

**HYDROCHEMICAL EVALUATION OF GROUNDWATER QUALITY OF  
PART OF LAFIA METROPOLIS, NORTHCENTRAL NIGERIA**

**BY**

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**A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL  
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DEGREE MASTER OF TECHNOLOGY IN ENVIRONMENTAL GEOLOGY**

**AUGUST, 2023**

## **DECLARATION**

I hereby declare that this thesis titled **“HYDROCHEMICAL EVALUATION OF GROUNDWATER QUALITY OF PART OF LAFIA METROPOLIS, NORTHCENTRAL NIGERIA”** is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

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## **CERTIFICATION**

The thesis titled **“HYDROCHEMICAL EVALUATION OF GROUNDWATER QUALITY OF PART OF LAFIA METROPOLIS, NORTHCENTRAL NIGERIA”** by: Buba Wilson Mbore (MTech/SPS/2018/8437) meets the regulations governing the award of the degree of MTech of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literacy presentation.

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## ABSTRACT

Geological mapping, lithological and hydrochemical data had been acquired and analysed in part of Lafia area in the Middle Benue Trough of Nigeria. This was with a view to characterizing the geologic rock types, assessing its groundwater quality and environmental impact of heavy metal in the soil and water in study area. Soil and groundwater samples were collected from Boreholes and soil, analysed for physio-chemical, heavy metal and major and minor oxides. Fieldwork started with reconnaissance survey of the study area, followed by detailed geological, lithological and hydrochemical mapping. The area is underlain by cretaceous sedimentary rocks of the Middle Benue Trough consisting of sandstones, shale and ironstone. The EC and TDS of the area are within the permissible limit and also the temperatures are all within the ambient conditions. The pH is slightly below the recommended limit. The hydrogeological facies are Earth alkaline water with prevailing  $\text{SO}_4$  and Cl. The hydrochemical facies corresponds to the  $\text{Ca}^{2+}$ - $\text{Mg}^{2+}$ -Cl- $\text{SO}_4^{2-}$ . The hydrochemical process responsible for the water chemistry from the Durov plot is simple dissolution or mixing. The major anions composition in all the water samples is in the order  $\text{Cl}^- > \text{HCO}_3^- + \text{CO}_3^{2-} > \text{SO}_4^{2-}$  while the major cation is in the order  $\text{Na}^+ + \text{K}^+ > \text{Mg}^{2+} > \text{Ca}^{2+}$ . The anions indicated that the geological processes responsible for the chemistry of the water are a combination of evaporation and precipitation, while precipitation alone is responsible for the remaining water samples. The hydrogeochemistry is with respect of precipitation, atmospheric, interaction of rock water and evaporation over the management of groundwater geochemistry. The chart proportion of cation  $[(\text{Na} + \text{K})/9\text{Na} + \text{K} + \text{Ca}]$  and anion  $[(\text{Cl}/(\text{Cl} + \text{HCO}_3))]$  against TDS. However, Gibb's plot using the cations indicated that the geological process responsible for the chemistry of the water samples is rock-water interaction while the remaining samples indicated precipitation dominance. The heavy metals; Fe, Mn, Cd and Pb enrichment is attributed to the anthropogenic activities going on in the area as well as geogenic processes of chemical weathering and dissolution. The groundwater is contaminated with all the heavy metals especially Cd and Pb which are indicators of environmental contamination and calls for mitigation and remediation measures. The contamination factor (CF) intensity of the analysed heavy metals decreased in the following order  $\text{Pb} > \text{Fe} > \text{Mn} > \text{Cu} > \text{Ni} > \text{Cd}$ . The geological phenomena such as weathering and dissolution may possibly be responsible in releasing these metals from the host rock to the surrounding water bodies. The major oxides distribution in the soil samples are depicted on the ternary plot. It is observed that most of the soil samples are richer in Fe and Si, Si and Fe oxides as compared to Fe and Al and Al and Si oxides. The groundwater quality of Lafia and environs varies from excellent to good quality used for irrigation purposes.

## **TABLE OF CONTENTS**

Cover page

Title page

i

Declaration

ii

Certification

iii

Acknowledgement

iv

Abstract

v

Table of Contents

vi

List of Table

ix

List of Figures

x

List of Plates

xii

### **CHAPTER ONE**

1.0 Introduction

1.1 Background of Study

1

1.2	Statement of Research Problem	2
1.3	Justification	3
1.4	Aim and Objectives of the Study	4
1.5	Location and Accessibility of the Study Area	5
1.5.1	Relief and Drainage	6
1.5.2	Climate and Vegetation	6
1.5.3	Human Geography	7

## **CHAPTER TWO**

2.0	Literature Review	8
2.1	Geology and Groundwater Basins	8
2.2	Geology and Hydrogeology of Benue Trough	10
2.2.1	The Middle Benue Trough	12

2.3	Hydrogeology of the Benue Trough	
		16
2.3.1	Interbedded Beds of the Awe Formation	
		16
2.3.2	Sandstones of the Makurdi/Keana and Ezeaku Formation	
		17
2.3.3	The Sandstones of the Awgu Formation	
		17
2.3.4	The Basal Sandstones of the Lafia Formation	
		18
2.3.5	Aquifer of the Lafia Formation	
		18
2.4	Review of Related Work	
		19
2.4.1	Geochemistry of rocks and groundwater in the Middle Benue Trough	
		19

### **CHAPTER THREE**

3.0	Methodology	
		24
3.1	Research Design	
		24
3.2	Preliminary Studies	
		24
3.3	Geological Field Mapping and Sampling	
		24



3.4	Water Sample Collection	26
3.5	Laboratory Analysis	27
3.6	Data Analysis (Quantitative and Qualitative)	29
3.6.1	Hydrochemical reliability	30
3.6.2	Groundwater suitability for drinking purposes	30
3.6.3	Hydrochemical facies characterisation	31
3.6.4	Multivariate statistical analysis	32
3.6.5	Mechanism and processes controlling groundwater chemistry	33
3.6.6	Irrigation parameters indices	36

## **CHAPTER FOUR**

### **4.0 RESULTS AND DISCUSSION**

40

#### 4.1 Geology of the Study Area (Lafia and Environs)

40

##### 4.1.1 Agwu Formations

41

4.1.2	Lafia Formation	
		41
4.2	Hydrogeochemistry	
		41
4.2.1	Contamination Factor (CF) and Contamination Degree (CD)	
		42
4.3	Irrigation suitability of groundwater in the study area	
		46
4.3.1	pH	
		46
4.3.2	Total dissolved solids (TDS)	
		46
4.3.3	Electrical conductivity (EC)	
		46
4.3.4	Total hardness (TH)	
		47
4.3.5	Sodium adsorption ratio (SAR)	
		47
4.3.6	Magnesium adsorption ratio (MAR)	
		47
4.3.7	Permeability index (PI)	
		47
4.3.2	Residual sodium carbonate (RSC)	
		48

4.3.9 Soluble sodium percentage

48

4.3.10 Kelly ratio (KR)

49

4.4 Hydrogeochemical Facie Characterization of Groundwater

49

4.5 Geochemical analysis of borehole cuttings

57

## **CHAPTER FIVE**

### **5.0 CONCLUSION AND RECOMMENDATION**

59

5.1 Conclusion

59

5.2 Recommendation

62

5.3 Contribution to Knowledge

63

## **REFERENCES**

64

## **LIST OF TABLES**

3.1	Concentration ratios and their meaning in terms of process	
34		
4.1	Contamination Factor and Contamination Degree	
45		
4.2	Irrigation water quality	
50		
4.3	Classification of water based on Durov diagram (Lloyd and Heathcoat, 1985)	
52		
4.4	Stiff plot describing the grouped pattern of the study area	
56		

## LIST OF FIGURES

- 1.1 Topographical map showing the location of the study area  
5
- 2.1 Geological map of Nigeria showing Basement Complex and  
Sedimentary terrain (Bassey, 2012)  
9
- 2.2 Sedimentary Basins of Nigeria (Obaje, 2009)  
11
- 2.3 Stratigraphic successions in the Middle Benue Trough  
13
- 2.4 Stratigraphic of Lafia Formation  
14
- 3.1 Research design  
25
- 4.1 Geological map and cross section of Lafia and its environs  
40
- 4.2 Concentration of Fe in groundwater of the study area, compared with  
WHO standard for drinking water  
43
- 4.3 Concentration of Mn in groundwater of the study area, compared  
with WHO standard for drinking water  
43
- 4.4 Concentration of Zn in groundwater of the study area, compared  
with WHO standard for drinking water  
43

4.5	Concentration of Cu in groundwater of the study area, compared with WHO standard for drinking water	44
4.6	Concentration of Pb in groundwater of the study area, compared with WHO standard for drinking water.	44
4.7	Average Contamination Factor of metals	45
4.8	Suitability of water samples based on permeability index	48
4.9	Wilcox plot showing irrigation water quality	49
4.10	Piper trilinear diagram for the study area	51
4.11	Durov plots of groundwater samples of the study area	52
4.12a	Stiff plots of groundwater samples of the study area	53
4.12b	Stiff plots of groundwater samples of the study area	54
4.12c	Stiff plots of groundwater well water samples of the study area	55
4.13	Gibb's plot of groundwater samples of the study area	57

#### 4.14 Major oxide distributions in borehole cuttings

58

## **LIST OF PLATES**

- I      Collection of water sample at River Amba  
27
- II     Soil samples preparation for laboratory analysis  
28
- III    Collection of water sample and physical parameters insitu measurement at Emir  
Palace Lafia  
29



## CHAPTER ONE

### 1.0 INTRODUCTION

#### 1.1 Background of Study

Next to air, water is the most indispensable natural resources needed for life. Access to safe drinking water is essential to health; it is a basic human right (World Health Organization, 2011). Groundwater is the world's largest freshwater reservoir and important resource for drinking, water supply, irrigation and industrial purposes as well as for global food security (Sefie *et al.*, 2015). The quality of life, stability of the ecosystem, and socioeconomic development are critically dependent on the provision of safe water resources. In response to the high demand for groundwater and increased risk of contamination, a better understanding of groundwater availability and quality is needed (Montcoudiol, 2015). The total volume of fresh groundwater is only a small fraction of the overall volume of water on earth but it is under severe threats due to over consumption and deteriorating quality.

Geology of an area, the degree of chemical weathering of various rock types and anthropogenic factors affect the chemistry of groundwater (Amadi *et al.*, 2010). Groundwater is vulnerable to pollution through multiple pathways which may cause critical health damages, therefore deteriorating quality of groundwater must be controlled for sustainable environment and preservation of the ecosystem (UNEP, 2007). The improper use of fertilizers, pesticides, mining activities, and industrial effluents has a direct impact on groundwater quality. Besides anthropogenic activities, some natural processes are also associated with serious damages, including waterlogging/salinization and seawater intrusion.

Water is essential for life but it does transmit diseases in countries in all continents-from the poorest to the wealthiest (WHO, 2011). Millions of people are exposed to unsafe levels of chemical contaminants in their drinking water (WHO, 2011). Monitoring contaminants in surface or groundwater supplies provide background information needed to determine the suitability of water resources for human consumption (United Nations Environmental Programme and Global Environmental Monitoring System (UNEP, 2007). Every twenty second, a child dies from a water related disease (WHO, 2009). Diarrhea remains the second leading cause of death among children under five globally. Nearly one in five child deaths – about 1.5 million each year is due to diarrhea. It kills more young children than AIDS, Malaria and Measles combined (WHO, 2009). Various researchers have reported on the serious and severe illnesses like typhoid, cholera, dysentery etc resulting from the use of contaminated water supply (Edet *et al.*, 2011). The quality of drinking water is a function of treatment and natural process as well as anthropogenic activities. Nitrate compounds, heavy metals pesticides etc. that are contained in our drinking water can also constitute undesirable pollutant when they are not within World Health Organization guidelines for drinking water (WHO, 1996). From environmental standpoint, there is a need to ascertain the level of water quality of a locality to avoid or reduce some of the health hazards (Shah *et al.*, 2007).

Hydrogeochemical studies have over the years played an essential role in interpreting mineralogical composition of the sub-surface and inherent conditions in most geological settings (Ekwere and Edet, 2012). However, little is done to assess and understand the quality of groundwater especially within the different aquifer systems (Edet *et al.*, 2011).

Factors which have made groundwater use quite attractive for agricultural is the relatively cheap cost of getting the water to the farm by sinking boreholes on site and not piping or channeling the water over long distances (Shah *et al.*, 2007).

## **1.2 Statement of Research Problem**

One of the primary goals of Nigeria government is to ensure that their populaces regardless of their social and economic conditions have access to an adequate supply of safe drinking water (Amadi *et al.*, 2010). Groundwater is continuously being explored in order to achieve that said goal. However, even though groundwater is believed to be safe and free from contaminants this is hardly the case as both geogenic and anthropogenic factors can have significant effect on its quality (Amadi *et al.*, 2010).

Iron is an essential element in human nutrition, however excessive concentration of iron in water gives it a bitter taste, causes gastrointestinal upset and stains cloth, teeth, gums and utensils. Normal amounts of iron is essential, but abnormally larger amount adversely affects the human system and results in a condition known as hemochromatosis wherein tissues are damaged due to prolonged iron accumulation. Similarly iron deposition in the skin gives rise to a characteristic pigmentation. The area was chosen because of the colour nature of the groundwater appearance of the existing wells, boreholes, artesian (boreholes) in Akunza area and Federal University of Lafia main campus.

## **1.3 Justification**

The iron incrustation on borehole fittings and water storage facilities is so common in some part of Lafia metropolis but the source of the iron pollutant is not established. Studies revealed that about 85% of all communicable diseases affecting humans are either water-borne or water-related (WHO, 2006). Access to good quality water is a

fundamental right and in the wake of the COVID-19 pandemic, this has proven to be even more crucial (UNICEF, 2020)

Umar *et al.* (2019) carried out an hydrochemical assessment of groundwater within the Lafia Formation, where the high iron content of the sampled water was identified, however borehole cuttings were not analyzed in that study and thus there was no attempt to establish source of the high iron content observed.

The present research analysed borehole cuttings and groundwater samples from Lafia metropolis thus providing an insight on the source of iron pollution observed in most groundwater samples within the study area.

#### **1.4 Aim and Objectives of the Study**

The aim of this research is to comprehensively carry out hydrogeochemical evaluation of groundwater in the Lafia town in order to guarantee reliable supply for all purposes and okay a sustainable groundwater management strategy.

The specific objectives include;

- i. Carry out geological mapping of the study area on a scale of 1:40,000
- ii. Determine the concentration of some chemical constituents in both groundwater and borehole cuttings within the study area.
- iii. Determine the irrigation suitability of groundwater in the study area.
- iv. Identify possible sources of chemical contaminants in the study area.
- v. Determine the dominant hydrofacies of groundwater in the study area.
- vi. Define sustainable groundwater management strategy to guarantee reliable supply.

## 1.5 Location and Accessibility of the Study Area

The study area is located within the Middle Benue Trough, North Central Nigeria on the Federal Survey of Nigeria (FSN), Lafia sheet 231 NW. It is on the scale of 1: 40,000. It is bounded with latitude N8° 26' 00" to N8° 30' 00" and longitude E8° 30' 00" to E8° 34' 00". It covers a total area of about 105 square kilometres. Geologically the area is underlain by sedimentary rocks of the Lafia Formation.

The area is accessible through Lafia – Makurdi and Lafia – Awe trunk “A” roads, and many rural roads and foot paths linking the area. Rivers and annual streams form the drainage networks that cover the entire area of study.

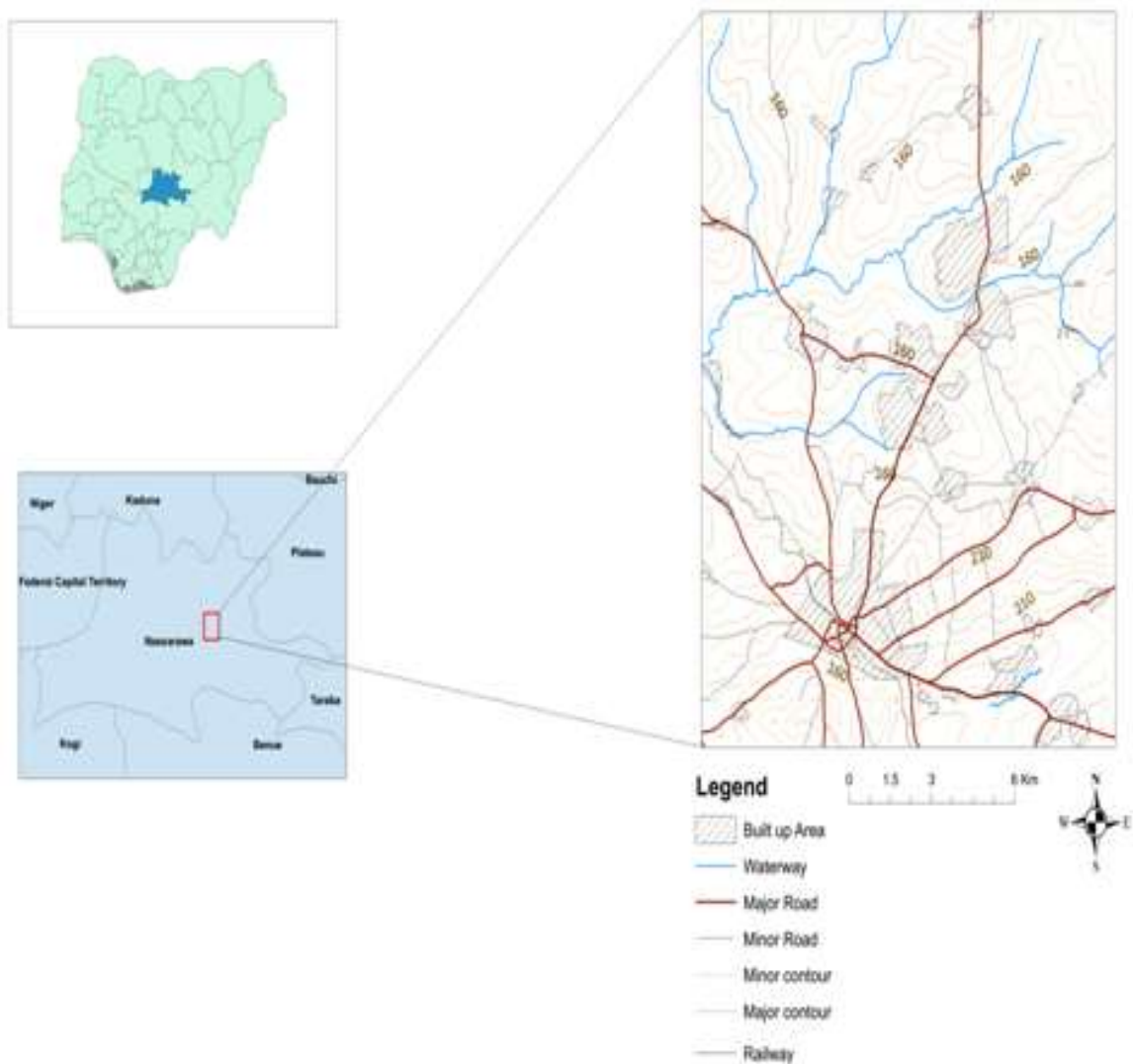


Figure 1.1 Topographical map of the location of the study area

### **1.5.1 Relief and Drainage:**

The area is generally undulating lowland. The highest point is 252m (above sea level) and the lowest point is 143m (above sea level).

