INVESTIGATION OF THE CONCENTRATIONS OF POTENTIALLY TOXIC ELEMENTS IN GROUNDWATER WITHIN BARIKI AND ENVIRONS, NORTH CENTRAL NIGERIA

BY

ZAKARI, Mohammed Sani MTech/SPS/2017/6725

DEPARTMENT OF GEOLOGY SCHOOL OF PHYSICAL SCIENCES, FEDERAL UNIVERSITY OF TECHNOLOGY,

MINNA

OCTOBER, 2021

INVESTIGATION OF THE CONCENTRATIONS OF POTENTIALLY TOXIC ELEMENTS IN GROUNDWATER WITHIN BARIKI AND ENVIRONS, NORTH CENTRAL NIGERIA

By

ZAKARI, Mohammed Sani MTech/SPS/2017/6725

THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY (MTech) IN GEOLOGY (ENVIRONMENTAL GEOLOGY)

OCTOBER, 2021

ABSTRACT

An integrated geological, geo-chemical and geophysical studies were carried out to investigate the concentrations of potentially toxic elements in groundwater within Bariki and environs, North Central Nigeria, in order to ascertain the effect of mining on the water quality. The investigation involves surface geological mapping of Bariki and environs on a scale of 1:12,500, groundwater level mapping, Determination of toxic elements concentration using Atomic Absorption Spectroscopy (AAS) and geoelectrical sounding. The lithology at every outcrop was identified on the basis of textural and visual inspections of mineral composition using hand lens and further refined by petrographic examination which reveals that the area studied is dominantly schist, granite and amphiboles schist, other rock bodies includes gneiss, quartzites and localized muscovite schist. The groundwater level mapping (Surface water level, depth of the well and elevation above sea level) were recorded. Hydraulic head of each well was calculated and the groundwater flow map was also generated indicating NW, SE and SS flow directions. The physical parameters measured in-situ were Temperature (T), pH, Electrical Conductivity (EC) and Total Dissolved Solid (TDS) using a multifunctional TDS/EC/pH/TEMP water quality meter tester, pH shows slightly low values of 6.22, 6.24 and 6.31 at BKW L2, BKW L3 and BKW L5 when compare to WHO and NSDWQ standards. Out of the ten toxic elements analysed, Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni), Zinc (Zn) and Arsenic (As), only Cadmium 0.075 ppm, Manganese 0.73 ppm, Lead 0.037 ppm and Iron 22.71 ppm were found to be above WHO and NSDWQ standard. Computed Metal Pollution Index (MPI) of 135.5002 indicates the groundwater is highly polluted from multi-metal effect. The subsurface apparent resistivity decreases in both NW and SE direction of groundwater flow. An active mine site upsets the NW, SE and the resultant SS decrease in heavy metal concentration. This implies that groundwater pollution in Bariki and environs is attributed to mining activities.

TABLE OF CONTENTS

CON	CONTENT	
Cove	er Page	
Title	Page	i
Decl	aration	ii
Certi	ification	iii
Dedi	ication	iv
Ackr	nowledgement	V
Abstract		vi
Table of Content		vii
List	of Tables	х
List	of Figures	xi
List	of Plates	xii
Abbı	reviation, Glossaries and Symbols	xiii
CHA	APTER ONE	
1.0	INTRODUCTION	1
1.1	Background of the Study	1
1.2	Statement of the Research Problems	2
1.3	Justification of the Research	3
1.4	Study Area	3

1.4	Study Area	3
1.5	Relief and Drainage	5
1.5.1	Climate and Vegetation	5
1.5.2	Settlement and Land Use	6
1.6.0	Aim and Objectives of the Research	6

1.6.1 Scope of Work

6

CHAPTER TWO

2.0	LITERATURE REVIEW	10		
2.1	General Review of Potential Toxic Elements	10		
2.2	Geochemical Analysis of Potentially Toxic Elements in Groundwater	13		
2.3	Groundwater Flow Direction	14		
2.4	Principle of Geo-electrical Method	17		
2.4.1	Schlumberger Configuration	19		
2.5	Regional Geology of North Central Nigerian Basement Complex	20		
2.5.1	The Migmatite/Gneiss Complex (MGC)	21		
2.5.2	The Schist Belt	21		
2.5.3	The Older Granites (Pan African Granitoids)	22		
2.5.4	The Undeformed Acid and Basic Dykes	23		
2.6.0	Toxic Elements	24		
CHAI	CHAPTER THREE			
3.0	RESEARCH METHODOLOGY	26		
3.1	Materials	26		
3.2	Methods	27		
3.2.1	Preliminary Studies	27		
3.2.2	Surface Geological Mapping	27		
3.2.3	Micrographic Thin Section Preparation	28		
3.3.1	Groundwater Level Mapping and Hydraulic Head Determination	29		
3.3.1	Groundwater Sampling and Field Measurements	30		
3.4	Physico-chemical Parameters	30		
35	Geochemical Laboratory Analysis	30		

CHAPTER FOUR

4.0	RESULTS, INTERPRETATION AND DISCUSSION	32
4.1	Results of Surface Geological Mapping	32
4.2	Results of Groundwater Level Mapping	43
4.3	Results of Physical Parameters Measurements	46
4.4	Results of Elemental Concentration Analysis for Toxic Elements	51
4.5	Results of Geo-electrical Resistivity Measurements	61

31

CHAPTER FIVE

5.0	CONCLUSION AND RECOMMENDATION	64
5.1	Conclusion	64
5.2	Recommendations	65
REFERENCES		66
APPENDICES		70

LIST OF TABLES

TABLE		PAGE	
4.1	Geographic Coordinate of Outcropping Rock Bodies	32	
4.2	Statistical Data for Joint Trends in the Study Area	36	
4.3	Groundwater Level Mapping Data	44	
4.4	Results of measured Physical Parameters Value	46	
4.5	Comparing Physical Parameters Data with WHO (2011) and		
	NSDWQ (2007) standards	50	
4.6	Concentration Values for potentially Toxic Elements	52	
4.7	Comparing Toxic Element Concentration Values, with		
	WHO (2011) and NSDWQ (2007) standards	53	
4.8	MPI Estimation Data	61	
4.9	Results of Geo-electrical Data	62	

