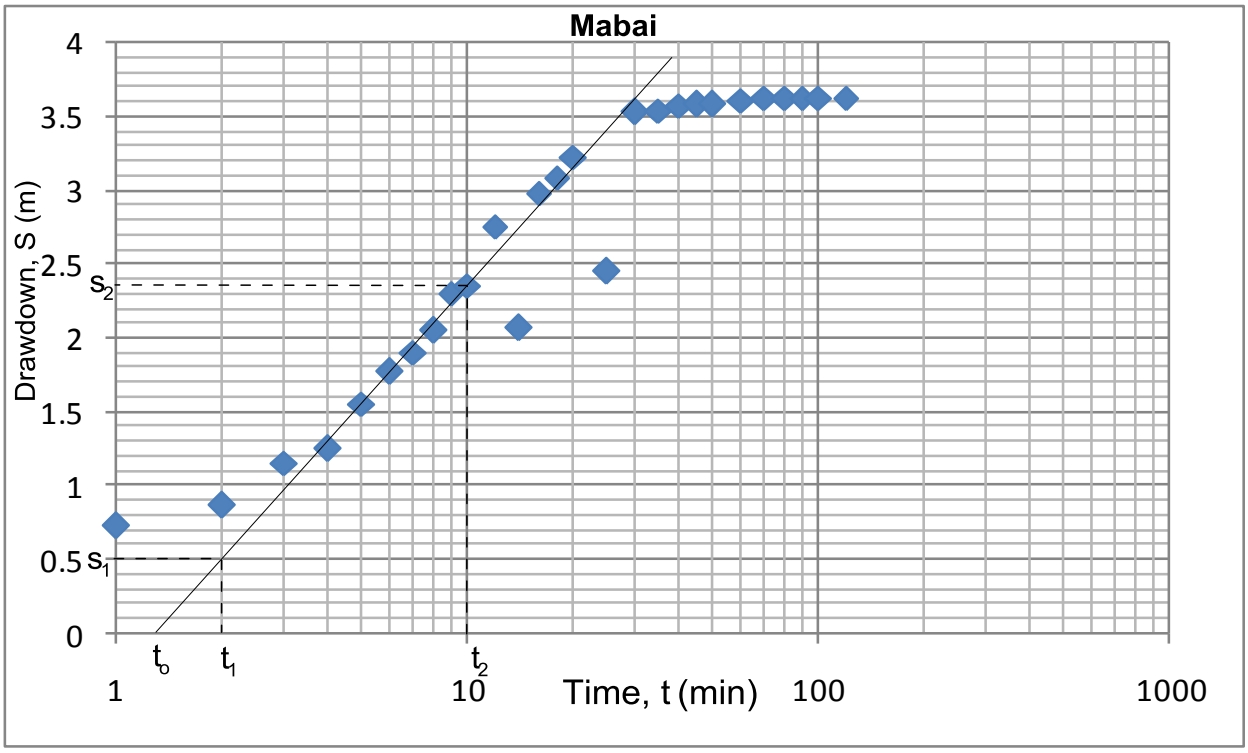
2	13.02	0.87	0.41/s	2	17.76	5.61	
3	13.30	1.15		3	17.92	5.77	
4	13.40	1.25		4	17.96	5.81	
5	13.70	1.55		5	18.06	5.91	
6	13.92	1.77		6	18.23	6.08	
7	14.05	1.90		7	18.48	6.33	
8	14.20	2.05		8	18.70	6.55	
9	14.45	2.30		9	18.80	6.65	
10	14.50	2.35		10	18.90	6.75	
12	14.90	2.75		12	19.0	6.85	0.60/s
14	15.02	2.07		14	19.10	6.95	
16	15.13	2.98		16	19.15	7.00	
18	15.24	3.09		18	19.40	7.25	
20	15.38	3.23	0.41/s	20	19.45	7.30	
25	15.60	2.45		25	19.63	7.48	
30	15.68	3.53		30	19.72	7.57	
35	15.69	3.54		35	19.84	7.69	
40	15.72	3.57		40	19.98	7.83	
45	15.73	3.58		45	20.16	8.01	
50	15.73	3.58		50	20.36	8.21	
60	15.76	3.61		60	20.52	8.37	
70	15.77	3.62		70	20.71	8.53	
80	15.78	3.63		80	20.89	8.74	0.60/s
90	15.78	3.63	0.41/s	90	20.94	8.79	
100	15.78	3.63		100	21.26	9.11	
120	15.78	3.63		120	21.52	9.32	

AppendixVll: Pumping Test Data and Corresponding Drawdown-Time Graphs


Garagi
Drawdown, S (m)
3
2.5
2
1.5
1
0.5
0
S_2
S_1
t_o
t_1
t_2
1
10
100
1000
Time, t (min)


Nagamala
Drawdown, S (m)
12
10
8
6
4
2
0
S_2
S_1
t_o
t_1
t_2
1
10
100
1000
Time, t (min)


Turare
Drawdown, S (m)
7
6
5
4
3
2
1
0
s_2
s_1
t_o
t_1
t_2
0.1
1
10
100
1000
Time, t (min)


Mabai
Drawdown, S (m)
4
3.5
3
2.5
2
1.5
1
0.5
0
s_2
s_1
t_o
t_1
t_2
1
10
100
1000
Time, t (min)

s