The area is well drained by major rivers like Ashara which flows to the NW of Lafia town. Others are Agbaide, Atabula, Duduguru and Agyaragun Tofa, which all eventually drained into River Benue. The highest temperatures are recorded between March and April. The relative humidity ranges from 88% during the raining season to 30% during the dry season. However, the later could be lower during the dry harmattan period (NIMET, Lafia, 2012).

### **1.5.2 Climate and Vegetation:**

Nigeria is entirely situated in the tropics and is bounded by latitude 4N and 40N. The climate of the study area is dependent on the movements of the Inter-tropical Convergence Zones (ITCZ), which marks the boundary between the humid air masses of the south and the dry air masses of the north (Musa *et al.*, 2004). The ITCZ moves from north to south or south to north depending on the season. In general, the humid air masses and associated rain-bearing south westerly winds dominate the area, while the dry harmattan reaches the area only occasionally in the months of December – February. Thus, there are two main seasons, the rainy season and the dry season. The rainy season is from April to October, giving an average wet season of seven (7) months and dry season of five (5) months (Nov – April). The area enjoys a mean annual rainfall of 1,290mm–1,595.7mm (Chukwu, 2008). Generally, rainfall decreases from the north to the south. The annual mean minimum temperature ranges between 21.8<sup>0</sup>C – 22.2<sup>0</sup>C and the annual maximum mean temperature is about 23.5<sup>0</sup>C (Achohwora, 1986; Ariyo, 1987; Yaya and Ahmed, 2010).

The Vegetation is typically of Guinea Savannah characterized by a transition between forest and grassland with typical transition woodland and tall grasses (along the river channels or courses). The rest of the area is covered by open savannah woodland consisting of trees and grasses of varying heights. The original vegetation has been tempered with due to human activities such as farming, bush burning and grazing, hence giving rise to a secondary forest (Achohwo, 1986; Ariyo, 1987; Yaya and Ahmed, 2010).

### **1.5.3 Human Geography**

The people living in this area are the Kanuris, Gwandaras, Eggons, Alagos, Migilis, Fulanis and some other minor tribes. The prominent towns and villages in this area are Lafia, Agyaragu, Agwade, Daddare, Agyaragun Tofa, Gidan Ausa, Duduguru, Ome, Atabula, Wakwa, Gandu, Akunza, Kantsakuwa, Bukan Buzu, Bukan Tambari, and so on. The land is fertile hence the main occupation of people is farming. The farm products are yams, guinea corn, groundnuts, millet, cassava, maize, rice, beans, melon, beni seed, and so on.

The Fulanis rear cattle for beef and milk. The inhabitants of this area are known for their production of yams for which people go there from all parts of the country to buy (Achohwo, 1986; Ariyo, 1987; Yaya and Ahmed, 2010).

## CHAPTER TWO

### 2.0 LITERATURE REVIEW

#### 2.1 Geology of Nigeria

The geology of Nigeria consists of two main lithological units. These are the Precambrian Crystalline Basement and Cretaceous-Tertiary sedimentary rocks (Figure 2.1). The Basement Complex rocks are of metamorphic-igneous-volcanic origin. The main rock types include units include: Migmatite-Gneiss Complex (migmatites, gneisses), Schist Belts (schists, quartzites, metaconglomerates, amphibolites, phyllites), Older Granites (granites) and Younger Granites (basalts, rhyolites, tuff), Oyawoye (1970). The sedimentary basins include the northern inland sedimentary basins consisting of the Sokoto and Chad Basins while the middle belt and southern coastal basins is made up of the Nupe, Benue, Benin and Niger Delta Basins. The sedimentary sequences in these basins were broadly divided into basal non marine sandstones, siltstones, and mudstones; a middle marine shales and limestone intercalated with sandstones and siltstones and an upper sandstone sequence that is continental or paralic (Petters, 1982).

The Sokoto Basin of northwestern Nigeria is the southern sector of the Iullemeden Basin transboundary aquifer shared by Mali, Niger, and Algeria. The depth of water level in the Sokoto Basin aquifers is typically in the range 15 to 75 m (BGS, 2003), while the Gwandu aquifer has an estimated yield of 10 to 35 L/s (Akujieze *et al.*, 2003). The Chad Basin consists of three main aquifers: an upper aquifer at 30 to 100 m depth, a middle aquifer about 40 to 100 m thick and a lower aquifer consisting of sands and clays at a depth of 425 to 530m (Akujieze *et al.*, 2003; BGS, 2003).



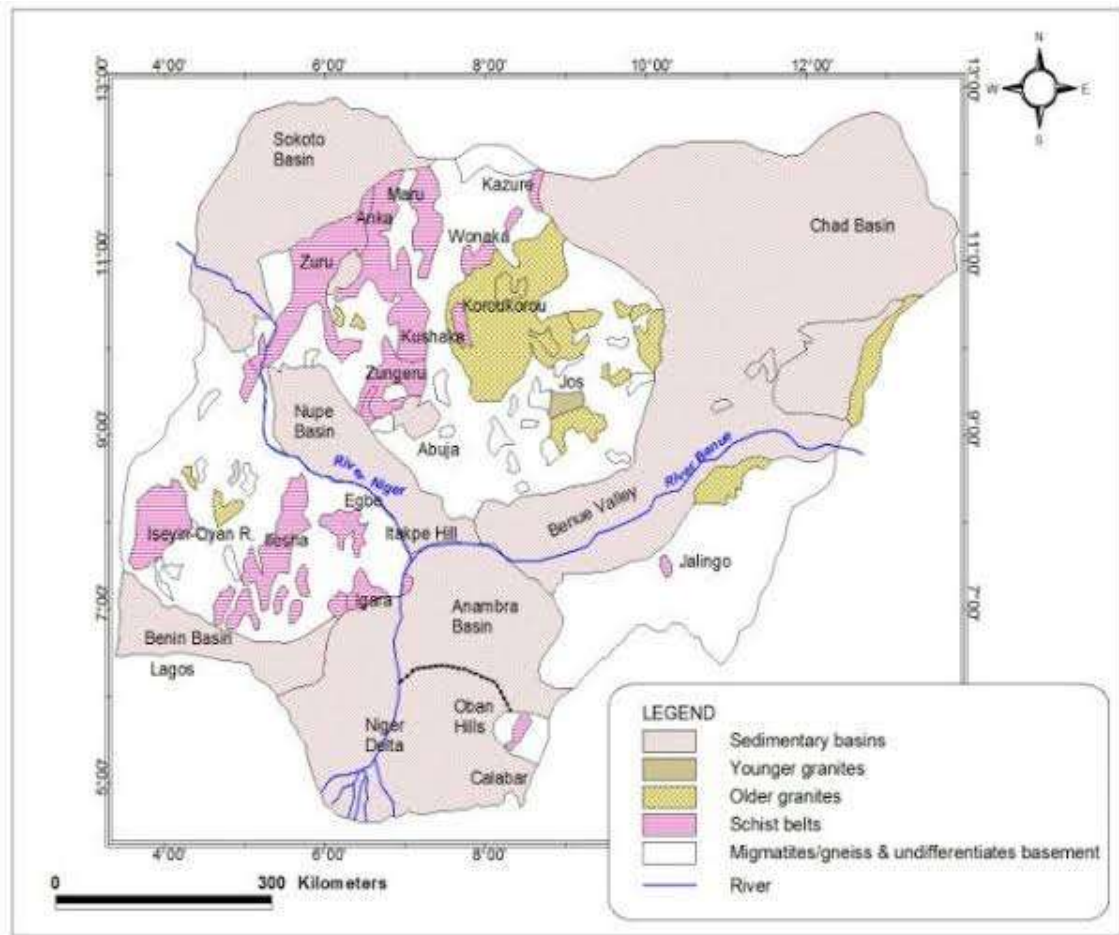


Figure 2.1: Geological Map of Nigeria showing Basement Complex and Sedimentary terrain (Bassey, 2012)

In the Benue Basin, three broad hydrogeological groups were identified in the southern Benue Basin (Uma and Onuoha, 1990; Adelana *et al.*, 2008). These include the first hydrogeological group underlain predominantly by shaly formations. The thickness is in the range of 10 to 40 m and water levels are generally < 20 m. The second hydrogeological group consists of mainly sandy and shaly horizons. The lower hydrogeological group consists predominantly of sands, sandstones and clays. The upper Benue Basin has the Gombe Sandstone and Kerri Kerri Formations as the main aquifers. These aquifers consist of coarse grained and highly permeable materials. The Nupe Basin contains significant groundwater resources with occasional artesian conditions. Good aquifers are present in the Tertiary and Quaternary sediments of the

southern coastal areas (Benin and Niger Delta Basins). The water level varies between 0 and 9 m while, the specific capacities, were in the range 90 to 1400 m<sup>3</sup>/d/m (Offodile,1992; Okereke,1997; Edet *et al.*, 1998; Okereke *et al.*,1998).

The groundwater storage in the crystalline basement is relatively small. Groundwater availability is largely limited to fracture zones and areas of deep weathering (Ajayi and Hassan, 1990; Olorunfemi, 1990; Edet, 1992; Edet and Okereke, 1997; Edet *et al.*, 1998; Okereke *et al.*, 1998). Generally, the principal source of groundwater is from hand dug wells and boreholes. Details on the hydrogeology of Nigeria are contained in (Offodile, 1992; Akujieze *et al.*, 2003; BGS, 2003 and Adelana *et al.*, 2008).

## **2.2 Geology of the Benue Trough**

The Benue Trough of Nigeria is a rift basin in central West Africa that extends NNE–SSW for about 800 km in length and 150 km in width. The southern limit is the northern boundary of the Niger Delta, while the northern limit is the southern boundary of the Chad Basin. The trough contains up to 6,000m of Cretaceous – Tertiary sediments of which those predating the mid-Santonian have been compressionaly folded, faulted, and uplifted in several places. Compressional folding during the mid-Santonian tectonic episode affected the whole of the Benue Trough and was quite intense, producing over 100 anticlines and synclines (Benkhelil, 1989). Major such deformational structures include the Abakaliki anticlinorium and the Afikpo syncline in the Lower Benue, the Giza anticline and the Obi syncline in the Middle Benue, and the Lamurde anticline and the Dadiya syncline in the Upper Benue Trough. Following mid-Santonian tectonism and magmatism, depositional axis in the Benue Trough was displaced westward resulting in subsidence of the Anambra Basin. The Anambra Basin, therefore, is a part of the Lower Benue Trough containing post-deformational sediments

of Campanian-Maastrichtian to Eocene ages. It is logical to include the Anambra Basin in the Benue Trough, being a related structure that developed after the compressional stage (Akande and Erdtmann, 1998). The Benue Trough is arbitrarily subdivided into a lower, middle and upper portion (Figure 2.2).

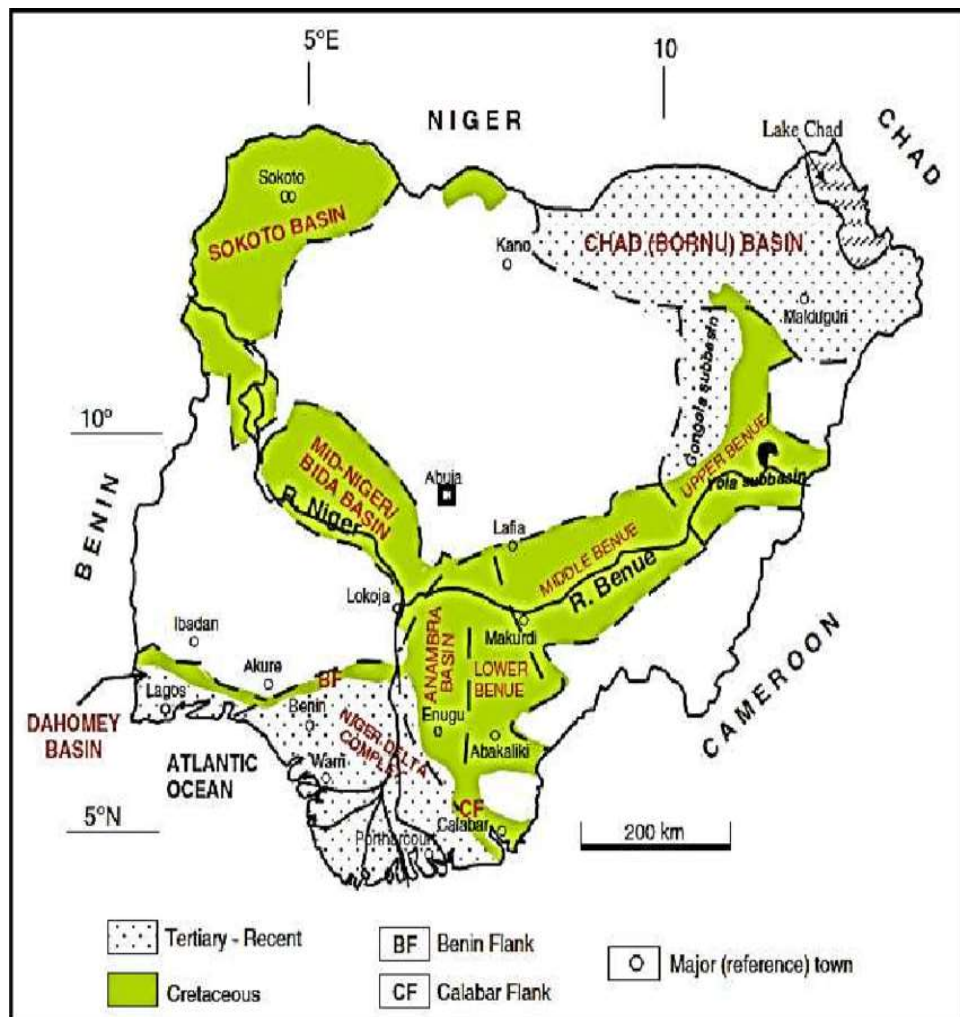


Figure 2.2: Sedimentary Basins of Nigeria (Obaje, 2009)

No concrete line of subdivision can be drawn to demarcate the individual portions, but major localities (towns/settlements) that constitute the depocentres of the different portions have been well documented (Petters, 1982; Nwajide, 1990; Idowu and Ekweozor, 1993; Obaje *et al.*, 1999). The depocentres of the Lower Benue Trough comprise mainly the areas around Nkalagu and Abakaliki, while those of the Anambra Basin centre around Enugu, Awka and Okigwe. The Middle Benue Trough comprises

the areas from Makurdi through Yandev, Lafia, Obi, Jangwa to Wukari. In the Upper Benue Trough, the depocenters comprise Pindiga, Gombe, Nafada, Ashaka (in the Gongola Arm) and Bambam, Tula, Jessu, Lakun, and Numan in the Yola Arm.

### **2.2.1 The Middle Benue Trough**

In the Middle Benue Trough, around the Obi/Lafia area, six Upper Cretaceous formations comprise the stratigraphic succession (Figure 2.3). This succession is made up of Albian *Arufu*, *Uomba* and *Gboko Formations*, generally referred to as the *Asu River Group* (Offodile, 1976; Nwajide, 1990). These are overlain by the Cenomanian–Turonian *Keana* and *Awe Formations* and the Cenomanian–Turonian *Ezeaku Formation*. The Ezeaku Formation is coterminous with the *Konshisha River Group* and the *Wadata Limestone* in the Makurdi area. The Late Turonian – Early Santonian coal-bearing *Awgu Formation* lies conformably on the Ezeaku Formation. In the Makurdi area, the Makurdi Sandstone interfingers with the Awgu Formation. The mid-Santonian was a period of folding throughout the Benue Trough. The post-folding Campano-Maastrichtian *Lafia Formation* ended the sedimentation in the Middle Benue Trough, after which widespread volcanic activities took over in the Tertiary.

The Asu River Group outcrops mainly in the Keana anticline east of Keana town and south of Azara; and in the area around Gboko with a typical section in the Quarry of the Benue Cement Company near Yandev. The lithologic composition of the Asu River Group comprises limestones, shales, micaceous siltstones, mudstones and clays (Offodile, 1976; Obaje, 1994). The average thickness is estimated to be about 1,800m.

The Awe Formation was deposited as passage (transitional) beds during the Late Albian Early Cenomanism regression. Its typical sections occur around the town of Awe, where Offodile (1976) estimated the thickness to be about 100 m. The Formation consists of

flaggy, whitish, medium to coarse grained calcareous sandstones, carbonaceous shales and clays. The Keana Formation resulted from the Cenomanian regression which deposited fluviodeltaic sediments. The formation consists of cross-bedded, coarse grained feldspathic sandstones, occasional conglomerates, and bands of shales and limestones towards the top. Massive outcrops occur at Keana, Noku, Chikinye, Jangerigeri, Azara, and Daudu.