LIST OF FIGURES

FIGURE		PAGE	
1.1	Location Map of the Study Area	4	
2.1	Diagrammatic Illustration of Darcy's Experiment	15	
2.2	Generalized Field Electrodes Spacing Used in Resistivity Survey	19	
2.3	Basement Geology of Nigeria	24	
4.1	Geological Map of the Study Area	34	
4.2	Sampling Points Within the Study Area	35	
4.3	Rosette Diagrams for Joints Trends	43	
4.4	Groundwater Flow Direction Map	45	
4.5	pH Contoured Map	47	
4.6	TDS Contoured Map	47	
4.7	EC Contoured Map	48	
4.8	Concentration Map of Copper	54	
4.9	Concentration Map of Zinc	54	
4.10	Concentration Map of Cobalt	55	
4.11	Concentration Map of Nickel	56	
4.12	Concentration Map of Cadmium	57	
4.13	Concentration Map of Manganese	57	
4.14	Concentration Map of Lead	58	
4.15	Concentration Map of Chromium	59	
4.16	Concentration Map of Iron	60	
4.17	Iso-resistivity Map for Regolith	63	

LIST OF PLATES

PLATE		PAGE
Ι	Washing of River Sediment for Gold	7
II	Washing of Scooped Sediments	7
III	Processing Scooped Sediments	8
IV	An Abandoned Mine Site	8
V	An Abandoned Mine Site	9
VI	Fine Grain Granite Body with Quartzo-feldspartic Vein	37
VII	Medium Grain Granite Body	37
VIII	PP Biotite Granite	38
IX	XP Biotite Granite	38
Х	PP Granite	38
XI	XP Granite	38
XII	Muscovite Schist	39
XIII	Amphibole Schist	39
XIV	PP Amphibolite Schist	40
XV	XP Amphibole Schist	40
XVI	Gneiss Outcrop	40
XVII	PP Gneiss	41
XVIII	XP Gneiss	41
XIX	Quartzite	41
XX	Joint Sets in Medium Grain Granite	42

ABBREVIATION, GLOSSARIES AND SYMBOLS

- **GPS:** Global Positioning System
- LGA: Local Government Area
- **PPM:** Part Per Million
- NGSA: Nigeria Geological Survey Agency
- **NIMET:** Nigerian Meteorological Agency
- NSDWQ: Nigerian Standards for Drinking Water Quality
- **pH:** Potential of Hydrogen
- **EC:** Electrical Conductivity
- **TDS:** Total Dissolved Solid
- **TEMP:** Temperature
- **BKr:** Sample Locations for Rocks
- **BKW:** Sample Locations for Groundwater
- LAT: Latitude
- LONG: Longitude
- **ELEV:** Elevation
- LOC CODE: Location code
- WHO: World Health Organization
- **SWL:** Surface Water Level
- AAS: Atomic Absorption Spectrometry
- **VES:** Vertical Electrical Sounding

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Groundwater is subsurface water beneath water table in saturated soils and geologic formations (Unuevho et al., 2016). It is one of the natural resources that support human existence and other lives on earth (Ajusa, 2003). Groundwater is exploited from boreholes and hand dug wells in urban and semi urban areas for domestic, agricultural and industrial usage. The chemistry of groundwater is influenced majorly by aquifer mineralogy, the residence time and dominant anthropogenic activities Amadi and Nwankwala, (2013). Groundwater pollution is a gradual degradation in water quality through the addition of chemicals and pathogens to a level that constitutes health hazards, and adversely affects domestic and agricultural products, as well as industrial utilization (Akhilesh et al., 2009). In recent years there is growing concern on the impact of anthropogenic activities on groundwater quality Amadi and Nwankwala, (2013). Water polluted by toxic element increases the risk of hypertension, skin cancer, Kidney failure, liver dysfunction and neurological diseases (Unuevho et al., 2016). Virtually any activity that releases chemicals or industrial wastes to the environment has the potential to pollute groundwater. Among such chemicals and wastes is heavy metal. These are metallic elements that have a relatively high density and become toxic or poisonous at high concentration. They include Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni), Zinc (Zn) and Mercury (Hg) (Adekoye, 2003).

Informal artisanal mining activities have been going on for some time now in Bariki. This constitutes a very high potential for polluting the groundwater in this vicinity via the release of toxic elements. Heavy metal or toxic elements are natural component of the earth's crust and are undegradable or indestructible. However, to a small extent, they enter our body through food, water and air. Some heavy metal such as Copper (Cu), Zinc (Zn), Iron (Fe) and Magnesium (Mn) are essential to life. But they become harmful and can be fatal at high concentration. Their occurrence in the environment results from the anthropogenic activities and natural processes such as rock weathering and volcanic activities (Amadi, 2011).

World Health Organization WHO (2010) opined that the accessibility to potable water is a fundamental objective in the fight against developmental challenges such as poverty, hunger, child mortality and maternal health. Rapid population growth and urbanization leads to an increase in demand and exploration for potable water (Lacerda, 1997).

The high level of toxic elements in natural water bodies can be attributed to some anthropogenic activities such as mining, oil spillage, farming and improper municipal waste disposal (Yusuf *et al.*, 2017). According to the European Environmental Bureau (EEB, 2000) the major environmental problem associated with mining is the uncontrolled discharge of contaminated water (effluent) from the mines. Effluent discharge from gold mine is characterized by raised levels of toxic elements especially sodium of cyanide silver, mercury, arsenic and lead in soil and groundwater bodies (Adler and Rustler, 2007).

1.2 Statement of the Research Problem

Gold mining is accompanied by environmental degradation that bears adverse health effects in developing countries. Weaning gold from host rock in Bariki and environs involves mining, transportation, crushing, milling and washing. These activities do release toxic elements which infiltrate the groundwater in Bariki and environs, and thereafter get ingested by humans. The health implications of ingesting toxic elements necessitated the investigation of toxic element concentrations in groundwater within the vicinity of the Bariki mines. Such investigation is yet to be conducted in Bariki and environs.

1.3 Justification of the Research

Toxic elements are commonly found in concentrations that are harmful to human health in mining districts. Hypertension, Skin cancer, Kidney failure, Liver dysfunction, Neurological diseases are among health challenges that have been associated with ingesting heavy metal. Determination of toxic element or heavy metal concentrations in groundwater within Bariki is necessary to ascertain the potability of the water, with respect to past and present mining activities in the area.