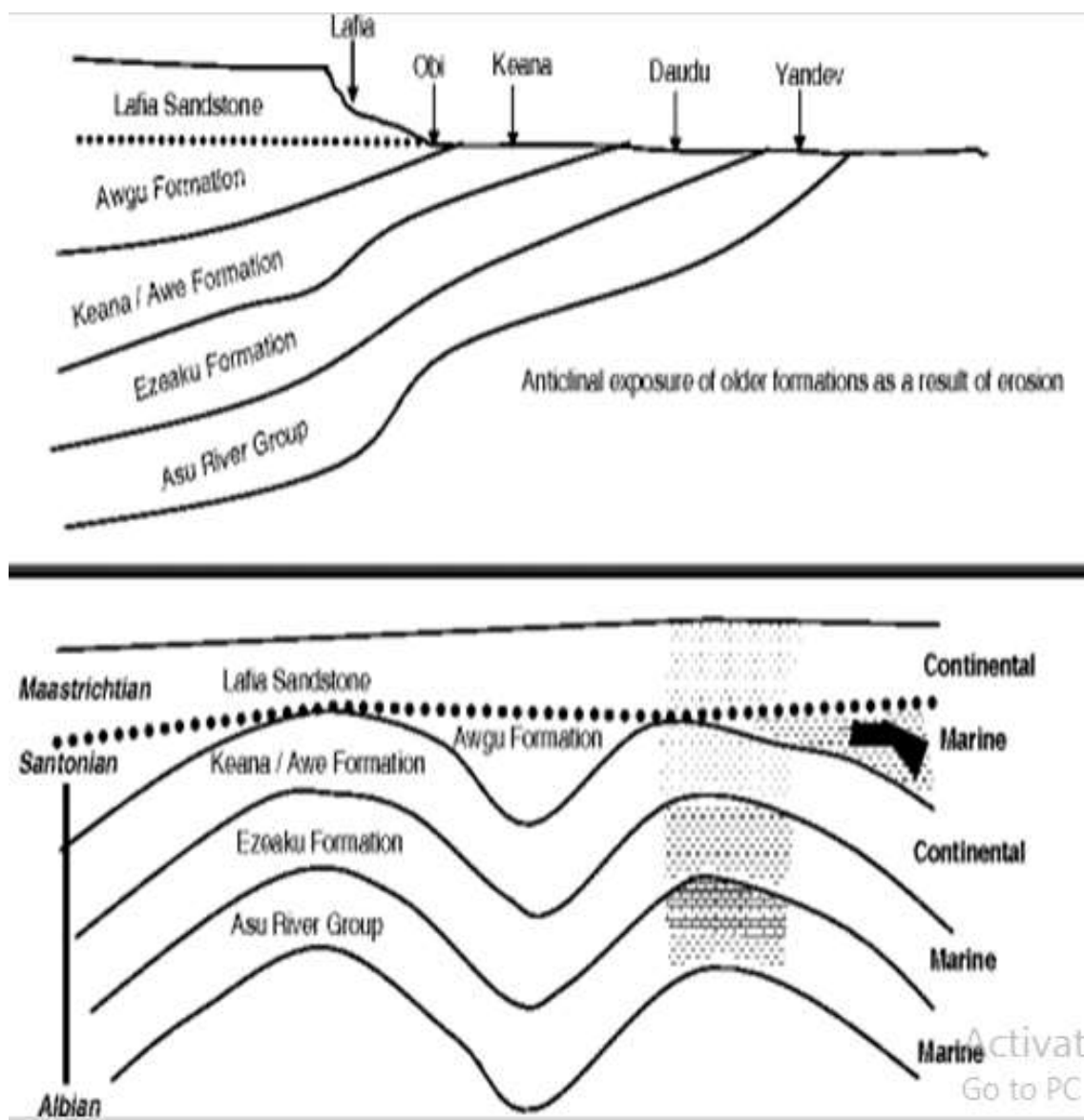


Figure 2.3: Stratigraphic successions in the Middle Benue Trough (Obaje, 2009)

The deposition of the Ezeaku Formation is attributed to the beginning of marine transgression in the Late Cenomanian. The sediments are made up mainly of calcareous shales, micaceous fine to medium friable sandstones and beds of limestones which are in places shelly. The deposition took place in a presumably shallow marine coastal environment. Outcrops of the Ezeaku Formation include those at Ortesh, about 4 km east of the village of Jangerigeri, where the sediments are composed mainly of shelly limestones (almost entirely of oyster shell). In the bank of River Tokura, about 20 km east of Keana town, on the Chikinye–Awe road, a typical section of the Ezeaku Formation occurs, consisting mainly of intercalations of shelly limestones and black shales, with brownish fine to coarse grained feldspartic sandstones at the top. The deposition of the Awgu Formation marks the end of marine sedimentation in this part of the Benue Trough. The formation is made up of bluish-grey to dark-black carbonaceous shales, calcareous shales, shaley limestones, limestones, sandstones, siltstones, and coal seams. The major outcrop of the coal-bearing Awgu Formation is at the bank of River Dep in Shankodi, 7 km to the west of the village of Jangwa. Along the bank of this river, the coal seams can be traced laterally for about 500 m. The borehole cores of the Steel Raw Materials Exploration Agency (formerly National Steel Council) stock-piled at the Obi camp contain coal seams and coal bands at various depths within the Awgu Formation. The occurrences of low diversity arenaceous foraminifera in the Awgu Formation indicate deposition in marshy, deltaic and shallow marine conditions (Obaje, 1994 and 2005).

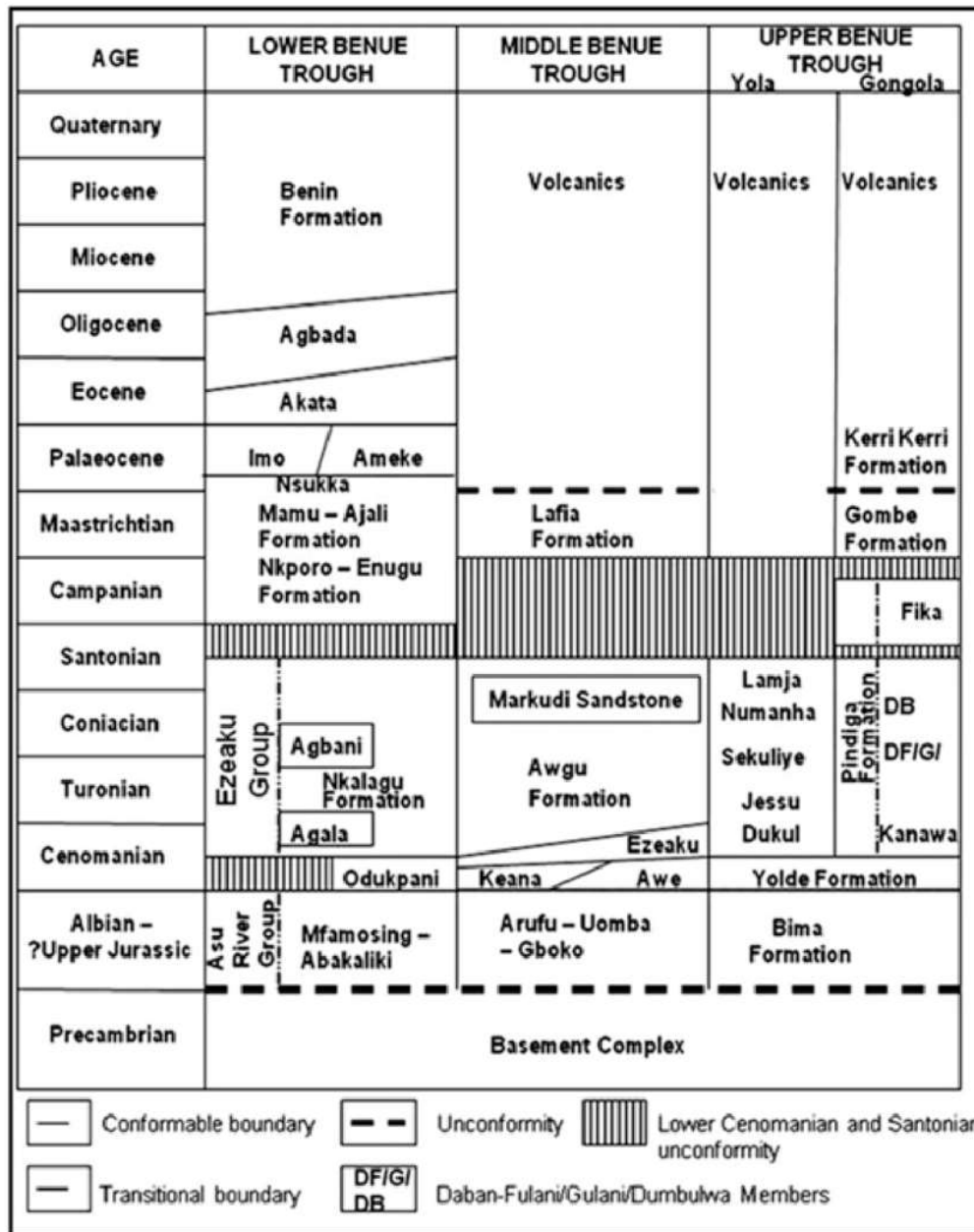


Figure 2.4: Stratigraphic of Lafia Formation (Obaje *et al.*, 2004 and Obaje, 2005)

The Lafia Formation is the youngest formation in this area. The formation was deposited under continental condition (fluvatile) in the Maastrichtian and lies unconformably on the Awgu Formation. It is lithologically characterized by ferruginized sandstones, red, loose sands, flaggy mudstones, clays and claystones. Outcrops and sections of the Lafia Formation occur in and around the town of Lafia, and along the bank of River Amba on the Lafia–Doma road

## **2.3 Hydrogeology of the Benue Trough**

The important sections of the Benue Trough for the occurrence of groundwater are within the following formations (Offodile, 2002).

1. Interbedded sandstones of the Awe Formation
2. The sandstones of the Makurdi and Ezeaku Formation
3. Sandstones of the Awgu Formation
4. Basal sandstones of the Lafia Formation

### **2.3.1 Interbedded Beds of the Awe Formation**

The Asu River Group, the oldest known sedimentary group of formations in Nigeria is essentially an aquitard or aquiclude and underlain the Awe Formation. Despite the problematic hydrogeological characteristics of this group of formations, water may occur in limited quantities within the fissured and fractured shales siltstones and fine grained sandstones. The overlying Awe Formation comprises flaggy whitish, medium to coarse, sometimes calcareous sandstones, with interbedded shales thin Limestone and clays from which brines issue. Towards the base the sandstones become finer grained and successively more micaceous. The outcrops underlie most areas of Awe, Zurak, Ribi and Parts of Makurdi. The sandstone beds usually multi-layered appear highly porous and water yielding. However, the water from these aquiferous beds are contaminated by the brines from the interbedded shales. The shales also confine the aquifers and present artesian to subartesian situations.

A few boreholes drilled into this formation have produced good water yields, though often not potable due to the brine contamination. A borehole (Electrical log) from one of the boreholes, and geochemical characteristics of the borehole water sample from the region areas suggest that in order to obtain potable water from the aquifers of the Awe



Formation it is necessary to case off the saline horizons. The exercise implies that the depth ranges of the saline layers should be identified through accurate logging techniques and the boreholes appropriately designed. The hydrogeology of Awe area is described below as a case study.

### **2.3.2 Sandstones of the Makurdi/Keana and Ezeaku Formation**

The Makurdi Formation, like the Bima, comprises highly indurated sandstones, through diachronous, they are thought, in parts, to be laterally equivalent to each other. The Makurdi Formation, like the Bima, comprises highly indurated sandstones, which are almost impermeable in places. Where well fractured or where less indurated, however, the formation, usually less compact, more permeable and has better prospects as an aquifer. In the Middle Benue area the Makurdi/Keana and Ezeaku Formations appear most important as aquifers. Nearer the core of the Keana anticline, the sandstones are hard and much less permeable than in the synclinal areas. In the upper parts of the Middle Benue the equivalent is the Keana sandstone which is more compact and highly cemented than the Makurdi sandstone. Like the Makurdi sandstone its usefulness as a potential ground water reservoir depends on its secondary permeability derived also from weathering and fracturing.

### **2.3.3 The Sandstones of the Awgu Formation**

The Awgu Formation in this area consists of grey bedded shales with occasional sandstone beds and limestones. The sandstone beds are usually fine to coarse. Where coarse, they are very permeable and water bearing. But if is often limited in thickness and lateral extent, hence reducing the ground water potential. The lenticular sandy aquifers are confined by the overlying clay beds, and recharge is therefore restricted by the clay shale aquicludes.

When the rocks are fractured or faulted the aquifers are interconnected and recharge into them increases considerably. Most boreholes drilled into the Agwu Formation area were for coal exploration purposes. These are restricted to the Obi-Agwantashi and Lafia areas. Hence no indication of yields or pumping test data can be cited. However one 10cm diameter borehole in Assakio, north of Lafia, encountered artesian water at about 150m and free flowed at 900 lit/hr. (0.3 lits/sec), with a head of 1.5m above ground level. It was expected that the yield would improve when pumped (Offodile, 1992).

#### **2.3.4 The Basal Sandstones of the Lafia Formation**

This Formation overlies the Awgu Formation and comprises essentially sandstones. The sandstone beds are generally brownish at the top, to whitish at depth. It is fine to coarse-grained, friable and feldspathic. It ranges in thickness from about 10m to 150m in Lafia area, and much thicker towards the southwest of the town (Offodile, 2002). The whole formation appears to thin out from the south-west to the north-east, forming a wedge against the older formations. Towards the northeastern edge of the outcrop area, for example Dedere area, the Lafia Sandstone only thinly covers the underlying Awgu Formation. A borehole in this area passes through only a thin cover of the Lafia Formation into highly argillaceous black clayey and shaly highly impermeable non water bearing top section of the Awgu Formation. The basal sands of the Lafia Formation, is highly permeable and gives rise to several springs at its contact with the less permeable underlying Awgu Formation.

#### **2.3.5 Aquifer of the Lafia Formation**

The aquifer of the Lafia Formation is a fresh water sedimentary sequence of Maastrichtian age (youngest), containing much groundwater. It covers areas at the western part Lafia including: Tudun Kauri, Agyaragun Tofa, Bukan Buzu, Bukan

Fadama, Agyragu Station, Gwadenye, Tudun Kwashini, Wakwa, Gandu, Mararaba Akunza, Bukan Kwato and Akunza.

The Lafia Formation is highly permeable and gives rise to several springs (or marshy areas) called Fadama at its contact with the less permeable underlying Awgu Formation. At the Fadama area, irrigation farming is the major practice all year round. It extends to its contact with the Awgu Formation at about 2 km to Daddare town. The thickness of the sandstone aquifer is established to be 150 m (Offodile, 2002).

## **2.4 Review of Related Work**

### **2.4.1 Geochemistry of rocks and groundwater in the Middle Benue Trough**

Tijani and Loehnert (2004) studied the “Evolution of saline waters and brines in the Benue Trough, Nigeria”. The work outlined the hydrochemical characteristics of saline groundwaters and brines in the Cretaceous Benue Trough of Nigeria with emphasis on their genetic source and hydrochemical evolution. The result revealed that hydrogen ion exponent (pH) values range from 5.1-7. He concluded that the saline waters are of marine origin/source generally localized in terms of area coverage. One widely addressed issue is on quality assessment for drinking, domestic, agricultural and industrial uses in some cities. Ocheri *et al.* (2010) reviewed status of the quality of groundwater in urban areas of Nigeria, the current status, trend and identification of factors influencing the quality of urban groundwater and possible remedial measures in Nigeria. Studies have shown that Nigeria urban groundwater quality is influenced by the geology and geochemistry of the environment, rate of urbanization, industrialization, landfill/dumpsite leachates, heavy metals, bacteriological pollution, and effect of seasons (Olorunfemi, 1990; Edet and Okereke, 1997; Jatau *et al.*, 2008; Yerima *et al.*, 2008, Yaya and Ahmed, 2010). Remedial measures suggested include protection of water sources, proper handling of wastes and construction of sanitary landfills, control

of all land use polluting activities, and treatment of water before is used for consumption. Continuous monitoring of groundwater quality is necessary to forestall any unpleasant consequences. Other works in literature were on the interaction of groundwater with the host rock in Anambra State, parts of Lower Benue Trough, (Ezeigbo, 1987; Amadi *et al.*, 1989; Abimbola *et al.*, 2002a; Olobaniyi and Owoyemi, 2006; Edet and Ekpo, 2008; Nganje *et al.*, 2010; Amadi *et al.*, 2010). Impact of human activities received some attention on the groundwater situation in Nigeria. Most of the impacts were due to poor sanitation and agricultural practices, petroleum related activities and mining. Examples of these studies as documented in literature are nitrates in shallow aquifers of Sokoto and acid mine drainage pollution in Enugu. Others are on impact of waste dumps on groundwater quality in Orita-Ibadan, Oramiriukwa River Basin-Owerri, Minna, Benin and Lagos (Uma, 1993; Ezeigbo and Ezeanyim, 2006; Abimbola *et al.*, 2002b; Tijani *et al.*, 2002; Ibe and Sowa, 2002; Chukwu, 2008; Yerima *et al.*, 2008; Omo-Irabor *et al.*, 2008; Edet, 2009; Omofonmwan and Esegbe, 2009). Saline groundwater problem has also been given prominent attention in Cross River Basin and Niger Delta (Uma *et al.*, 1990; Uma, 1997; Awalla and Ezeigbo, 2002; Frank-Briggs, 2005; Edet, 2009; Amadi *et al.*, 2010; Edet and Okereke, 2001a, b; Edet *et al.*, 2011).

**Heavy Metals** Heavy metals are individual metals and metal compounds that can impact human health. Common heavy metals of toxic effects are arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver. They are naturally occurring substances which are often present in the environment at low level but augmented by anthropogenic activities. Generally, humans are exposed to these metals by ingestion (drinking and eating) or inhalation (breathing) (Martin and Griswold, 2009). These metals may come from natural sources, leached from rocks and soils according to their

geochemical mobility or come from anthropogenic sources, as a result of human land occupation and industrial operation. The increase in industrial activities has intensified environmental pollution problems and the deterioration of several aquatic ecosystems with the accumulation of metals in biota and flora. These trace metals are dangerous because they tend to bioaccumulate resulting in heavy metal poisoning (Abolude *et al.*, 2009). Because of the harmful effect of heavy metal in drinking water researches have been carried in these areas. Oyeku and Eludoyin (2010) assessed heavy metal pollution of groundwater resources in Ojota area of Lagos metropolis, noted that hand dug wells and boreholes near Olusosun landfill were contaminated with heavy metals. The uncontrolled disposal of lead and batteries, spent petroleum products probably caused the relatively high level of lead, copper and iron in groundwater. The spatial and seasonal variations in the concentration level suggest point sources pollution. In a related study, Yaya and Ahmed (2010) found high concentration of heavy metals in water sources of Abuja FCT, Nigeria .Arsenic, lead, iron and zinc concentrations were particularly noted to be high in both surface and groundwater sources. At Ibadan metropolis, Laniyan *et al.* (2010) in a geochemical investigation note quartzite rocks to have the highest arsenic concentration. They concluded that water sources in Ibadan are prone to arsenic contamination from both leaching of weathered bedrock and indiscriminate discharge of wastes and industrial effluent. Trace metals in surface and subsurface area of Kaduna south industrial area was examined by (Jatau *et al.*, 2008). Of the parameters studied, vanadium, chromium, iron, cobalt, nickel, gallium, arsenic, selenium, lead, strontium, zirconium, and Molybdenum accounting for 73.68% of the well have concentrations above the WHO guide limit for drinking water. Nwankwoala *et al.* (2011) investigated heavy metal pollution of groundwater of Yenegoa town, and found the concentrations of iron, manganese, nickel, chromium, lead, arsenic, cadmium,

mercury and copper to be above the WHO allowable limit for drinking water. They attributed this to industrial discharges and subsurface injection of chemicals being an oil producing area. Mile *et al.* (2013) assessed heavy metal pollution in groundwater sources of Makurdi and sub-urban, noted high concentrations of chromium, cadmium, iron and copper above the WHO prescribed limit for drinking water. They attributed this to soil mineralogy, use of chemical fertilizers and agro-chemicals and other land uses. Of the heavy metal studied, lead because of its abundance due to industrial activity and its toxicity have been suspected in water sources. Sridhar *et al.* (1998) pioneered a study on lead contamination levels in indoor and outdoor environment of the populous city of Lagos and Ibadan. Lead pollution level in surface and groundwater beside soils, dust and foods were investigated. The results of analyses of lead level in various water sources indicate that majority of the waters showed lead level above the WHO prescribed limit. Water from low density areas in Ibadan recorded relatively higher lead levels. However, the groundwater from high areas in both cities showed significantly higher lead levels. Musa *et al.* (2004) determined lead level in wells and boreholes in Zaria City and found that 91% of the wells sampled had lead concentrations above the WHO permissible limit for drinking water. Higher lead level was noted in well near motor mechanic and industrial areas of the city. Iron level at objectionable proportion in boreholes across various formation of Benin town was noted (Ohaji and Akujieze, 1989). The source of iron in these boreholes according to them could be traced to geology of the ferrugised formation, drilling method, size of submersible pumps and quality of pipes used in the distribution.

Season is believed to influence the concentration level of the physico-chemical and bacteriological loading in water sources. Agbaire and Oyibo (2009) investigated seasonal variability of physico-chemical elements in boreholes in Abraka town. The

result show total dissolved solids were lower in the dry season. Ocheri *et al.* (2010) assessed seasonal variation in nitrate level in Makurdi metropolis and found 80% of the wells had nitrate concentrations above the WHO allowable limit for drinking water for wet season. Other parameters whose concentrations were higher in the wet season are pH, turbidity, electrical conductivity, chloride, iron, calcium, chromium, biochemical oxygen demand and faecal coliform bacteria. Nwafor *et al.* (2013) analyzed the seasonal influence on the physico-chemical concentrations in hand dug wells in Akure town noted, of the parameters studied, pH, total dissolved solids, total alkalinity, potassium, iron, sulphate have higher concentrations in the wet season.

A number of groundwater quality studies have been carried out in Nigeria, though generally on local basis with few numbers of chemical constituents. BGS (2003) noted that the shallow aquifers are vulnerable to pollution from domestic, agricultural and industrial waste. Oil spillages are known to have some impact on groundwater a good example being the recent report on the environmental assessment of Ogoni land (UNEP, 2011). Natural water quality problem have also been noted especially, in relation to dissolution of evaporate minerals in the Benue Basin (Ekwere and Ukpong, 1994; Uma, 1998; Tijani, 2008). Over exploitation of coastal aquifers, tidal influences and shallow wells in the coastal parts of Nigeria has led to problems with saline intrusion. This is noted around Lagos, Ondo, Delta, Bayelsa, Rivers, Akwa Ibom and Cross Rivers States. Problems of acid mine drainage have also been reported in some areas especially, the coal mining areas in Enugu (Nganje, 2010, 2011). .

## **CHAPTER THREE**

### **3.0 MATERIALS AND METHODS**

#### **3.1 Research Design**

The method followed for this research process was based on the objectives formulated in the aim and objectives of this project. The methodology designed for this research consists of following phases:

- i. Preliminary Studies includes desktop studies, reconnaissance survey and review of available literature as well as maps related to the study area.
- ii. Fieldwork includes field mapping, collection of water samples and soil samples from designated points at the study area.
- iii. Laboratory analysis of the samples obtained from designated points at the study area.
- iv. Data analysis that involves qualitative and quantitative analysis that includes statistical tests, hydrochemical reliability checks carried out on the acquired data to obtain useable and useful information used in the interpretation and report writing.

#### **3.2 Preliminary Studies**

Preliminary studies involved desktop studies, reconnaissance survey, and review of the available literature as well as maps related to Lafia and environs. The various sources of groundwater in Lafia and environs were also observed and examined.

#### **3.3 Geological Field Mapping and Sampling**

These involve field reconnaissance and geological mapping of Lafia its environs which reveals the various rock types and structural elements. This was done with the aid of a base map of the area on a scale of 1:40,000 derived from the topographic map of part of



North Central Nigeria on the Federal Survey of Nigeria (FSN), Lafia sheet 231 NW. An open traverse method of surveying with the help of Global Positioning System (GPS) devices was used to take coordinates and elevation readings which were subsequently carefully located on the base map of the area. Visual identification of outcrops with detailed description and readings of its associated structural features such as joints, veins, strike, faults and folds were taken with a compass-clinometers while on the field. The colour, mineral assemblages, texture and size of various outcrops were likewise noted.

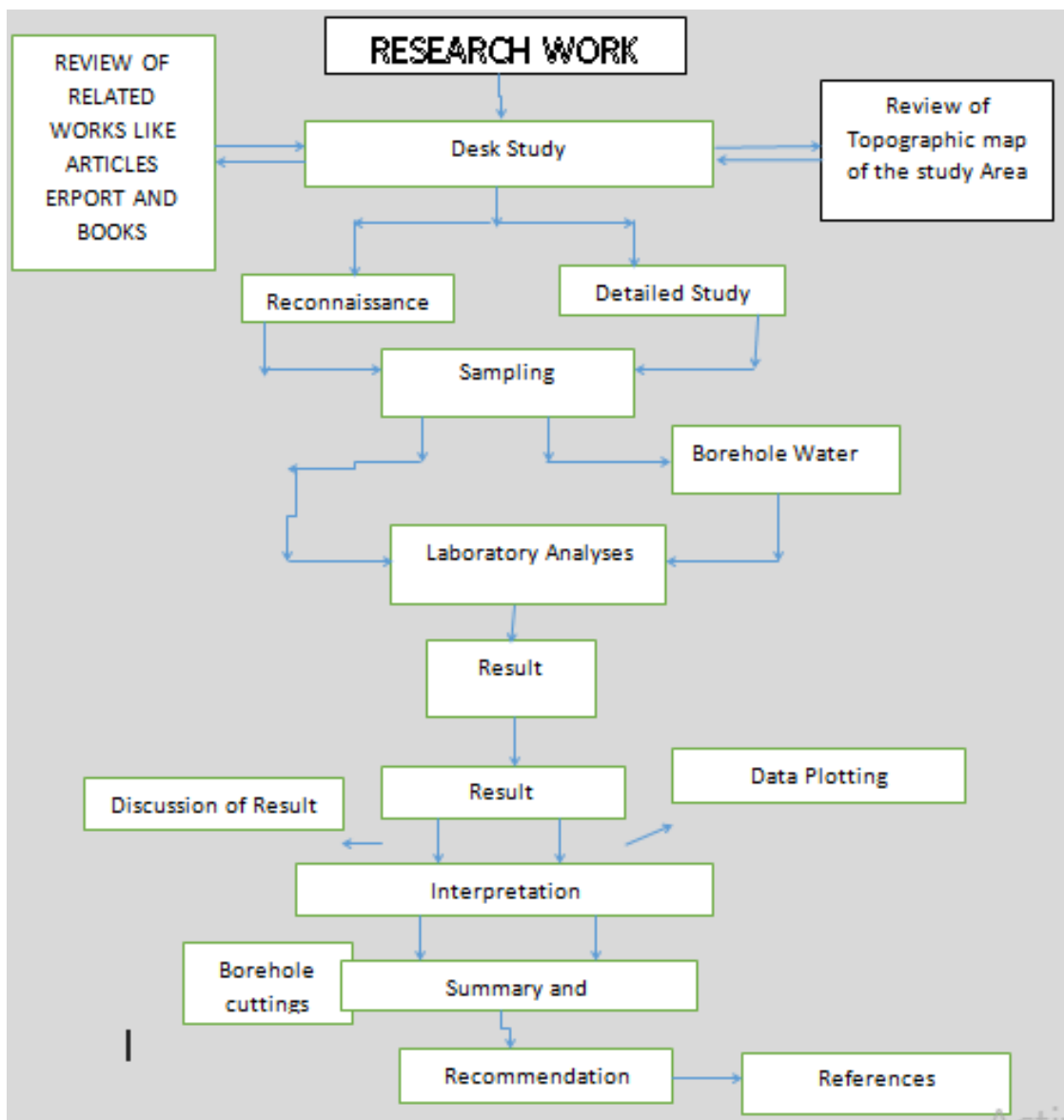


Figure 3.1: Research design

### **3.4 Water Sample Collection**

Groundwater sources in Lafia and its environs are hand dug wells, boreholes and rivers. 15 water samples from Boreholes and one surface water sample were collected in one litre plastic bottles and these bottles were rinsed twice with the water at the sampling point before they were then labeled with paper tapes to avoid mix-up. Water samples were collected and kept inside a cooler filled with ice blocks so as to stabilize the samples before sending them to the laboratory for analysis of major cations, anions, major oxides and trace elements.

Certain precautions were taken to ensure that the water did not change significantly between the time samples were collected and analysis. These were

- i. The sample bottle was cleaned, sterilized and rinsed out before collecting the sample.
- ii. The top of the sterile container was not removed until the sample was ready for collection and the container was held at the bottom to avoid contamination by hands during sampling.
- iii. After sampling the stopper was placed and the outside of the bottle was dried.
- iv. The sample was kept cool and protected from direct sunlight between the time the samples were collected and examined in the laboratory.
- v. The samples were analysed in the laboratory soon after collection.
- vi. The samples were properly packaged to avoid contamination by the handling of the sample during collection and transportation to the laboratory.
- vii. Quality assurance measures for major cations and anions were done using an ionic balance.



Plate I: Collection of water sample at River Amba  
(N8° 29' 21.48."N, E8° 30' 15.09"E)

### 3.5 Laboratory Analysis

Physical and chemical analyses of fifteen (15) water samples were done at the Faculty of Science Central Laboratory, Usmanu Danfodiyo University, Sokoto. Major ions concentration was determined using photometry and titrimetry at the Faculty of Science Central Laboratory, Usmanu Danfodiyo University, Sokoto. Heavy metal concentration would be determined using Microwave Plasma- Atomic Emission Spectroscopy (MP-AES) at the Centre for Dry Agriculture, Bayero University Kano. (Fe, Hg, Se, Zn, Pb, As, Cd, Cr, Mn, and Zn) using standard water analysis techniques.

The physical parameters of water evaluated were temperature, turbidity, colour, pH, electrical conductivity and total dissolved solids (TDS). The following were measured chemical parameters: potassium, calcium, magnesium, sodium, sulphate, chloride, bicarbones, carbonate, nitrate, nitrite, fluoride, phosphate, iron, copper, manganese, zinc, chromium, arsenic, nickel and silica.

**a) Determination of turbidity**

Turbidity was estimated with turbidity meter which utilizes Nephelometric strategy for investigation. To utilize turbidity meter Switch on the turbidity meter by squeezing “On/Off” key. Embed recently arranged alignment principles of 800 NTU and press “Read”. Evacuate the principal alignment standard of 800 NTU and embed the second adjustment gauges of 200 NTU, at that point squeeze “Read”. Also evacuate the second and the third adjustment standard of 100NTU; at that point squeeze “Read”. Fill the example cell to the check and after that embed test holder at the point squeeze “Read/Enter” key. The turbidity meter will shine unsteadily as it shows the turbidity value. Go over same strides for all the samples.



Plate II: Soil Samples preparation for laboratory analysis

**b) Determination of pH**

pH was estimated with a pH meter which uses electrometric method of analysis. The pH meter defensive top was expelled, and after that the pH meter was exchanged on the pH meter test or cathode was inundated into the pH meter cushions 7 answer for adjustment. To maintain a strategic distance from debasement, the pH meter was washed in distilled water. The pH meter was then inundated into the water test and mixed with pH meter test delicately as we held up till the show on the pH meter was

balanced out. After examining is balanced out, the pH value was recorded. To limit pollution after each test, the pH meter terminal or test was rinsed in distilled water.



Plate III: Collection of water sample and physical Parameters in situ measurement at Emir Palace Lafia (E8°29'24.0."N, E8°30'30.45.3"E)

### c) **Determination of electrical conductivity and temperature**

Electrical Conductivity and temperature was estimated with multipurpose meter (Multi 3420) demonstrate which utilize electrometric technique for examinations. To quantify conductivity and temperature, the mechanical assembly test was connected to the unit. Adjustment of the multipurpose meter was finished by the producer detail for the gear. The show was changes in accordance with read in °C and S/cm for temperature and electrical; conductivity individually.

### 3.6 **Data Analysis (Quantitative and Qualitative)**

The data were processed using software like rockworks, aquachem, surfer; arc GIS, Microsoft word, Microsoft excel and statistical package for social science (SPSS) were used for graphical and statistical presentation of the results. Major ions compositions in

groundwater are presented in different types of graphical form such as bar chart, pie chart, Stiff diagram, scattered diagram, Durov plot, Schoeller diagram and Piper diagram. Statistical methods were used to obtain the mean, minimum maximum principal component analysis (PCA) and Pearson correlation of major ions.

### 3.6.1 Hydrochemical reliability

Physicochemical results of groundwater samples from the laboratory analysis were checked to ascertain their accuracy using cation-anion balance. It recommends that a solution must be electrically neutral as the sum of major cation ( $Mg^{2+}$ ,  $Ca^{2+}$ ,  $Na^+$  and  $K^+$ ) in meq/L must be equal to sum of major anion ( $CO_3^{2-}$ ,  $HCO_3^-$ ,  $Cl^-$  and  $SO_4^{2-}$  in meq/L when

Computed (Hounslow, 1995)

$$\text{Cation – anion balance} = \left[ \frac{\sum \text{Cations} - \text{anions}}{\sum \text{Cations} + \text{anions}} \right] * 100 \dots \dots \dots (3.1)$$

Hounslow (1995) recommends cation-anion balance is below  $\pm 5\%$  as the analysis is assumed to be good while values above  $\pm 5\%$  is assumed to be poor some constituents are missing or not included in the calculation or the water is acidic. However about  $\pm 10\%$  is acceptable in dilute and saline water due to errors during measurement (Fetter, 2001).

### 3.6.2 Groundwater suitability for drinking purposes

Groundwater suitability is measure by comparing the derived values of parameters directly with World Health Organization (WHO, 2011) and Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) desirable and permitted limits.

### **3.6.3: Hydrochemical facies characterization**

#### **i. Scholler diagram**

Schoeller (1965) proposed the use of semi logarithmic graph paper to plot the concentration of anions and cations. The concentrations are plotted in milliequivalent per litre, Schoeller diagram permits visual comparison of the composition of different water. Major cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$   $\text{K}^+$ ) and major anions ( $\text{CO}_3^{2-}$  +  $\text{HCO}_3^-$  Cr,  $\text{SO}_4^{2-}$ ) are plotted on six equally spaced logarithmic scales in the arrangement as the points plotted are joined by straight line Schoeller diagram shows not only the absolute value of each ion but also the concentration differences among various groundwater analyses. Because of the logarithmic scale, a straight line joining the points A and B of two ions in a water sample is parallel to another straight line joining the point A and B of the same ions in a water sample is parallel to another straight line joining the point A and B of two ions in a water sample is parallel to another straight line joining the point A and B of the same ions in another water sample the ratio of the ions in both analyses is equal.

#### **ii. Piper Diagram**

Piper diagram helps in understanding geochemical evolution of groundwater (Piper, 1944). Aquachem software version was used to plot piper diagram. Piper diagram is a multifaceted plot wherein milliequivalents percentage concentration of major cation like  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$  and  $\text{K}^+$  as well as anions like  $\text{HCO}_3^-$   $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  plotted into two triangular fields, which were then projected further into the central diamond field.

#### **iii. Durov plot**

Durov plot is another method of data presentation is that aid understanding of geochemical evolution of groundwater (Durov, 1948). Durov plot has advantage over piper diagram as it indicates some possible geochemical processes that affects water

genesis. The diagram is based on percentage major ion in milliequivalents per litre values but the cation and anion together total 100 per cent. The cation and anion values plotted in the appropriate triangle and projected into the square main field.

#### **3.6.4 Multivariate statistical analysis**

Statistical methods was used to compute arithmetic mean of 31 physicochemical parameters (temperature, Ph, EC, TDS, TH,  $\text{Ca}^{2+}$ ,  $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ , CT, F,  $\text{N}_3$ ,  $\text{NO}_2$ ,  $\text{PO}_4^{3-}$ , TA, Fe, Cu, Cr, Mn,  $\text{SiO}_2$ , Zn, TS, DO, As, Ni, Colour, TSS and Turbidity) of 15 groundwater samples. They indicate significant interactions in the hydrochemical conditions of water in location where they are found in addition, strength of linear relationship among chemical variables was also evaluated through calculation using multivariate among chemical variables was also evaluated through calculation using multivariate statistical analysis like Pearson's coefficient of correlation and principal component analysis (PCA).

##### **i. Principal component analysis (PCA)**

Principal component analysis (PCA) which is analytic instrument was used to identify geochemical drifts in groundwater was additionally used to decrease the dimensionality of the informational collection and also to locate an intricate framework designs. To decrease the dimensionality of informational index varimatrix symmetrical rotation with Kaiser Standardization was connected to the Central part investment keeping mind the end goal to limit the impact of non-ordinary information (Al-Sulaiman, 2012). Principal component Analysis extracts the Eigen value and eigenvectors from the covariance matrix of original variables (Amadi *et al.*, 2012). In order to get a clear picture of principal component analysis Eigen values greater than 1 was retained.



**ii. Pearson correlation**

Pearson correlation coefficient is commonly used to measure and establish the strength of a linear relationship between two variables or two sets of data. It is a simplified statistical tool used to analyse the degree of dependency of one variable to other (Belkhiri *et al.*, 2010). The person correlation coefficient (rxy) is computed by using the formula as given (Jothivenkatachalam *et al.*, 2010):

$$R = \frac{(n \sum x_i y_i) - (\sum x_i)(\sum y_i)}{\sqrt{[n \sum x_i^2 - (\sum x_i)^2][n \sum y_i^2 - (\sum y_i)^2]}} \dots\dots\dots (3.2)$$

Where, x (x = value of x variable) and y (y = value of x variable) represents two different water quality parameters. N = number of data points.