1.4 Study Area

The study area is Bariki and environs. It is located in the southwestern part of Paiko Sheet 185NW on the scale of 1:50,000, North Central Nigeria. It lies between Latitudes N09° 29' 00" to N09° 30' 00" and Longitudes E006° 31' 00" to E006° 33' 00", within the Basement Complex of Northern Nigeria. Major Villages within the study area includes Bariki, Gado and Laitapi as indicated in figure 1.1 below.



Figure 1.1: Location map of the study area

1.5.0 Relief and Drainage

The study area is well drained by numerous seasonal streams and also dissected almost at the middle by the SW flowing river Maidna which empties her water in to river Chanchaga, which also empties it water in to river Gbako down-stream.

1.5.1 Climate and Vegetation

The study area is located within the tropical climate which is characterize by two season in a year (wet and dry seasons), the annual rainfall received within the region is less than 1000mm in The wet season last between April and September with a maximum downpour between months of July and August (Nigerian Metrological Agency, 2010). The dry season lasts between the month of October and March. Temperature varies within the region annually with the season. During the dry season temperatures are law because the sun is in the southern hemisphere. Minimum temperatures below 30°C are recorded during the harmatan period, which is late December and January in the following year. Maximum temperature is above 26^oC. During the raining or wet season, the sun moves northwards from equator to the tropics of cancer. This result to high temperature because the sun overheads at noon. According to the Nigerian metrological agency (Nigerian Metrological Agency, 2010), the minimum temperature average above 26°C and maximum temperatures average of about 30°C particularly at mid-day between May and July. The vegetation is purely that of the Guinea savanna characterized by sparse vegetation and tall trees with patchiest of forest (Nigerian Metrological Agency, 2010).

1.5.2 Settlement and Land Use

Nucleated settlements characterize the study area. Pipe born water is unavailable and residence obtain water from hand dug wells and boreholes for drinking and domestic purposes. The borehole taps groundwater from regolith lithology or layer.

Plate I to V shows the various mine sites in Bariki.

1.7.0 Aim and Objectives of the Research

This project is aimed at ascertaining the quality status of groundwater in Bariki and environs, with respect to toxic element concentration.

The objectives are to:

- Conduct the geological mapping of Bariki and environs on a scale of 1:12,500 in order to ascertain the water bearing units in the area.
- Map groundwater levels to establish principal flow directions, using hand-dug well data.
- 3. Determine toxic element concentrations and its spatial distributions.
- 4. Obtain Isoresistivity map for top soil and weathered basement for pollution plume and aquifer evaluations.

1.6.2 Scope of Work

The research work is limited to surface geological mapping, water level mapping, pH, Electrical conductivity and Total dissolve solid mapping, determination of concentration of toxic elements and geo-electrical sounding.



Plate I: Washing of river sediment for gold at N09° 29' 23.0" E006° 32' 48.8"



Plate II: Washing of scooped sediments N09° 29' 21.6" E006° 32' 47.6"E



Plate III: Processing scooped sediments N09° 29' 32.6" E006° 31' 41.0"



Plate IV: An abandoned mine site N09° 29' 21.1" E006° 32' 48.8"



Plate V: An abandoned mine site N09° 29' 32.6" E006° 31' 41.0"

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General Review of Potential Toxic Elements

Artisanal gold mining has been discouraged recently worldwide due to its devastating effects on the environment because during exploitation and processing, a lot of toxic elements are released in to the environment which is toxic to the soil and other living organisms within that environment (Martins, 2001). All over the world, Agriculture generates high concentration of solid waste effluents, the Mining sector is the second largest source of pollution (Prasad *et al.*, 2014).

Akankpo and Igbuekwe (2011) employed surface electrical resistivity and geochemical methods to monitor groundwater contamination in parts of Uyo. They reported that low resistivity values (< 75 Ω m) characterised top layers in areas where dumpsite leachates contaminated the groundwater, while high resistivity values (rho = 60700 Ω m) characterised top layer in areas (mechanic village) where leachate from waste oil deposits contaminated groundwater.

Adegoke *et al.*, (2009) evaluated heavy metal status of water and soil at Ikogosi Warm Spring, in Ondo State of Nigeria. They attributed high concentrations of heavy metal to anthropogenic sources and related such high concentrations to chronic human diseases.

In Anka, Zamfara State, North West Nigeria. Human right watch (2012) reported that at least 400 children suffered from lead and mercury poisoning as a result of artisanal gold mining in their local communities. Martins, (2001). Took a total number of 24 soil samples from the areas around Artisanal Gold and associated Pb-Zn-Cu sulfide mining and mineral processing sites in the Anka mining district. The samples were

geochemically analyzed with the main objective of assessing the degree of Pb and Hg pollution in the environment resulting from the mining and mineral ore processing activities in the mining district and to consider the effect on human health. The geochemical results show that the concentrations of Pb and Hg especially at the mineral processing sites significantly exceed the established thresholds (4,152 ppm and 12.92 ppm respectively). These revelations call for efficient bioremediation measures for the removal of Pb and Hg from the contaminated soils.

Harter (2003) examined groundwater quality and groundwater pollution in Zing Taraba State of Nigeria. He opined that groundwater contains dissolved mineral ions which it slowly dissolved from soil particles, sediments and rocks as the water travels along mineral surfaces in the pores or fractures of the unsaturated zone and the aquifer. He grouped the dissolved ions into primary (or major), secondary and tertiary constituents in natural groundwater. He further remarked that human activities can alter the natural composition of groundwater through the disposal or dissemination of chemicals at the land surface and into soils.

Yusuf *et al.*, (2017) examined the level of heavy metal in boreholes and hand dug wells within Kashere town and environs. Ten samples were analyzed for toxic element concentrations, five from borehole and the remaining five from hand dug wells using atomic absorption spectrum (AAS). The result shows that there is high concentration of most of the heavy metal in groundwater sample and it was recommended that a systematic treatment of the toxic element concentration in groundwater source be carried out regularly in the study area.