The inter dependence of different water quality parameters on each other was evaluated on the basis of rxy from equation (3.2). The correlation coefficient is always between -1 and +1. A correlation closer to  $\pm 1$  implies that the association is closer to a perfect linear relation. Interpretation of the Pearson correlation coefficients, adopted in the present study are: r=-1 tp -0.7 (strong negative association); r =  $\pm 0.7$  to +1.0 (strong positive association); r=-0.7 to -0.3 (weak negative associated); r = +0.3 to +0.7 (weak positive association) r = -0.3 to +0.3 (negligible or no association). Thus, for the water for water quality parameters, the possible correlations between every pair were computed using SPSS Statistical software and arranged into a correlation matrix. Precisely, a correlation matrix is a table of all possible correlation coefficients between a set of variables.

**3.6.5 Mechanism and processes controlling groundwater chemistry**

**i. Glibbs plots**

Gibbs plots (1970) which is based on ratios of  $(Na^+ + K^+) / (Na^+ + K^+ + Ca^{2+})$  for cations an  $Cl^- / (HCO_3^-)$  for anions against TDS was used to analysed the mechanism controlling

the groundwater chemistry of Lafia and environs whether it is weathering of rocks or evaporation or crystallization.

**ii. Stoichiometric or concentration ratios**

Concentration ratios are also very helpful when interpreting groundwater analyses in terms of hydrogeochemical processes (Domenico, 1972). Table 3.1 lists species ratios that are of general use together with the information that these ratios may provide. Note that these rules are based on many groundwater quality studies; however, there are extreme environments that do not behave according to these general insights. Molar ratios or equivalent concentration ratios are often more convenient than weight concentration ratios to identify hydrochemical ratios. To be able to accept or reject hypotheses about the ongoing processes, the information derived from the ratios needs to be combined.

Table 3.1 concentration ratios and their meaning in terms of process (Paliwal, 1972)

<b>Ratio</b>	<b>Application</b>
SO <sub>4</sub> /Cl	Seawater has a typical weight ratio of 0.14. When both constituents originate from seawater smaller ratios suggest SO <sub>4</sub> and/or additional process such as dissolution of gypsum or oxidation of pyrite.
Na/Cl	The seawater weight ratio is 0.55. Higher values imply Na-desorption during freshening, if paleohydrological studies have revealed that marine water was once present higher ratios can also be indicative of silicate weathering.
Mg/Cl	The seawater weight ratio is 0.071. Deviations from this value together with deviations for Na/Cl suggest that there has been cation-exchange for the appropriate Hydrogeological Environment. Silicate weathering also gives rise to high ratios.
Na/HCO <sub>3</sub>	If seawater/fresh water displacements can be excluded, high ratios indicate substantial weathering of Na-feldspar or other

	Na-Silicates.
Ca/HCO <sub>3</sub>	To identify calcium carbonate dissolution (Check with saturation index with respect to calcite and other calcium carbonates) or calcium silicate weathering.
Ca/SO <sub>4</sub>	To identify gypsum dissolution.
Ca/Mg	To identify dissolution or precipitation of dolomite, calcite etc. (check with saturation index with respect to dolomite calcite, etc.). Deviations from the seawater ratio occur in coastal regions due to cation-exchange, albeit combined with carbonate reactions.
(Ca+Mg)/(Na+K)	To identify aquifer lithology: importance of carbonate reactions versus silicate weathering.
Fe/SO <sub>4</sub>	To identify oxidation of iron sulphide.
HCO <sub>3</sub> /sum anions	To distinguish between weathering reactions and input of dissolved species from the surface in the recharge area.

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### iii. Source rock deduction

Source-rock method helps to gain insight into the possible origin of water. The initial composition of groundwater originates from rainfall, which may be diluted and altered during its return to the ocean by weathering evaporation (Gibb's, 1970). During weathering Ca<sup>+</sup> Mg, SO<sub>4</sub><sup>2-</sup>, HCO<sub>3</sub> and SiO<sub>2</sub> are added to the water. The amount of each is dependent on the mineralogy. The plots of (Ca<sup>+</sup> + Mg) versus HCO<sub>3</sub>, Na/Cl versus EC, and Na versus Cl were used to describe hydrogeochemical variation and evolution. The Gibbs (1970) diagram, and indices explained by Hounslow (1995) and Srinivasamoorthy (2014) were used to deduce the source rocks. They are as follows:

- i. Plagioclase weathering index =  $(Na^+ + K^+ - Cl^-) / (Na^+ + K^+ - Cl^- + Ca^{2+})$
- ii. Sodium/Chloride index =  $Na^+ / (Na^+ + Cl^-)$ ; TDS dependence
- iii. Rock weathering/evaporation =  $Cl^- / \sum anions$ ; TDS must be considered
- iv. Rock weathering/evaporation =  $Cl^- / \sum anions$ ; TDS must be considered
- v. Gypsum dissolution, brine/carbonate or silicate weathering  $HCO_3^- / \sum anions$  ;

#### iv. Chloro alkaline indices

Chloro alkaline indices analyse the ionic exchange between groundwater and their host environment during residence or travel time (Schoeller, 1965).

Chloro alkaline indices such as CAI 1 and CAI 2 were estimated using equations below (Schoeller, 1965):

$$\text{CAI 1} = \frac{\text{Cl}^- - (\text{Na}^+ + \text{K}^+)}{\text{Cl}^-} \dots\dots\dots (3.3)$$

$$\text{CAI 2} = \frac{\text{Cl}^- - (\text{Na}^+ + \text{K}^+)}{\text{HCO}_3^- + \text{SO}_4^{2-} + \text{CO}_3^{2-} + \text{NO}_3^-} \dots\dots\dots (3.4)$$

Negative Schoeller indices means exchange of  $\text{Ca}^{2+}$  or  $\text{Mg}^{2+}$  in groundwater  $\text{Na}^+$  or  $\text{K}^+$  will be released into the groundwater. In addition, negative value indicates Chloro alkaline disequilibrium also known as cation-anion exchange reaction. During this process, the host rocks are the primary sources of dissolved solids in the water. On the other hand, if positive values indicate that inverse reaction possibly occurs thus Base Exchange reaction.

#### 3.6.6 Irrigation parameters indices

Irrigation parameters for example, sodium absorption ratio (SAR), Kelly's ratio (KR), percent sodium (%Na), Magnesium absorption ratio (MAR), residual sodium carbonate (RSC), and permeability index (PI) were basic parameters used to decide the appropriate usage of groundwater for horticultural reason in Kafin Koro and its environs. Plants and soils are physically and artificially influenced by intemperate centralizations of broke down particles in water system water as they bring down the osmotic weight in plant auxiliary cells (Thorne and Peterse, 1954). This lessens agrarian efficiency as it keeps water from getting to the branches and take off.

Total dissolved solids and electrical conductivity were both used to decide the reasonableness of groundwater for rural reason. Add up to dissolved solids ought to be beneath 500 mg/l while the electrical conductivity ought to be underneath 1,000 uS/cm (WHO, 2011) and (NSDWQ, 2007).

Sodium absorption ratio (SAR) is a critical parameter for deciding the reasonableness of groundwater for water system since it is measure of antacid/sodium risk to crops (Al-Zarah, 2008). Soil penetrability is decrease by exorbitant sodium content in respect to the calcium and magnesium as it addresses the supply of water required for crops. The overabundance sodium or restricted calcium and magnesium are assessed by SAR which is communicated as:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \dots\dots\dots (3.5)$$

**United States Salinity Laboratory (USSL) diagram**

The United States salinity laboratory (USSL) has constructed a diagram for the classification of irrigation water (Wilcox, 1955) describing 16 classes with reference to SAR as index for sodium hazard and EC as an index for salinity hazard. Sodium and salinity hazards are two important parameters, which can indicate the suitability of water for irrigation uses.

To classify the groundwater suitability irrigation, Wilcox (1955) constructed a diagram using sodium content as sodium percentage and electrical conductivity. A Wilcox plot can be used quickly determines the viability of water for irrigation purposes. The Wilcox plot is a simple scatter of plot of sodium percentage on the Y axis Versus Electrical conductivity on the X axis.

**i. Percent sodium (%Na) or soluble sodium percent (SSP)**

Sodium percent is a basic parameter in organizing water framework water in view of the reason that sodium reacts with soil to decrease its permeability (Janardhana, 2007). Sodium content is normally conveyed as far as per penny sodium or dissolvable sodium rate portrayed as:

$$\%Na = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100 \dots\dots\dots (3.6)$$

**ii. Residual sodium carbonate (RSC)**

Carbonate ions ( $HCO_3^- + CO_3^{2-}$ ) have a great effect on water quality due to the precipitation of alkaline earths ( $Ca^{2+} + Mg^{2+}$ ), in this way expanding the structure of  $Na^+$  as this is the situation when the convergence of carbonates is in abundance of the centralization of antacid earths (Eaton, 1950). The excess carbonates will join with  $Na^+$  to outline  $NaHCO_3$ , as sodium centre argumentations get settled in the soil in this way decreasing the earth vulnerability which impacts the earth structure. This methodology is suggested as the Residual Sodium Carbonate (RSC). The association between carbonates centre and acid neutralizer earth obsession can be used to elucidate the fittingness of water for water framework as RSC is enlisted by subtracting the measure of essential earth the measure of carbonates as:

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \dots\dots\dots (3.7)$$

**iii. Magnesium hazard ratio (MAR) or magnesium hazard (MH)**

Szaboles and Darab (1964) have proposed a magnesium hazard for assessing the suitability of water quality for irrigation. (Paliwal, 1972) introduced a ratio called index of magnesium hazard which was used to determine suitability of groundwater for agricultural purpose. Generally,  $Ca^{2+}$  and  $Mg^{2+}$  maintain a state of equilibrium in water by they do not behave equally in the soil system as Magnesium damages soil structure,

when water contains more Na<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, HCO<sub>3</sub> and Cl substance of soil and subsequently influenced by long haul utilization of water system water, with high salt substance (Paliwal, 1972)s. the PI is a proportion of the blend of Na<sup>+</sup> and the square base of HCO<sub>3</sub> particles fixation to mix of Ca<sup>2+</sup>, Mg<sup>2+</sup>, and of Na<sup>+</sup> particles focus which is duplicated by 100 as takes after (Paliwal, 1972).

$$PI = \left[ \frac{Na + \sqrt{HCO_3}}{Ca^{2+} + Mg^{2+} + Na} \right] * 100 \dots \dots \dots (3.9)$$

#### IX. Kelly's ratio

The Kelly's ratio demonstrative of the great nature of water for water system though over one is suggestive of inadmissibility for farming reason because of soluble base dangers (Karanth 1987). Kelly's Ratio was figure by –utilizing the accompanying articulation

$$KR = \frac{Na}{Ca^{2+} + Mg^{2+}} \dots \dots \dots (3.10)$$

## CHAPTER FOUR

### 4.0 RESULTS AND DISCUSSION

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

#### 4.1 Geology of the Study Area

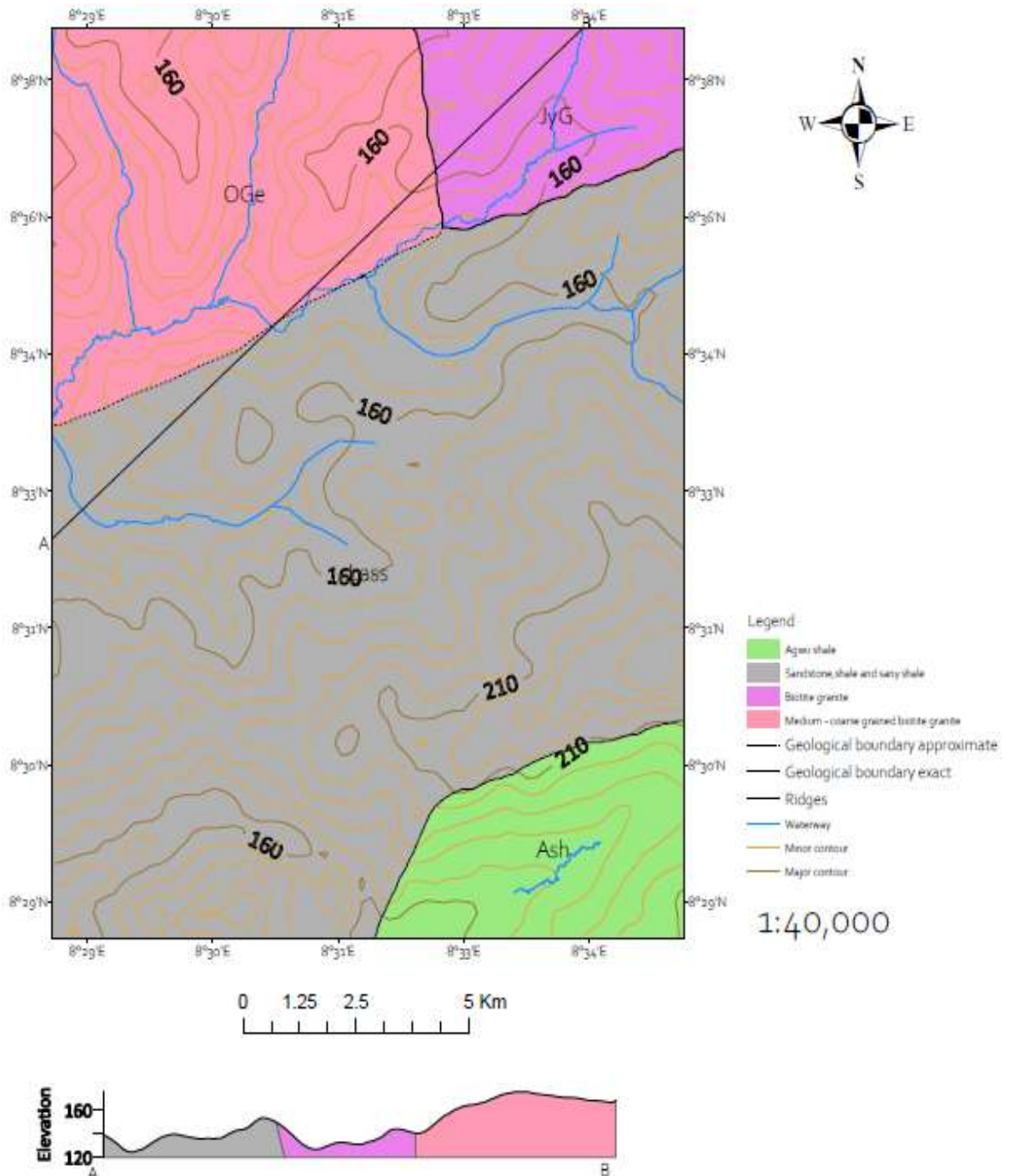


Figure 4.1: Geological map and cross section of Lafia and its environs, the Study Area is underlain by the Agwu and Lafia Formation



#### **4.1.1 Agwu Formations**

The Agwu Formation consists of grey bedded shale, sandstones beds, limestone and contains coal seams/beds sandstones beds, brownish at top in some places with thick lateritic cover. It indicates deposition in marshy, deltaic and shallow marine conditions.

#### **4.1.2 Lafia Formation.**

The formation overlies the Awgu Formation, deposited under continental condition (fluvial) and comprises essentially of sandstones beds, brownish at top in some places with thick lateritic cover, and sandstones whitish downward, coarse grained friable and feldspathic.

### **4.2 Hydrogeochemistry**

Fifteen groundwater samples and borehole cuttings from sixteen drilling sites within Lafia environs were obtained. The data of the physio-chemical parameters (electrical conductivity EC, and Total Dissolved Solid TDS) obtained from the water samples across the survey area are as shown in Table 4.2. The spatial distribution of EC in the area shows high values around Novel water, FULafia central Admin. Block and River Amba all the samples falls within the permissible standards of (WHO, 2011 and NSDWQ, 2015). The spatial distribution of TDS across the area shows similar trend with that of the EC and are also within WHO and NSDWQ acceptable limit for drinking water. The pH distribution across the area shows slight acidity except for River Amba which falls below WHO and NSDWQ acceptable or recommended limit for drinking water. The temperatures are all within the ambient conditions.

The heavy metals concentration (Fe, Mn, Zn, Cu and Pb) data obtained from the geochemical analysis of the groundwater samples is presented in Figures 4.2-4.6. Six (6) out of the fifteen (15) samples of groundwater had Fe concentration above the

(WHO,2011) permissible limit (Figure 4.2), the concentration of Pb was above the WHO standard in 5 of the collected samples(Figure 4.6) while the concentration of Mn was above WHO standard in 2 of the collected samples (Figure 4.3). The concentration of Zn and Cu are however within (WHO, 2011) permissible limit (Figures 4.4-4.5).

#### **4.2.1 Contamination Factor (CF) and Contamination Degree (CD)**

The average contamination factor of the heavy metals are presented in Figure 4.7, the CF for Fe ranged from 0.3 to 20.2 with an average value of with an average value of 3.25 while that of Pb ranged from 1 to 9 with an average value of 1.8. The result suggests that there is significant contamination of Pb and Fe in the groundwater of the study area. The enrichment of these metals may be attributed to both geogenic and anthropogenic activities. The Fe is most likely geogenic from the ironstones of the Lafia Formation while the Pb is most likely anthropogenic possibly from domestic waste disposal going on in the area. The contamination factor (CF) intensity of the analyzed heavy metals decreased in the following order Fe>Pb>Mn> Cu>Ni>Cd.

The result of the Contamination Degree (CD) reveals that GW9 is the most contaminated with a CD value of 21.82 while GW12 is the least contaminated with a CD value of 1.28.The major contaminants that contributed to the high contamination of degree observed in some of the ground water sample are Fe and Pb.

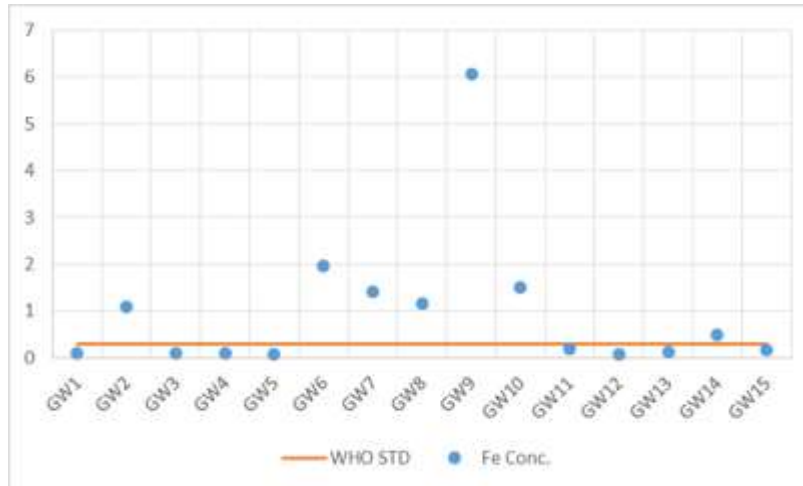


Figure 4.2 Concentration of Fe in groundwater of the study area, compared with WHO standard for drinking water

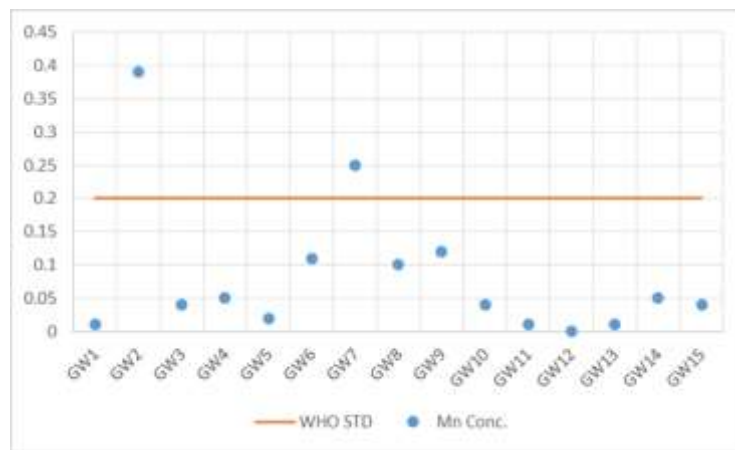


Figure 4.3 Concentration of Mn in groundwater of the study area, compared with WHO standard for drinking water

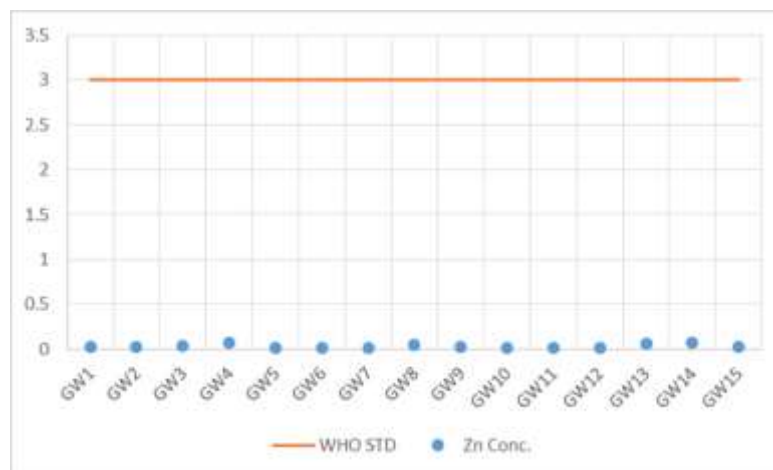


Figure 4.4 Concentration of Zn in groundwater of the study area, compared with WHO standard for drinking water

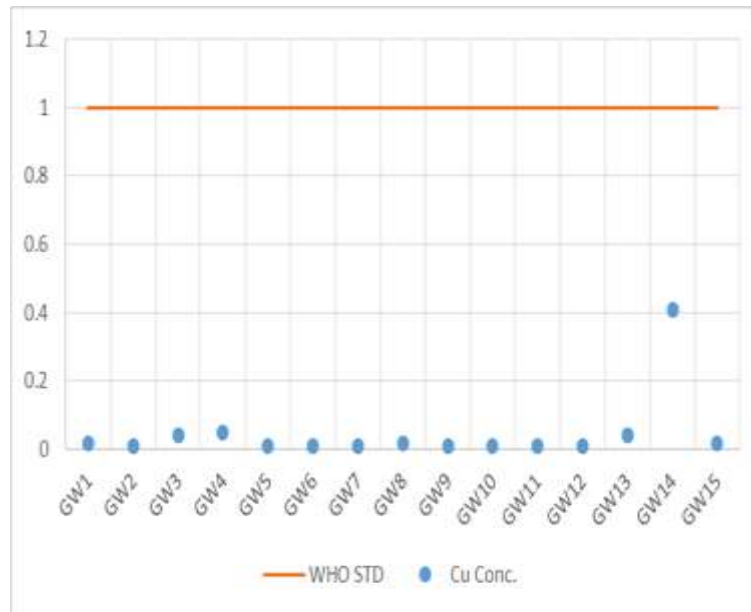


Figure 4.5 Concentration of Cu in groundwater of the study area, compared with WHO standard for drinking water

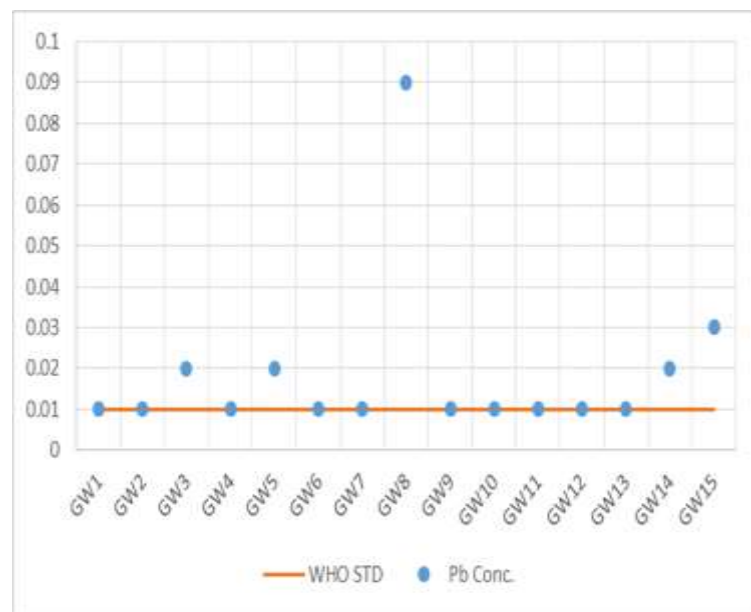


Figure 4.6 Concentration of Pb in groundwater of the study area, compared with WHO standard for drinking water.

Table 4.1: Contamination Factor and Contamination Degree

ID	CF	CF	CF	CF	CF	CF	CF	CF	CF	CD
	FE	MN	ZN	CU	CR	CD	PB	NI	CO	
<b>GW1</b>	0.3333	0.05	0.01	0.02	0	3.33	1	0	0	4.75
<b>GW2</b>	3.6333	1.95	0.01	0.01	0	0	1	0	0	6.60
<b>GW3</b>	0.3333	0.2	0.0133	0.04	0	0	2	0.5	0	3.09
<b>GW4</b>	0.3	0.25	0.0233	0.05	0	0	1	0	0	1.62
<b>GW5</b>	0.2333	0.1	0.0067	0.01	0	0	2	0	0	2.35
<b>GW6</b>	6.5667	0.55	0.0067	0.01	0	0	1	0	0	8.13
<b>GW7</b>	4.6667	1.25	0.0067	0.01	0	0	1	0	0	6.93
<b>GW8</b>	3.8667	0.5	0.0167	0.02	0	0	9	0	0	13.40
<b>GW9</b>	20.2	0.6	0.01	0.01	0	0	1	0	0	21.82
<b>GW10</b>	5	0.2	0.0033	0.01	0	0	1	0	0	6.21
<b>GW11</b>	0.6333	0.05	0.0067	0.01	0	0	1	0	0	1.70
<b>GW12</b>	0.2667	0	0.0067	0.01	0	0	1	0	0	1.28
<b>GW13</b>	0.4333	0.05	0.02	0.04	0	0	1	0	0	1.54
<b>GW14</b>	1.6	0.25	0.0253	0.41	0	0	2	0.5	0	4.79
<b>GW15</b>	0.6	0.2	0.01	0.02	0	0	3	0	0	3.83

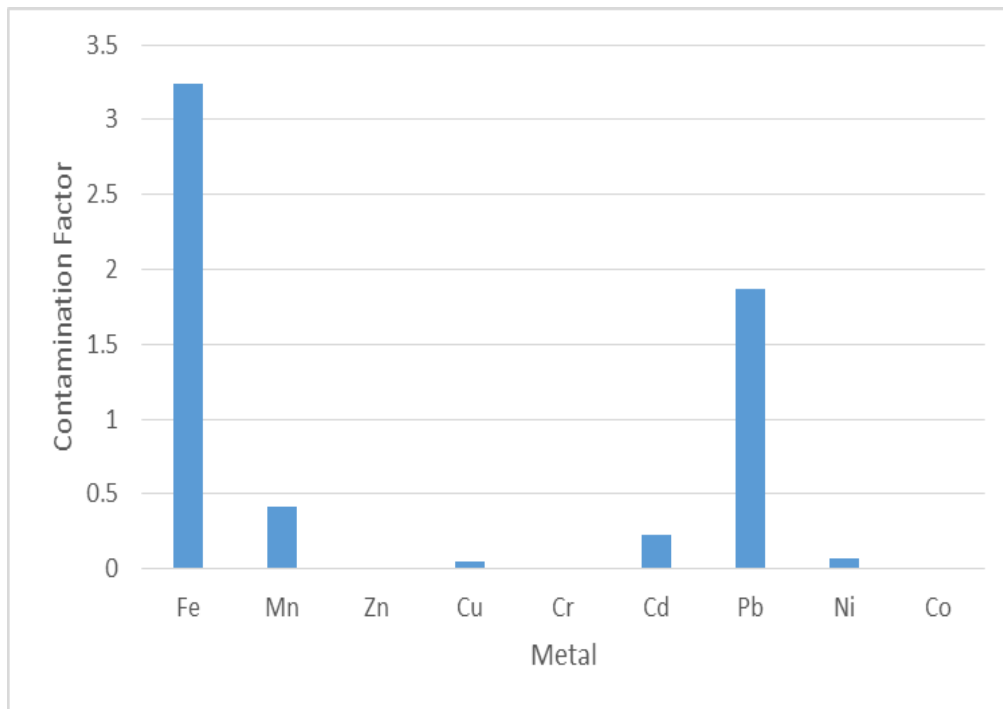


Figure 4.7: Average Contamination Factor of metals

### **4.3 Irrigation Suitability of Groundwater in the Study Area**

Alongside physical parameters such as pH, Electrical Conductivity (EC) and Total Dissolved Solids TDS, the measured concentration of major ions in the ground and surface water in the study area was analyzed using irrigation water quality indices such as Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR), Kelly Ratio (KR), Residual Sodium Carbonate (RSC), Soluble Sodium Percentage (SSP), Total Hardness (TH) and Permeability Index (PI).

The result of the irrigation water quality indices is as presented below;

#### **4.3.1 pH**

The pH of the groundwater samples collected ranged from 4.7 to 6.8 Ayers and Westcot (1985) categorized irrigation water as either Acidic (pH<7), Neutral (pH=7) or Alkaline (pH>7). They however agreed that a pH range of 6.5 to 8.4 (slightly acidic to moderately alkaline) is suitable for irrigation purposes. Based on that, the pH of sampled groundwater in the study area was categorized as generally unsuitable for irrigation.

#### **4.3.2 Total dissolved solids (TDS)**

The value of TDS obtained from the sampled groundwater ranged from 0.01mg/l to 0.26mg/l Ayers and Westcot (1985) suggested that a TDS of below 450mg/l is most suitable for irrigation, based on that submission the all of the collected groundwater samples have TDS values that is suitable for irrigation purpose.

#### **4.3.3 Electrical conductivity (EC)**

The EC values obtained from water samples obtained in the study area varied from 0.02  $\mu\text{s/cm}$  to 0.54  $\mu\text{s/cm}$  for groundwater. According to Ayers and Westcot (1985) EC value

above 700  $\mu\text{s}/\text{cm}$  is considered unsuitable for irrigation water. Thus all of the sampled groundwater has EC value that is suitable for irrigation.

#### **4.3.4 Total hardness (TH)**

The mean total hardness of groundwater water samples in the study area is 16.34mg/l, while that of surface water is 36.14 mg/l. According to Swistock *et al.* (2013), the ideal water TH required for irrigation purpose ranges between 50mg/l to 150mg/l, thus any water with hardness below 50mg/l or above 150mg/l is considered unsuitable for irrigation. Based on that, all of the groundwater and surface water samples have a TH value that is unsuitable for irrigation.

#### **4.3.5 Sodium adsorption ratio (SAR)**

The calculated SAR values ranged from (0.18 to 0.32) meq/l for groundwater. Ayers and Westcot (1995) suggested that an SAR value above 3 might be unsuitable for irrigation. The groundwater samples in the study area have SAR values far below 3, thus suitable for irrigation.

#### **4.3.6 Magnesium adsorption ratio (MAR)**

The calculated MAR values ranged from (47.68 to 71.88) % for groundwater and. Water with MAR value of less than 50% is considered suitable for irrigation. All but one of the sampled ground water has MAR values exceeding 50% and is thus categorized as unsuitable for irrigation.

#### **4.3.7 Permeability index (PI)**

The calculated permeability index ranged from (2.53 to 3.91%) for groundwater samples. It is generally accepted that a permeability index of less than 60% is suitable for irrigation. All groundwater samples in the study area have PI values below sixty percent and are thus suitable for irrigation. Doneen diagram after Doneen (1987),

provides a bivariate analysis for quality of irrigation water quality using PI and the total concentration of ions in mill equivalent per liter. Three classes of irrigation water quality are identified by the Doneen diagram. Class I and II are suitable for irrigation while Class III is considered unsuitable. All of the water samples from the study area plotted under Class II.

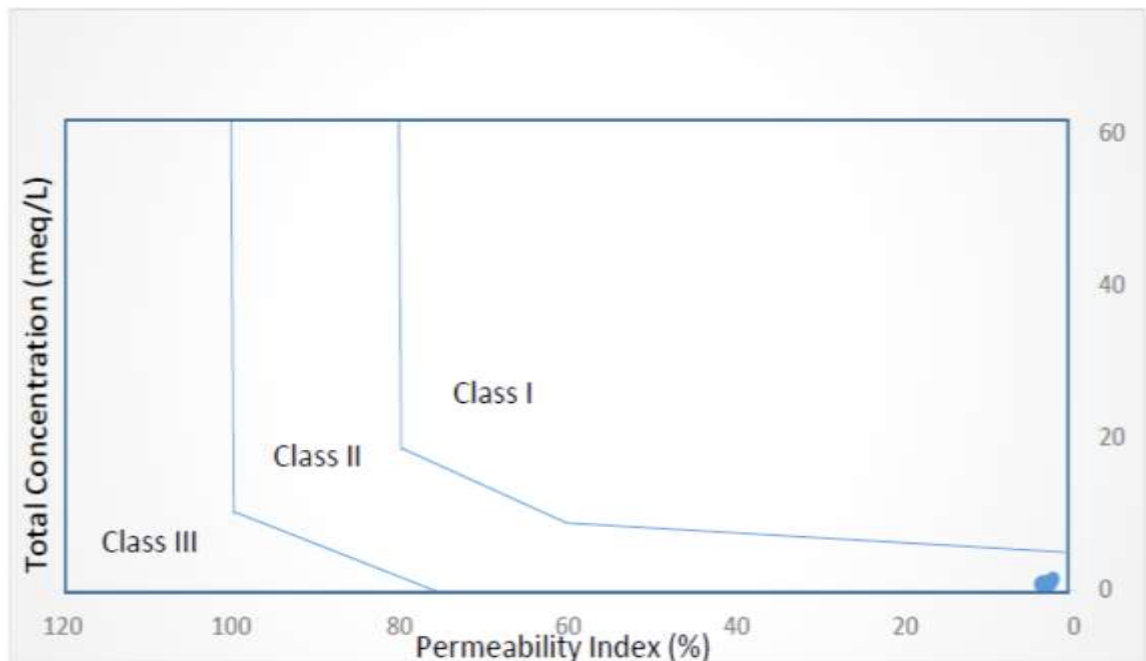


Figure 4.8: Suitability of water samples based on permeability index

#### 4.3.8 Residual sodium carbonate (RSC)

Calculated RSC values varied from (-0.68 to -0.30) meq/l for groundwater, RSC value greater than 2.5meq/l is considered unsuitable for irrigation. The groundwater samples in the study area have RSC values significantly lower than 2.5meq/l thus the samples were categorized as suitable for irrigation purposes.

#### 4.3.9 Soluble sodium percentage

Calculated SSP values ranged from (26.31 to 48.66) % for groundwater. Irrigation water with SSP value above 60% is considered unsuitable for irrigation. All of groundwater



samples obtained from the study area have SSP value below 60% thus the groundwater samples can be considered suitable for irrigation based on SSP.

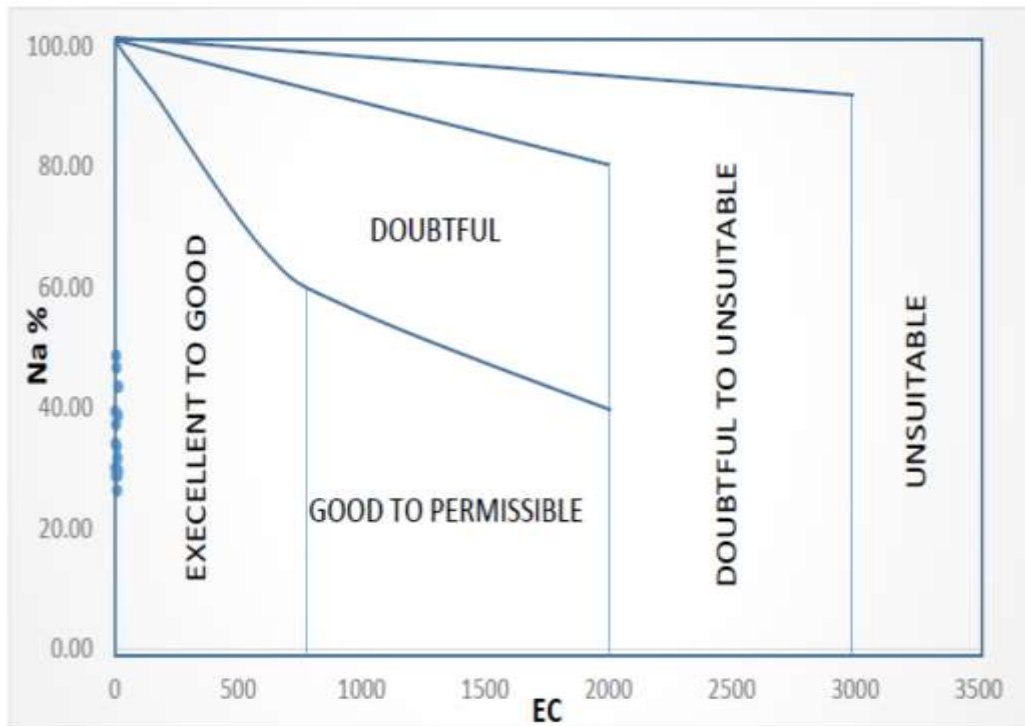


Figure 4.9: Wilcox plot showing irrigation water quality

#### 4.3.10 Kelly ratio (KR)

Calculated KR values ranged from (0.18 to 0.40) meq/l for groundwater. According Kelly (1963), KR value greater than 1 is considered unsuitable for irrigation. Both ground and surface water samples have KR values below 1 thus they are categorized as suitable for irrigation.