Abdullahi (2014) carried out a study on environmental effect of artisanal gold mining on water resources in Bida north central Nigeria, which was carried out with the primary aim of determining its effect on surface and groundwater chemistry. Mapping of the area was conducted using a topographical map of (Bida NE sheet 184). Granite and Schist are the major rock types in the study area which is drained by the NE/SE flowing river Chanchaga. Twenty surface and groundwater sample were collected within the study area at Gada-Eregi and Maiwayo village. The samples were analyzed for Cations, Anions and trace elements (heavy metal). Physical parameters like temperature, pH, conductivity and total dissolved solids were measured in-situ. The samples collected were analyzed using Atomic absorption spectrometry (AAS), the results were interpreted using sufur 9 and Microsoft excel softwares. The recorded average value for Chlorine, Nitrate, phosphate, Sodium, Potassium and bicarbonate are: 29.27ppm, 1.74ppm, 0.08ppm, 20.02 ppm, 11.65 ppm and 151.32ppm respectively. Manganese, Copper, Zinc, Iron and Lead had the following mean values: 0.65 ppm, 0.05 ppm, 0.10 ppm, 5.70 ppm, and 2.70 ppm. The result shows that the Anion and Cations are present in safe quantities in the water samples as recommended by the World Health Organization WHO (2010) but most of the groundwater and mine pits sampled, contain high percentage of Iron, Lead, manganese, Zinc and Copper especially Maiwayo wells, indicating their non-suitability for domestic uses. The author suggested a regular study to measure the level of toxic element concentration in water within the study areas.

Singh *et al.*, (2015) studied the physico-chemical parameters and toxic element concentrations of tap and borehole water in Minna metropolis. The experiment lasted over a period of three months from May to July 2012. Six (6) locations were identified within Minna metropolis: Bosso, Kpagungu, Chanchaga, Mobil, Maitumbi, and Tunga where water samples were randomly taken once every month. Hydrogen ions concentration, chloride, Sodium and Potassium were determined while temperature was

measured with thermometer. Air and Water temperature were determined in situ, while Hydrogen ions concentration (pH), Ionic conductivity, Alkalinity, Hardness, Chloride, Sodium, Potassium and Toxic element concentration, copper, zinc, Iron and Lead were determined in the laboratory. The parameters measured showed marked variation across months and locations. Mean values of physico-chemical and concentration of heavy metal in Tap and Borehole water variables studied showed that parameters measured fell within the recommended ranges for aquaculture and drinking water. Water temperature showed significant difference (P 0.05) while Conductivity, Hardness, Alkalinity, sodium and potassium showed no significant difference (p>0.05) amongst the months. The physico-chemical parameters assessed, indicated that most of the parameters fell within standards set by the Federal Ministry of Environment. Comparison between tap and borehole water of each location in Minna metropolis did not show significant difference in temperatures of the locations (p >0.05). However, significant difference was observed in conductivity of the various locations (p <0.05).

Tijani *et al.*, (2006) employed ICP – Emission method and Atomic Absorption Spectrometry (AAS) to determine heavy metal concentration in the stream sediments and water samples of Ogunpa drainage system in Ibadan metropolis of Southwestern Nigeria. They employed Contamination factor (CF) and geo-accumulation index (Igeo) as indices to assess the level of heavy metal concentration in the stream sediments and water samples. They employed average concentration of the metals in basement rocks in determining the CF and Igeo.

2.2: Geochemical Analysis of Potentially Toxic Element in Groundwater

Atomic absorption spectroscopy (AAS) in analytical chemistry is a technique for determining the concentration of a particular metal element within a sample. AAS can

be used to analyse the concentration of over 62 different metals in a solution (Larceda, 1997).

Todd and Mays (2005) said the technique makes use of a flame to atomise the sample solution. The flame is arrange such that it is laterally long (usually 10 cm) and not deep. The height of the flame must also be controlled by controlling the flow of the fuel mixture. A beam of light is focused through this flame at it longest axis (the lateral axis) on to a detector past the flame. The light that is focused in to the flame is produce by a hollow cathode lamp. Inside the lamp is a cylindrical metal cathode containing the metal for excitation, and an anode When high voltage is applied across the anode and cathode, the metal atom in the cathode are excited in to producing light with a certain emission spectra. The type of hollow cathode tube depends on the metal being analysed. The electron of the atoms in the flame can be promoted to higher orbitals for an instant by absorbing a set quantity of energy (a quantum) this amount of energy is specific to a particular electron transition in a particular element. As the quantity of the energy put in to the flame is known, and the quantity remaining at the other side (at the detector) can be measured, it is possible to calculate how many of these transitions took place, and thus get a signal that is proportional to the concentration of the element being measured.

2.3 Groundwater Flow Direction

Groundwater flow results from differences in energy of the water (groundwater) from one point to another. Groundwater flows from a point of higher energy to a point of lower energy. The energy of the water at a particular point is a function of the potential energy, elastic energy and kinetic energy at that particular point. However, the kinetic energy can be ignored in most cases due to the typically very low groundwater flow velocity; making its effect quite negligible compared to the elastic and potential energy (Todd and Mays, 2005). In 1856, Henry Darcy formulated the groundwater flow theory which up till date remains relevant in understanding groundwater movement. The analysis and solutions to problems related to groundwater flow and hydraulics began after Darcy's work. Equations for pumping test analysis, groundwater infiltration, and contaminant transport all involve Darcy's Law.

In his experiment, Darcy observed that for a given sand, the flow of water through it increased directly proportional to the difference in hydraulic head and inversely proportional to the length of flow. Darcy's Law can be expressed mathematically as:

$$q = \frac{Q}{A} = -K \frac{dh}{dl}$$
 Equation 2.1

Where q is the Darcy's velocity or specific discharge through cross-sectional area A [m/day]; Q is the flow rate $[m^3/day]$; A is the cross-sectional area through which flow occurs $[m^2]$; and K is the proportionality constant (Hydraulic Conductivity).



Figure 2.1: Diagrammatic illustration of Darcy's experiment (Darcy, 1856), (Todd and Mays, 2005)

The term dh/dl is the hydraulic gradient and is the driving force for groundwater flow. Hydraulic gradient is also represented by "i". The negative sign in Darcy's Law, by convention, signifies flow from a higher to a lower head. The proportionality constant (called the hydraulic conductivity) is a combined property of the fluid density and viscosity and the permeability of the porous medium (Todd and Mays, 2005).