#### 4.4 Hydrogeochemical Facie Characterization of Groundwater

The Piper trilinear plot are a combination of anion and cation triangles that lie on a common baseline diamond shape between them; can be used to make tentative conclusion as to the origin of the water represented in the study and to distinguish different water types. (Figure 4.10) is basically used for classification of water in two ways; that is Water type and Hydrochemical facies in which the water belongs. All of

the water samples plotted on the E portion of the piper diagram corresponding to the **Earth Alkaline water with prevailing SO<sub>4</sub> and Cl**. On the Piper hydrochemical facies plot, all the samples fall in **field I** corresponding to the **Ca<sup>2+</sup>-Mg<sup>2+</sup>-Cl-SO<sub>4</sub><sup>2-</sup>** hydrochemicalfacies.

Table 4.2: Irrigation water quality

<b>ID</b>	<b>SAR</b>	<b>MAR</b>	<b>PI</b>	<b>RSC</b>	<b>SSP</b>	<b>KR</b>	<b>TH</b>	<b>PH</b>	<b>EC</b>	<b>TDS</b>
<b>GW1</b>	0.19	68.32	3.00	-0.39	39.39	0.21	20.48	5.1	0.02	0.01
<b>GW2</b>	0.22	75.15	2.53	-0.68	29.99	0.18	36.14	6.8	0.45	0.22
<b>GW3</b>	0.19	71.21	3.77	-0.38	34.07	0.21	20.80	4.5	0.23	0.11
<b>GW4</b>	0.18	75.51	3.80	-0.43	28.78	0.19	23.43	4.7	0.17	0.09
<b>GW5</b>	0.19	69.16	3.57	-0.38	37.29	0.22	20.23	4.7	0.18	0.09
<b>GW6</b>	0.32	75.56	3.72	-0.30	48.66	0.40	16.34	5.7	0.12	0.06
<b>GW7</b>	0.20	47.68	3.91	-0.33	46.69	0.24	18.12	4.9	0.16	0.08
<b>GW8</b>	0.20	70.58	3.71	-0.35	33.67	0.23	18.66	5.3	0.20	0.10
<b>GW9</b>	0.18	77.15	3.31	-0.43	26.31	0.19	22.93	6.0	0.48	0.24
<b>GW10</b>	0.21	71.88	3.37	-0.34	31.58	0.25	17.75	4.8	0.07	0.04
<b>GW11</b>	0.28	66.43	3.04	-0.42	31.73	0.29	22.30	5.0	0.02	0.01
<b>GW12</b>	0.18	75.51	3.25	-0.44	28.78	0.19	23.43	4.7	0.10	0.05
<b>GW13</b>	0.21	63.17	3.89	-0.31	38.83	0.26	16.94	4.8	0.30	0.15
<b>GW14</b>	0.26	68.57	2.81	-0.47	29.64	0.27	24.61	4.7	0.37	0.18
<b>GW15</b>	0.28	70.12	3.36	-0.40	43.57	0.30	21.71	6.1	0.54	0.26

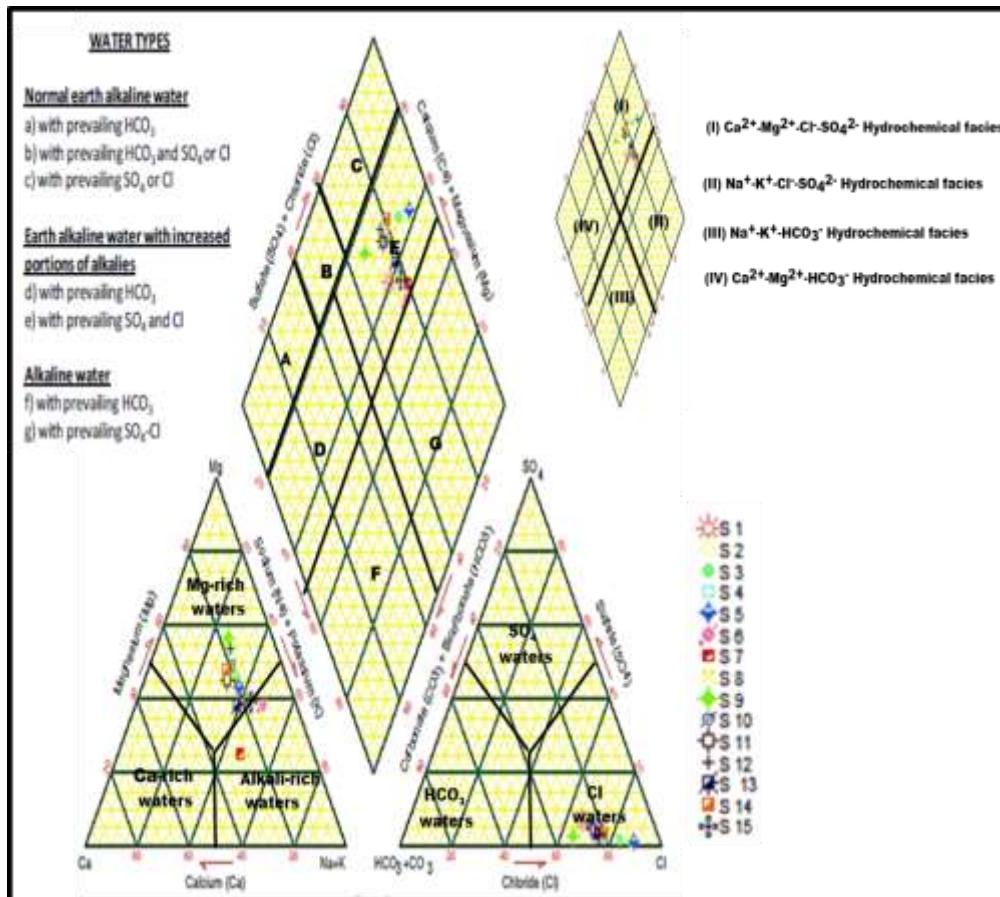


Figure 4.10: Piper trilinear diagram for the study area

Durov plot (Figure 4.11) which was used to understand possible geochemical processes which must have occurred over time and influenced the chemical concentration/composition of the groundwater in the study area by interpreting the center triangle of the plot (Figure 4.11). The plots show that majority of the samples plots in “Field 4” indicating  $\text{SO}_4$  S dominants, or anion discriminant and Ca dominant, which suggest mixed water or water exhibiting simple dissolution, therefore it may be possible that there was a recent recharge in the samples involved, this is well affirms the result/interpretation indicated by Piper plot. A sample plot in “Field 5” implies there is a no dominant anion or cation hence, the groundwater in the sample or study area is exhibiting simple dissolution or mixing (going by the Durov’s classification in Table

4.3). The hydrochemical process responsible for the water chemistry from the Durov plot is simple dissolution or mixing.

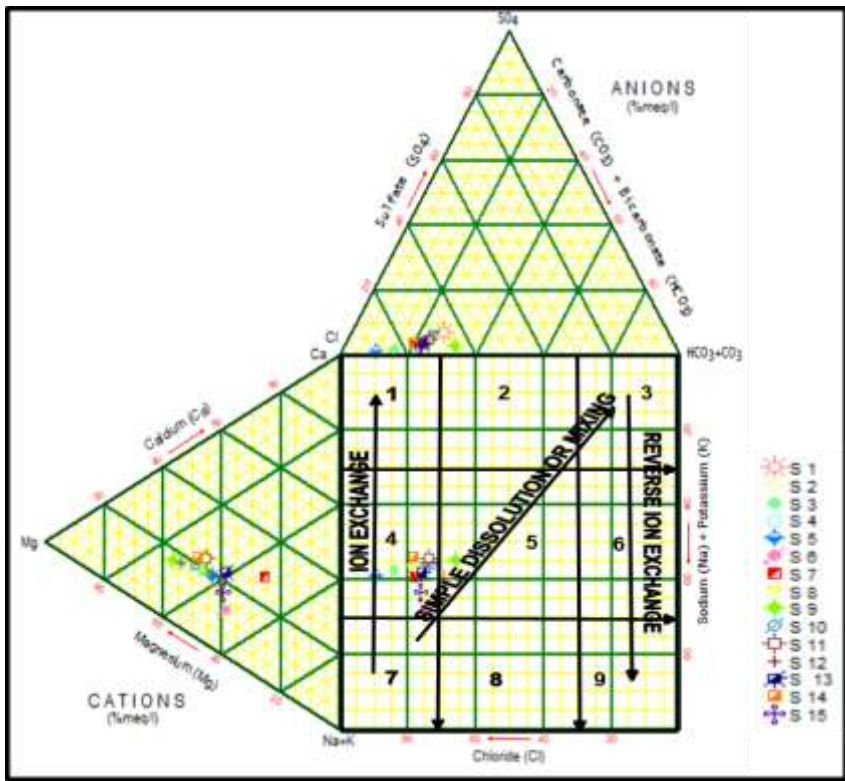


Figure 4.11: Durov plots of groundwater samples of the study area

Table 4.3 Classification of water based on Durov diagram (Lloyd and Heathcoat, 1985)

FIELD NO	WATER TYPES AND RESPECTIVE INTERPRETATION
1	HCO <sub>3</sub> and Ca dominant, frequently indicates recharging waters in limestone, sandstone, and many other aquifers
2	This water type is dominated by Ca and HCO <sub>3</sub> ions. Association with dolomite is presumed if Mg is significant. However, those samples in which Na is significant, an important ion exchange is presumed
3	HCO <sub>3</sub> and Na are dominant, normally indicates ion exchanged water, although the generation of CO <sub>2</sub> at depth can produce HCO <sub>3</sub> where Na is dominant under certain circumstances
4	SO <sub>4</sub> dominates, or anion discriminant and Ca dominant, Ca and SO <sub>4</sub> dominant, frequently indicates recharge water in lava and gypsiferous deposits, otherwise

mixed water or water exhibiting simple dissolution may be indicated.

- 5 No dominant anion or cation, indicates water exhibiting simple dissolution or mixing.
- 6 SO<sub>4</sub> dominant or anion discriminate and Na dominant; is water type that is not frequently encountered and indicates probable mixing or uncommon dissolution influences.
- 7 Cl and Na dominant is frequently encountered unless cement pollution is present. Otherwise the water may result from reverse ion exchange of Na-Cl waters.
- 8 Cl dominant anion and Na dominant cation, indicate that the ground waters be related to reverse ion exchange of Na-Cl waters.
- 9 Cl and Na dominant frequently indicate end-point down gradient waters through dissolution

## CATIONS

## ANIONS

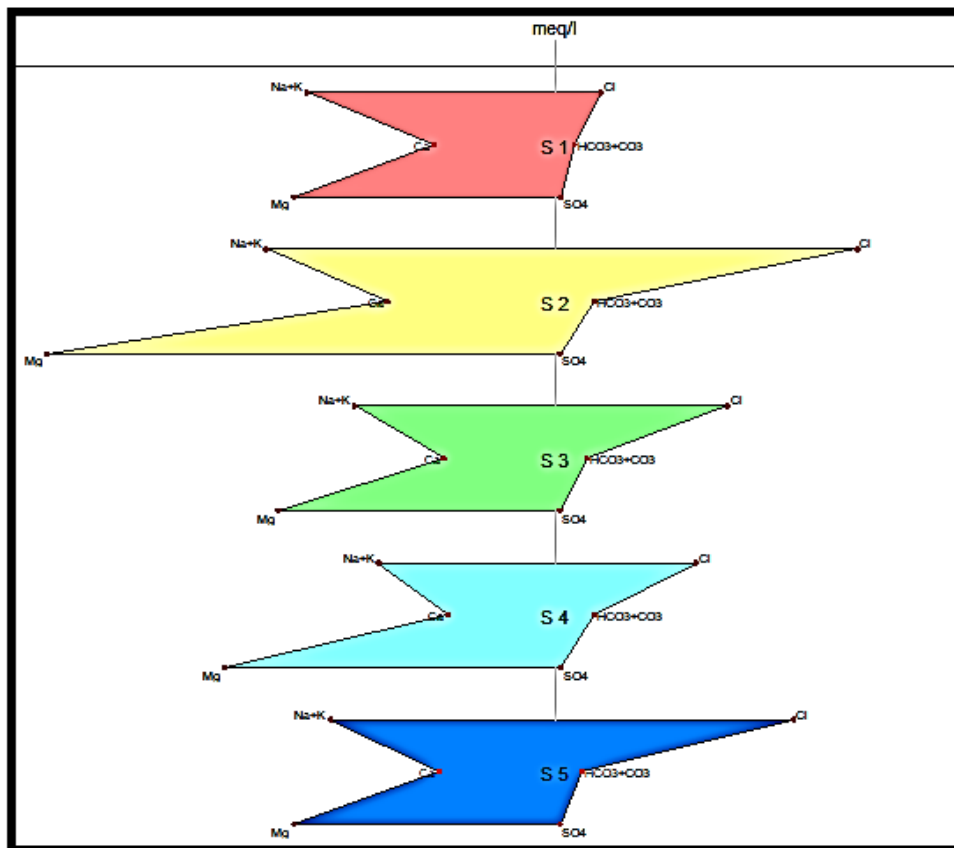


Figure 4.12a: Stiff plots of groundwater samples of the study area

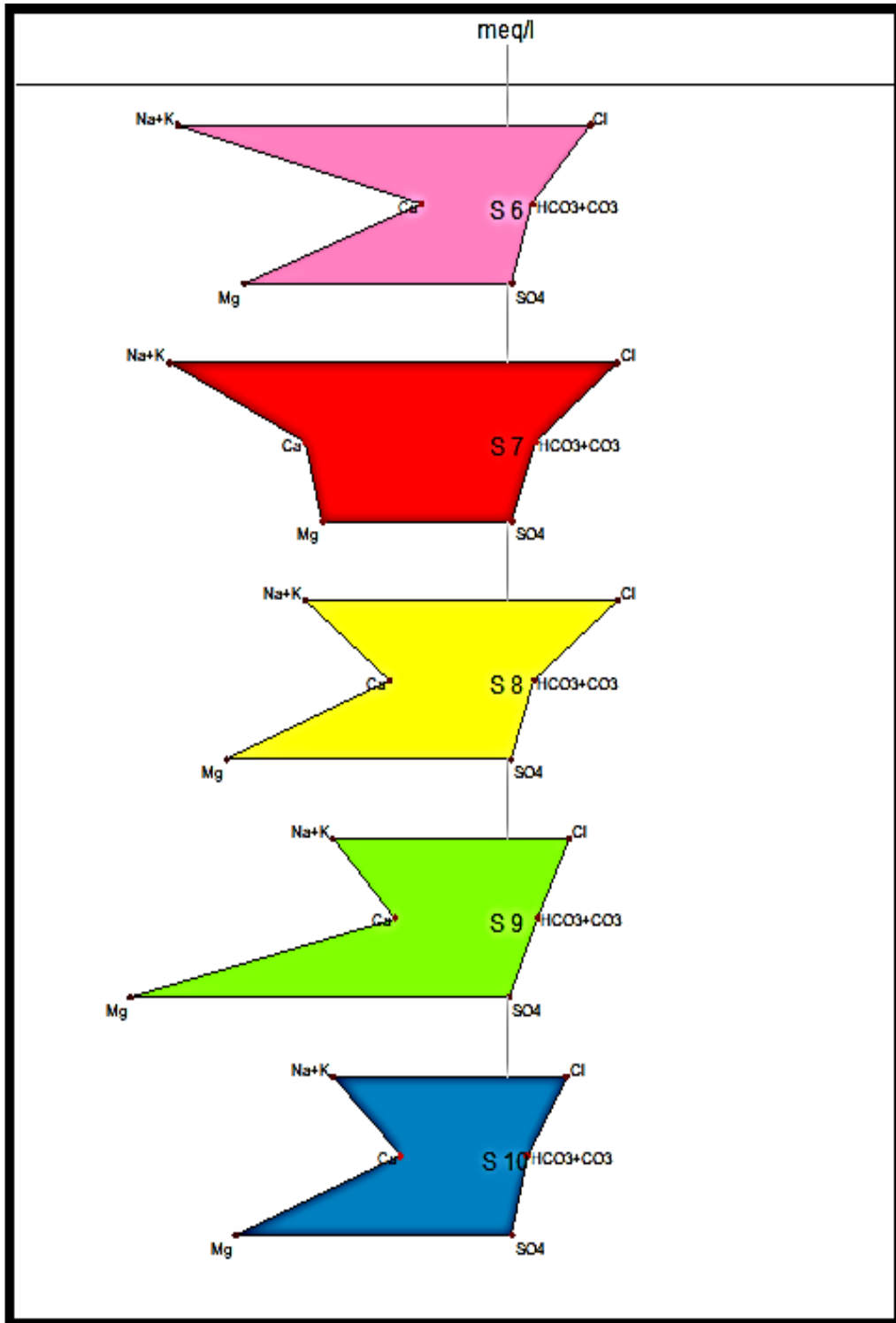


Figure 4.12b: Stiff plots of groundwater samples of the study area

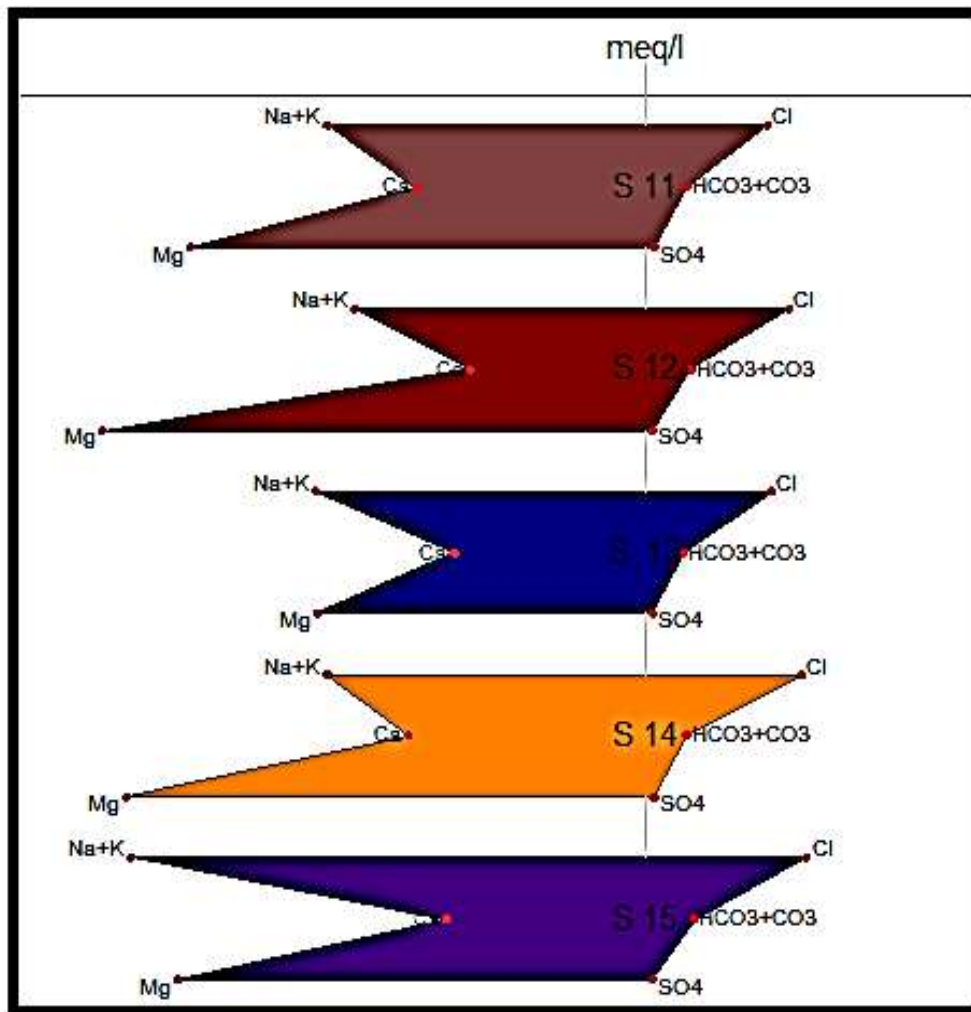


Figure 4.12c: Stiff plots of groundwater well water samples of the study area

The Stiff plots of the groundwater samples of the study area are illustrated in (Figures 4.12 and 4.13). Stiff plot is basically a graphical representation in form of polygons of the major ion composition of a given water sample. It aids in making a rapid visual comparison between water from different sources. It has two basic uses to visualize ionically related waters which could serve as a means to determine flow path and to show how the ionic composition of a water body changes over space and/or time. These stiff plot indicated that the major anions composition in all the water samples is in the order  $Cl^- > HCO_3^- + CO_3^{2-} > SO_4^{2-}$  while the major cation is in the order  $Na^+ + K^+ > Mg^{2+} > Ca^{2+}$  for 2 water samples (S6 and S15),  $Na^+ + K^+ > Ca^{2+} > Mg$  for 1 water