Niwas and Singhal (1981) opined that the Hydraulic Conductivity (K) is a measure of the ability of a fluid to flow through a porous medium. It differs from transmissivity which is a measure of how much fluid can be transmitted horizontally in an aquifer. i.e. transmissivity is hydraulic conductivity (K) multiplied by the saturated thickness of the aquifer whereas, a medium (such as soil or rock) is said to have a unit hydraulic conductivity K if it will transmit in unit time, a unit volume of groundwater at the prevailing kinematic viscousity through a cross section of unit area measured at right angle to the direction of flow, under a unit hydraulic gradient.

It is expressed mathematically as;

$$K = -\frac{v}{dh/dl}$$
 Equation 2.2

K is hydraulic conductivity but often confused with permeability, dh/dl is the hydraulic gradient, V is the velocity or specific discharge through cross-sectional area A However, the latter is a property of the porous medium only, while the former is a property of the porous medium and the fluid. For example, if the Darcy experiment (Figure 2.1) was performed using syrup instead of water (keeping everything else the same), the hydraulic conductivity of the system would decrease, but the permeability of the sand would still remain the same. Permeability has units of m^2 , whereas hydraulic conductivity has units of m/day.

It is important to note that specific discharge is not the "speed" of ground water flow, but the flow per unit area. The velocity of an actual water particle moving will on average be much greater than the value of specific discharge, because the water particle travels an intricate path which is much longer than the linear path from one end of the experiment column to the other. The average ground water velocity or Darcy's velocity V can be estimated by dividing the specific discharge, q by the porosity, n;

$$v = \frac{q}{n}$$
 Equation 2.3

Darcy's Law is however only valid for laminar flow at very low velocities. If flow velocities become high and turbulent flow exits, the relationship between specific discharge and hydraulic head gradient becomes non-linear; specific discharge would not be directly proportional to the hydraulic gradient

Since groundwater generally moves very slowly (typically up to 1 m/day), Darcy's Law applies in most situations of groundwater flow through porous media. Darcy's Law breaks down when turbulent flow occurs, such as in flow through very large pipes, fractures, karstic bedrock, or near very high pumping wells.

2.4 Principles of Geo-electrical Methods

The electrical resistivity method utilizes Ohm's law which associates Current (I), Potential Difference (V) and Resistance (R) by the following equation:

$$V = IR$$
 Equation 2.3.1

The resistance R of a body of a conducting wire is directly proportional to its length L and cross sectional area A

$$R \propto \frac{L}{A}$$

$$R = \frac{\rho L}{A}$$

$$\rho = \frac{RA}{L}$$
Equation 2.3

2.3.2

Where ρ is the resistivity, which is a constant that relates the Resistance of a material to its length and cross sectional area. The unit of Resistivity is ohm-meters (Ω m) and it is the inverse of conductivity of a material (Maillet, 1947).

In the electrical resistivity survey method, current is passed into the subsurface using a DC or a low frequency AC current. This is achieved by placing a current electrode pair at specified distances (AB) into the earth. Another pair of Potential electrodes is hammered into the ground at distance (MN) in between the two current electrodes to measure the resulting potential difference generated by the current. The electrodes arrangement and spacing varies depending on the electrical array type being employed (Maillet, 1947).

It is expected that values of the potential difference on homogenous grounds will fall within a range. Deviations from this range will mean that there is a presence of an electrical anomaly at the center position of the electrodes. This method could be deployed either by using the Vertical Electrical Sounding (VES) or the Horizontal Resistivity Profiling (HRP). The VES provides reliable information on measured potential difference varies in association with charges in distance between the pair of current electrode which is in turn related to depth of current electrodes. The Horizontal Resistivity Profiling (HRP) indicates the horizontal variation in resistivity values over an area within a particular depth interval (Zohdy, 1947).

2.4.1 Schlumberger Configuration

This array makes use of a pair of current electrodes together with a pair of potential electrodes arranged in a linear pattern. The currents electrodes are spread at distance AB apart and the potential electrodes spread apart at distance MN. The distance between the current electrodes AB is usually made to be equal to or greater than five times that of the potential electrodes MN. (Zohdy, 1947).



Figure 2.2: Generalized field electrodes spacing used in resistivity survey (Todd and Mays, 2005)

In this configuration, AB is current electrode spacing; MN is the Potential Electrode spacing and $AB \ge 5MN$. *C1P1* is the distance AM and *C2P2* is the distance NB as shown in figure (Figure 2.2).

The Geometric Factor G for Schlumberger array is given below

$$G = \frac{\pi \left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2 \right]}{2*\left(\frac{MN}{2}\right)}$$
 Equation 2.4.0

As the survey progresses, the current electrodes are spread apart continually in a symmetrical pattern about the center of the array while the potential electrode pair

remains constant until the maximum separation required (AB \geq 5MN) is attained (Henriet, 1976).

2.5 Regional Geology of North Central Nigerian Basement Complex

The study area is part of the North Central Nigeria Basement Complex. The rocks are of Precambrian to Paleozoic age and were affected by the Pan-African thermo-tectonic events that took place 600 million years. The rock consists of a variety of unmigmatised and migmatised gneisses, schists, amphibolites and quartzites into which granitic to dioritic bodies were emplaced during the Pan African Orogeny (Oyawoye, 1972). Associated with the intrusive suites are pegmatites and dolerite dykes. Strong foliations, joints, folds and shear zones constitute internal rock deformation (Grant, 1978).

The rocks of the North-central area are composed of gneisses, migmatites, granites, schists, phyllites and quartzites. The narrow, tightly folded North-South trending Schist belts of North Central Nigeria include igneous rocks, politic schists, and phyllites and banded Ironstones (Obaje, 2009). The migmatite-gneiss complex associated with gabbros, amphibolites, diorites, marbles and pegmatites form a transition zone between the schist belt of NW Nigeria and the granites of the Jos Plateau to the east. The Precambrian Older Granites outcrop extensively in the Jos Plateau area and have been intruded by Jurassic age Younger Granites that form characteristic ring complex structures (Rahaman and Ocan, 1978; Rahaman, 1988; McCurry, 1976; Dada, 2006; Obaje, 2009) studied the geology of the area with the objective of establishing structural and stratigraphic relationships of the rocks, as well as, reconstruct the metamorphic history of the area, decipher the evolution of rocks and create a lithostratigraphic classification for them.