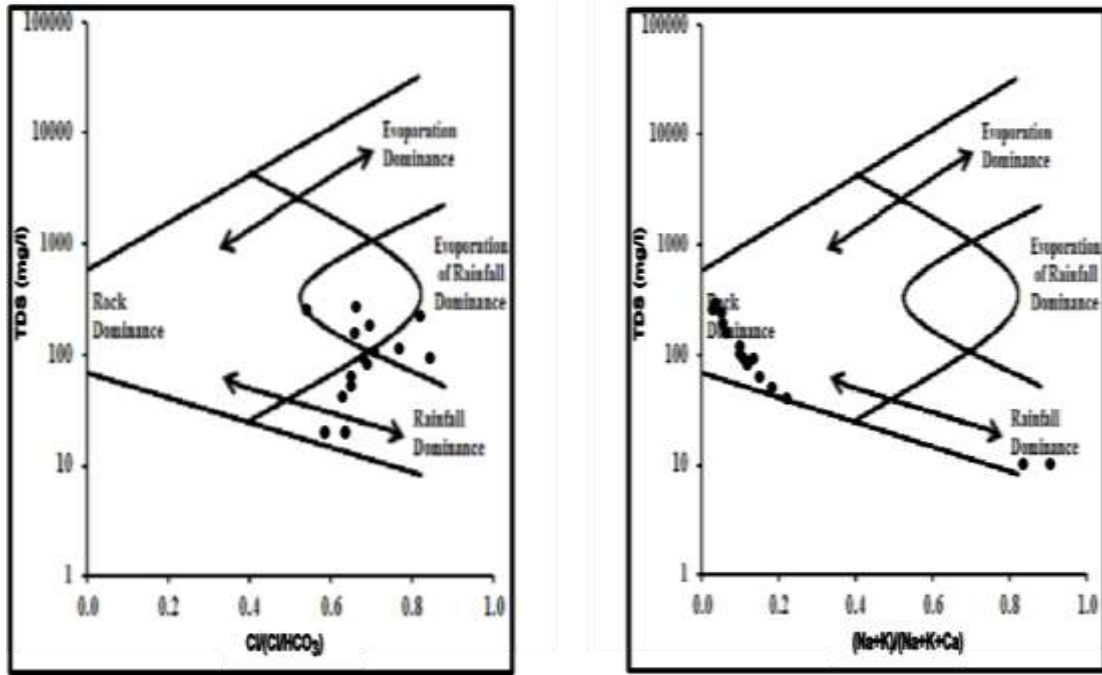
sample (S7) and  $\text{Na}^+ + \text{K}^+ = \text{Mg}^{2+} > \text{Ca}^{2+}$  for 1 water sample (S13) and  $\text{Mg} > \text{Na} + \text{K} > \text{Ca}$  for the remaining 11 water samples.

The pattern of the stiff plot showed similarity in 11 of the water samples with the exception of four water samples where the pattern appears to be distinctive; in S15 and S6 (which are similar), and in S7 and S13 which are distinctive. Furthermore a similarity in pattern can be used to identify ionically related water; based on this, the water samples were grouped together as shown in the (Table 4.3).

Table 4.4: Stiff plot describing the grouped pattern of the study area

Sample Location	Group (ionically related)	Peculiar characteristics
S1		
S2		
S3		
S4		
S5		$\text{Mg} > \text{Na} + \text{K} > \text{Ca}$
S8	A	
S9		
S10		
S11		
S12		
S14		
S6	B	$\text{Na}^+ + \text{K}^+ > \text{Mg}^{2+} > \text{Ca}^{2+}$
S15		
S7	C	$\text{Na}^+ + \text{K}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$
S13	D	$\text{Na}^+ + \text{K}^+ = \text{Mg} > \text{Ca}$





**Figure 4.13:** Gibb's plot of groundwater samples of the study area

The Gibb's plot (Figure 4.13) uses two plots to analyse the procedures of hydrogeochemistry with veneration of precipitation, atmospheric, interaction of rock water and evaporation over the management of groundwater geochemistry. The Gibb's plot is a chart of proportion of cation  $[(Na+ K)/9Na+ K+Ca]$  and anion  $[(Cl/(Cl+ HCO_3)]$  against TDS. Using the anions indicated that the geological processes responsible for the chemistry of 8 (53.3%) of the water samples is a combination of evaporation and precipitation while precipitation alone is responsible for the remaining 7 (46.7) water samples. However, Gibb's plot using the cations indicated that the geological process responsible for the chemistry of 13 (86.7%) of the water samples is Rock-Water interaction while the remaining two (13.3%) samples indicated precipitation dominance.

#### 4.5 Geochemical Analysis of Borehole Cuttings

The Major oxides distribution in the borehole cuttings are shown in (Figure 4.14) the ternary plot or ternary graph creates two dimensional graphs. It is observed that most of

the soil samples are richer in Fe and Si, Si and Fe oxides as compared to Fe and Al and Al and Si oxides. The high concentration of Iron oxides in most of the borehole cuttings is an indication that the possible source of Fe in the groundwater is geogenic as a result of chemical weathering associated with water-rock interaction.

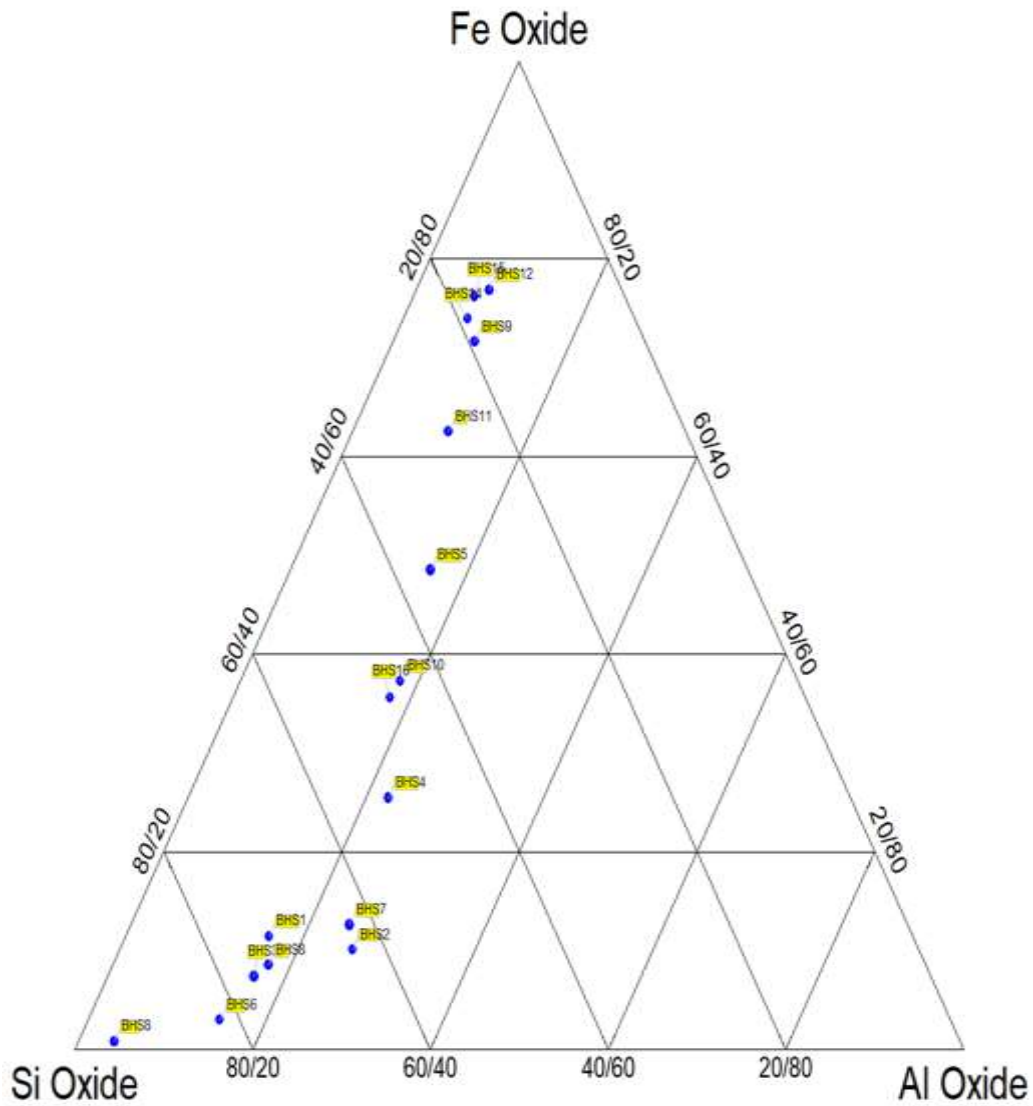


Figure 4.14: Major oxide distributions in borehole cuttings

## CHAPTER FIVE

### 5.0 CONCLUSION AND RECOMMENDATIONS

#### 5.1 Conclusion

The study area is underlain by the cretaceous sedimentary rocks of the Middle Benue Trough namely: Awgu and Lafia Formations. The Awgu Formation have different lithologic units ranging from grey bedded shales, sandstones beds, limestone and contains coal seams/beds sandstones beds. The Lafia Formation consists of sandstone being brownish at top in some places with thick lateritic cover and sandstones whitish downward.

A total of fifteen soil samples and fifteen water samples were analysed for Physical parameters (pH, Temperature, EC and TDS) and hydrochemical characteristics (cations, anions and heavy metals). All the results obtained were subjected to Quantitative and Qualitative analysis then compared with the NSDWQ and WHO drinking water guideline. Based on the on pH observed the samples are mostly acidic in nature (4.5-6.8). The pH distribution across the area shows acidity except for River Amba which falls within the WHO (2011) and NSDWQ (2018) acceptable limit for drinking water. The data of the physio-chemical parameters (electrical conductivity Ec, and Total Dissolved Solid TDS) obtained from the water samples across the study area are (0.010-0.48 $\mu$ /cm) and 0.01 -0.24mg/l). The spatial distribution of EC in the area shows high values around Novel water, FULafia Central Administration Block and River Amba all the samples falls within the permissible standards of (WHO, 2011 and NSDWQ, 2015). The spatial distribution of TDS across the area shows similar trend with that of the EC and are also within WHO and NSDWQ acceptable limit for drinking water.

The heavy metals concentration data obtained from the geochemical analysis of the groundwater samples were deduced. The concentration of Fe, Mn, Zn, Cu and Pb show that six samples of Fe are above the WHO (2011) permissible limit and also two samples of Mn, while Zn and Cu are within the permissible WHO (2011) Standard. Pb has five samples that are above WHO, 2011 permissible limits. The enrichment of heavy metals; Fe, Mn, Cd and Pb is attributed to the anthropogenic activities going on in the area as well as geogenic processes of chemical weathering and dissolution as observed in the Groundwater sample GWI which is seriously contaminated with all the heavy metals especially Cd and Pb which are indicators of environmental contamination and hence calls for mitigation and remediation measures. The contamination factor (CF) intensity of the analysed heavy metals decreased in the following order Fe>Pb>Mn>Cu>Ni>Cd. The geological phenomena such as weathering and dissolution may possibly be responsible in releasing these metals from the host rock to the surrounding water bodies.

The result of Wilcox plot shows that the irrigation groundwater quality of the study area, Lafia and environs has groundwater quality range from excellent to good quality for irrigation purposes. The major oxides distribution in the borehole cuttings are depicted on the ternary plot and it is observed that most of the soil samples are richer in Fe and Si, Si and Fe oxides as compared to Fe and Al and Al and Si oxides.

The Piper plot classified the water in two ways; that is water type and hydrochemical facies in which the water belongs. All of the water samples plotted on the E portion of the piper diagram corresponding to the Earth Alkaline water with prevailing SO<sub>4</sub> and Cl. On the Piper hydrochemical facies plot, all the samples fall in field I corresponding to the Ca<sup>2+</sup>-Mg<sup>2+</sup>-Cl-SO<sub>4</sub><sup>2-</sup>hydrochemicalfacies. The hydrochemical process responsible for the water chemistry from the Durov plot is simple dissolution or mixing.

The Stiff plot indicated that the major anions composition in all the water samples is in the order  $\text{Cl}^- > \text{HCO}_3^- + \text{CO}_3^{2-} > \text{SO}_4^{2-}$  while the major cation is in the order  $\text{Na}^+ + \text{K}^+ > \text{Mg}^{2+} > \text{Ca}^{2+}$  for 2 water samples (S6 and S15),  $\text{Na}^+ + \text{K}^+ > \text{Ca}^{2+} > \text{Mg}$  for 1 water sample (S7) and  $\text{Na}^+ + \text{K}^+ = \text{Mg}^{2+} > \text{Ca}^{2+}$  for 1 water sample (S13) and  $\text{Mg} > \text{Na} + \text{K} > \text{Ca}$  for the remaining 11 water samples. The pattern of the stiff plot showed similarity in 11 of the water samples with the exception of four water samples where the pattern appears to be distinctive; in S15 and S6 (which are similar), and in S7 and S13 which are distinctive.

The Gibb's plot using the anions indicated that the geological processes responsible for the chemistry of 8 (53.3%) of the water samples is a combination of evaporation and precipitation while precipitation alone is responsible for the remaining 7 (46.7) water samples. However Gibb's plot using the cations indicated that the geological process responsible for the chemistry of 13 (86.7%) of the water samples is Rock-Water interaction while the remaining two (13.3%) samples indicated precipitation dominance. The Gibb's plot was used two plots to analyse the procedures of hydrogeochemistry with veneration of precipitation, atmospheric, interaction of rock water and evaporation over the management of groundwater geochemistry. The Gibbs plot is a chart of proportion of cation  $[(\text{Na} + \text{K})/9\text{Na} + \text{K} + \text{Ca}]$  and anion  $[(\text{Cl}/(\text{Cl} + \text{HCO}_3))]$  against TDS. Using the anions indicated that the geological processes responsible for the chemistry of 8 (53.3%) of the water samples is a combination of evaporation and precipitation while precipitation alone is responsible for the remaining 7 (46.7) water samples. However, Gibb's plot using the cations indicated that the geological process responsible for the chemistry of 13 (86.7%) of the water samples is Rock-Water interaction while the remaining two (13.3%) samples indicated precipitation dominance.

## 5.2 Recommendations

The following recommendations are suggested to reduce the groundwater and environmental contamination, pollution in the study area.

- I. **Sensitization:** This research work has revealed that most of the residents of the area are not aware, some are nonchalant about environmental impact of waste disposal in the area, hence the first recommendation is appropriate for Ministry of Environment and Natural Resources and Ministry of Water Resources to educate her residents (residential and small business shops/workshops) on possible effect of waste water and waste disposal to her environment and water quality, This step is necessary precautions in management/ prevention of waste water and waste disposal from domestic and commercial fronts in the environment.
- II. **Localised waste water and waste disposal system:** Due to the absence of any central waste disposal and sewer system in the study area, it is recommended that resident should adopt an improved, well planned and structured localized management systems such as continuous open drainages lined with concrete, well designed septic tanks, provide proper waste disposal drums or tanks) for further evacuation by the relevant authorities, or reuse by companies or individuals to recycle or for conservation pending when the government intervention for a central systems for waste disposal and sewers or turning waste to wealth. The modern landfills constructed against infiltration of leachates to the subsurface should be deigned based on international best practices, such that the domestic/ commercial waste generated and collated in disposal facilities which will be safely disposed and managed.
- III. A seasonal (monsoon) water and soil samples can be collected for physical and chemical analysis for further study and correlation of the parameters.

- IV. The groundwater that are beyond the standard limits are recommended to be treated to the international best practice before use.
- V. It is recommended for future studies that other parameters such as organic compound, microbiological and trace elements not detected in this study and the influence/effects of seasonal changes on groundwater quality and the environment impacts in the area should also be investigated.

## **5.2 Contribution to Knowledge**

The research has been able to establish that the groundwater samples from the study area are acidic and there is enrichment of iron (Fe). Also, there are high concentration of some heavy metals like cadmium, manganese and lead in the water samples. It is ascertained from the hydrogeochemical analyses that, they resulted from anthropogenic activities within the area. Therefore, the water within the study area will require remediation before usage for domestic and irrigation purposes.

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