Four main rock units have been outlined to make up the Basement complex of Nigeria.

These units are Migmatite – Gneiss Complex, Schists, Older Granites and the undeformed acid – basic dykes.

2.5.1 The Migmatite – Gneiss Complex (MGC)

It is also called the Migmatite – gneiss quartzite complex, it has the widest area coverage in the Basement Complex regions of Nigeria, covering a total space of 60% (Rahaman and Ocan 1978). It ranges from Eburnean to Pan African in age, recording three major rocks forming episodes, with the earliest occurring about ± 2500 Ma and marking the beginning of crustal rocks formation and development. The Eburnean orogeny (± 2000 Ma) marked the formation of granite gneisses, typical of the Ibadan granite gneiss. The latest event (the Pan African orogeny) which dates back from 900 to 450 Ma greatly altered the rocks both structurally and mineralogically resulting in faulting, folding and formation of Migmatites – gneisses respectively (Rahaman and Lancelot, 1984).

The Complex is made up of a heterogeneous assemblage that includes; migmatites, orthogneises, paragneisses, and a series of basic and ultrabasic metamorphosed rocks. These outcrop in: Abuja, Keffi, Akwanga, Bauchi, Kaduna, Kano, Funtua, Okenne, Egbe, Ajaokuta (in northern Nigeria); Ibadan, Ile-Ife, Akure, Ikerre, (in western Nigeria) and Obudu and the Oban Massif areas in eastern Nigeria (Obaje, 2009).

2.5.2 The Schist Belt

This belt is constituted by meta-sedimentary and meta-volcanic rocks and is Upper Proterozoic in age. There have been diverse opinions concerning the lithologic composition of the Schist Belts of the Basement Complex of Nigeria. For example, lithologically (Grant, 1978). He noted that rocks of the Schist Belt may contain some portions of ocean floor materials believed to be derived from several basins of deposition but (McCurry, 1976) is of a different view that the rocks of the Schist Belts are remnants of a single supra rustal cover. Olade and Elueze, (1979) opined that the schist belts are rift like structure that were fault controlled. The rock units of the schist belt include; coarse to fine grained clastics, politic schists, phyllites, banded iron formation (BIF), marbles/ dolomitic marbles and amphibolites which have been infolded into the Migmatite Gneiss Complex (Obaje, 2009).

2.5.3 The Older Granites (Pan African Granitoids)

The Pan African orogeny is most recorded in the older granites (Rahaman, 1988). They were also called the Pan African granitoids to portray their age and the diverse groups of rocks that were formed during the Pan African orogeny originating from magmas of varying compositions (Dada, 2006).

Obaje (2009) indicated that rocks of this suite range in composition from tonalities, diorites through granodiorites to true granites and syenites. He continued that biotite granites, muscovite granite, syenites, serpentinites, anorthosites and chanockites are units of the older granite suite outcropping in the northern and southern parts of Nigeria and that Older Granites rocks are worthy of note in areas around Wusasa (Zaria), Abuja, Bauchi, Akwanga, Ado-Ekiti and Obudu.

Chanockites are special Older Granite rocks that have been mapped in some parts of Nigeria. "They are generally high level intrusions and anataxis played an important role in their formation (Rahaman, 1981). They appear dark greenish to greenish grey in color and may compose of quartz, feldspars, pyroxene, hornblende, biotite, fayalite, zircon, apatite, and iron ores (Olarewaju, 2006). Chanockites were first mapped in Nigeria by Falconer (1911) in Toro area of Bauchi state, where they are seen to have intruded into gniesses and migmatites. They are also present in Bauchi, Ado-Ekiti, Ikere (Ekiti), Akure, Idanre and Obudu areas.

Rahaman (1988) grouped the rocks of the older granites into six main constituents on the basis of textural features. These are; granite gneiss, migmatite granite, early pegmatites and fine grained granite, homogenous to coarse porphyritic granite, slightly deformed pegmatite aplites and vein quartz and finally the undeformed pegmatites. Generally, these rocks usually occur as intrusive bodies cutting across the Migmatite – Gneiss suites and the Schist belts in a concordant or semi concordant manner with marked presence of structures like faults, joints, and folds.

2.5.4: The Undeformed Acid and Basic Dykes

These consist of the felsic dykes and the basic dykes postulated to be late to post tectonic Pan African. They generally intrude the other rocks of the basement complex (the migmatite - gneisses, schist belts and older granites). The felsic dykes may be composed of one or more of Micro-granites, aplites, syenites as well as pegmatites with beryl, muscovites or tournaline (Dada, 2006). The basic dykes on the other hand include; Lamprophyric, basaltic and dolerite dykes. Figure 2.4 illustrates the Basement geology of Nigeria.



Figure 2.3: Basement geology of Nigeria (Obaje, 2009)

2.6.0 Toxic Elements

Tubosun *et al.* (1984) postulated that Toxic Elements are refers to as any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations, these metals cannot be degraded or destroyed and can enter our body through food, drinking water and air. Heavy metal are dangerous because they bio-accumulate. Bio-accumulation mean increase in the concentration of a chemical in a biological organisms over time compare to the chemical concentration in the environment. Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues of humans and animals (Amadi, 2013).

Unuevho *et al.* (2016) indicated that both natural processes and anthropogenic activities are the main sources of surface and groundwater contaminations by heavy metal. Regardless of origin, increase of toxic element concentration in water is becoming a serious threat to human health, animals, plants and aquatic ecosystems. The common heavy metal of health concern to human include Arsenic, cadmium, chromium, lead, nickel and zinc World Health Organization (WHO 2010). When toxic element concentrations in water exceed environmental tolerance limits, use of such water for domestic and agricultural (irrigation and aquaculture) activities could be harmful to the aquatic ecosystem and human via the food chain (Amadi, 2011). Implicit in the increased mining and mineral processing activities in developing nations is that water contamination by toxic element is likely to increase rapidly beyond these tolerance limits if best practices in mineral extraction and processing are not in placed and in an effort to implement best practices in mineral exploitation and processing some nations in Africa and other continents have formulated mining regulations that limit soil and water resources pollution by heavy metal (Akabzaa, 2000). For these regulations to be effective there must be a mechanism for verification of compliance with soil and water quality standards in the regulations. Such method requires establishment of toxic element concentration in soil and water prior to the commencement of a mineral exploitation practices (Hanaa et al., 2000). The data established for water in the area which would be affected by the mining activities is called Baseline Data. For the data to serve this purpose, it must be recognised in practice. Toxic element concentration in water can also be influenced by natural processes such as weather parameters (e.g. erosion, atmospheric deposition, volcanic activity) and forest fires (Singovszka el ta., 2017). The amounts of toxic element that dissolve in water or deposited onto sediments depend on pH, Total Dissolved Solids (TDS) and seasonal temperature and rainfall variation in a region (water aid, 2006).

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 MATERIAL

The following materials were used for the research work.

- i. Global positioning system (GPS)
- ii. A terrameter with a complete set of electrodes and cable reels
- iii. Existing topographic and geologic map of the area
- iv. Hammer and sampling bags
- v. Tape, ruler, padlock, pencil, pen and calculator
- vi. Data recording book
- vii. Water samples
- viii. MEIJI manufactured petrographic microscope
- ix. Atomic Absorption Spectrometry (AAS) (HACH 2800) model
- x. Multifunctional TDS/EC/PH/TEMP water quality meter tester
- xi. Compass clinometers
- xii. Water well sounder
3.2 METHODS

3.2.1 Preliminary Studies

Extensive literature review was carried out on the geology of the basement complex in North Central region, hydrogeology of the basement complex terrains, groundwater movement, definition of heavy metals and the health complications. Preliminary study was embarked upon to have a vivid background of the research terrain and to delineate areas to be sampled. Necessary literatures relating to the research were acquired and reviewed this includes a review of the general geology of Nigeria. Residents of Bariki and environs where the research was carried out were interviewed orally on possible negative effects of the artisanal mining activity going on in their environments also pits and wells were all visited to ascertain their locations and sanitary conditions.

3.2.2 Surface Geological Mapping

Topographical map of Paiko sheet 185NW of scale 1:50,000 was obtained and enlarged to scale 1:12,500. Rock lithology at outcrops was identified on the basis of texture and visual inspections of mineral composition using hand lens. The identification in hand specimen was refined by petrographic examination under plain polarize and cross polarized light of a MEIJI manufactured petrographic microscope of Np-107B model and serial number 000341.

Outcrop attitude (foliation strike and dip measurements) were obtained using compass clinometer. The geographic locations of the outcrops were obtained using etrex Garmin version of GPS (geographic positioning system) and outcrops were sampled with the aid of a geological harmer.

3.2.3 Micrographic Thin Section Preparation

A thin section is described as a 0.003mm (30μ m) thick slide of rock mounted in between two glass slide with the help of Canada balsam or epoxy. Thin sections of five representative rock samples were prepared.

Materials

- 1. Diamond and trim saws
- 2. Grinding motor and lap
- 3. Abrasive (Silicon Cabide)
- 4. Mounting table
- 5. Canada balsam

Cutting: The rock samples from the field were cut using diamond cutting saw. The saw was utilised in cutting a rock with regular thickness.

Lapping: This is the process of grinding to obtain a flat and smooth surface of the rock specimen attached to the glass. A piece of plate glass of about 8 in square and ¹/₄ in thick mounted on a wooden stand is used for the lapping process. The powdered abrasive (Silicon Carbide) is added to the surface of the grinding plate glass and water is also added to make slurry of the abrasive. The grinding is started with a coarser abrasive and ended with a finer one. After grinding the chip is thoroughly washed in the sink basin and allowed to dry in preparation for frosting.

Frosting: Frosting is the grinding of the glass slide to flatten it out and roughen the surface so the Canada balsam can bind well. The slide is placed on the grinder in the same orientation and grinded gently until the slide appears translucent. The glass slide is washed dry, ready for mounting.

Mounting: This is the point at which the rock cut chip is glued to the flat glass slide. The lapped slide of the rock chip is attached to the glass slide with the aid of Canada balsam. The rock cut chip is placed on the glass chip and slight gentle pressure is applied using the mounting stick, ensure that air bubbles are eliminated. The medium is permitted to air dry for few minutes to enable it attain a strong level of bond between the rock chip and slide.

Trimming: the trimming saw is used to reduce the chip to a size slightly smaller than the thin section (about 0.5mm).

Thinning: The slide is then gently grinded again to the correct thickness of about 0.03mm. The slide is grounded with care while water is been added and continuously viewed under the petrographic microscope until the desired section is achieved. When the desired thickness of 0.03mm is achieved excess gum and abrasives are removed with the aid of a blade and by thorough washing respectively. A glass cover slip is added to increase the clarity of the slide under the petrographic microscope and to protect the thin section from damage.

3.3.1 Groundwater Level Mapping and Hydraulic Head Determination

Depth to water table was obtained using a water well sounder. The ground surface topographic elevation at each location was determined with the aid of GPS. The water level elevation with respect to sea level was determined by subtracting depth to water level from ground surface topographic elevation above sea level to obtained the hydraulic heads.

3.3.2 Groundwater Sampling and Field Measurements

A total of fourteen (14) water samples were collected within the study area, eleven from domestic hand dug wells, one from borehole and the remaining two from pits at fourteen different locations within the study area. The samples were collected in precleaned 75cl plastic bottles containers because plastic gives least contamination that alters the water chemistry. For each plastic container of water sample collected for the determination of trace element, a drop of concentrated nitric acid (HNO₃) was added for trace element determination. The acid is to homogenies and prevents adsorption of trace elements to the wall of the plastic containers. Acidification stops most bacterial growth, blocks oxidation reaction and precipitation of cations. All wells inventories were recorded for plotting groundwater flow direction map.

3.4.0 Physico-chemical Parameters

The physical parameters measured in the field were temperature (T), pH, Electrical conductivity (EC) and total dissolved solid (TDS) using a multifunctional TDS/EC/PH/TEMP water quality meter tester. The samples were immediately transported to National geoscience research laboratory, Nigerian Geological survey agency Kaduna.

3.5.0 Geochemical Laboratory Analysis

The laboratory analysis was carried out at the National Geoscience Research laboratory center, Kaduna (NGRLC). Chemical analysis of the groundwater samples collected using Atomic Absorption Spectrometry (AAS) (HACH 2800) model DR machine (Spectrophotometer) to determine elemental concentration for toxic elements. The elemental concentrations were compared with standard concentration recommended for

water potability by WHO (2011) and NSDWQ (2007). Multimetal pollution effect was ascertained using MPI (Metal Pollution Index)

The MPI was obtained as follows:

 $MPI = \sum_{i=1}^{n} [Ci/(Mac)i]$

Where Ci = mean concentration

MAC maximum allowable concentration

3.6.0 Geo-electrical Resistivity Method

Field apparent electrical data acquisition

Schlumberger configuration for vertical electrical sounding (VES) was used to ascertain the pattern of resistivity variation with depth. The maximum electrical spacing employed was 50m. A total of twelve vertical electrical sounding was conducted within the study area both around the mines and along river channels to ascertain the resistivity variations within the study area for both aquifer and pollution plume evaluation.

CHAPTER FOUR

4.0 **RESULTS, INTERPRETATION AND DISCUSSION**

4.1 **Results of Surface Geological Mapping**

Geographical co-ordinates for locations of some outcropping rock bodies (BKr) are given in table 4.1.

LOCA	COOR	DINATES	LOCA	COOR	DINATES
TION			TION		
BKr 1	09° 30' 00.0"N	006° 32' 18.7"E	BKr 17	09°29' 43.9"N	006° 32' 16.7"E
BKr 2	09° 29' 53.7"N	006° 32' 18.5"E	BKr 18	09°29' 41.1"N	006° 31' 18.3"E
BKr 3	09° 29' 35.6"N	006° 32' 19.6"E	BKr 19	09°29' 38.4"N	006° 31' 16.4"E
BKr 4	09° 29' 32.3"N	006° 32' 29.8"E	BKr 20	09°29' 22.8"N	006° 31' 19.9"E
BKr 5	09° 29' 28.9"N	006° 32' 28.3"E	BKr 21	09°29' 18.1"N	006° 31' 16.1"E
BKr 6	09° 29' 17.0"N	006° 32' 23.0."E	BKr 22	09° 29' 21.1"N	006° 31' 19.3"E
BKr 7	09° 29' 14.3"N	006° 32' 19.9"E	BKr 23	09° 29' 32.0"N	006° 31' 21.8"E
BKr 8	09° 29' 58.9"N	006° 32' 42.7"E	BKr 24	09°29' 0.1"N	006° 32' 01.2"E
BKr 9	09° 29' 49.7"N	006° 32' 48.0"E	BKr 25	09°29' 10.9"N	006° 32' 19.7"E
BKr10	09° 29' 39.3"N	006° 32' 56.1"E	BKr 26	09°29' 39.4"N	006° 31' 15.3"E
BKr 11	09° 29' 20.6"N	006° 32' 47.6"E	BKr 27	09°29' 25.4"N	006° 31' 51.3"E
BKr 12	09° 29' 16.7"N	006° 32' 13.7"E	BKr 28	09°29' 23.1"N	006° 31' 26.1"E
BKr 13	09° 29' 23.5"N	006°31' 37.5"E	BKr 29	09°29' 01.3"N	006° 32' 22.0"E
BKr 14	09° 29' 32.6"N	006° 31' 41.0"E	BKr 30	09° 29' 06.1"N	006° 32' 16.3"E
BKr 15	09° 30' 00.0"N	006° 31' 34.7"E	BKr 31	09° 29' 10.5"N	006° 31' 35.8"E
BKr 16	09° 29' 55.7"N	006° 31' 19.2"E	BKr 32	09°29' 08.1"N	006° 31' 53.0"E

 Table 4.1: Geographical coordinates of outcropping rock bodies

The study area is part of Birnin-Gwari schist belt, characterized by near surface outcrops of underlying basement rocks with shallow overburden. The rock types within the study area are granite, gneiss, schist, amphibolite schist and quartzites. The Granite occupies approximately 10% of the mapped area. It intruded the schist and gneiss. The granite is fine grained and contains muscovite, quartz, biotite and feldspar. Quartzofeldspartic veins within, criss-cross the granite body. Some of these veins have a thickness of about 3 - 5cm wide in most continuous veining as shown in (Plate VI). Medium grained granite bodies outcropped within the study area (Plate VII).

The Schist are dominantly weathered rock with their mineralogy aligned in one direction in response to deformational stress which makes the rock split in parallel layered when forces are applied. Schist exposures cover more than half of the study area stretching to every location of the study area except areas where it is intruded by the granite, gneisses and the amphibolite schist. All mines are sited within the schist exposures. The schistosity is parallel to the bedding and dip between 30° to 46°E. Some of the exposures are brownish in color indicating weathering while other exposures are greenish indicating amphibolitic chemistry. The schist generally has a NE - SW orientation. The joints directions on both Schist and the granite were measured and recorded as indicated in appendix B, Table 4.2 shows the statistical summarized of the joint trends measured in the field. The metasediments (Quartzites) which could be describe as the metamorphism of sedimentary (arenaceous) rock. The constituent grains recrystallize and develop an interlocked mosaic textures with little or no trace of concentration. They are essentially made up of quartz and mica. They could be observed around NW within the granite intrusion and around NE within the amphibolitic schist all trending NE – SW direction. The map, figure 4.2 shows location where groundwater samples were taking and also indicates places of active mine and abundant mine sites within the study area. Figure 4.1 is a geological map of the study area showing different lithology as observed within the study area. Figure 4.3 shows Rosette diagram for joint trends within the study area.



Figure 4.1: Geological map of the study area



Figure 4.2: Sampling points within the study area

S/N	CLASS	FREQUENCY	SECTORAL
	INTERVAL	NUMBER	ANGLES
1	$00^\circ - 22.5^\circ$	6	13.3°
2	$23.5^\circ-045^\circ$	22	48.6°
3	046° – 067.5 $^\circ$	10	22°
4	$67.6^\circ - 090^\circ$	19	42°
5	091° – 112.5°	19	42°
6	113.5° – 135°	12	26.5°
7	$158.5^\circ - 180^\circ$	16	35.3°
8	$181^\circ - 202.5^\circ$	17	37.5°
9	$203.5^\circ - 225^\circ$	1	2.2°
10	$226^\circ-247.5^\circ$	3	6.6°
11	$248.5^\circ-270^\circ$	4	8.8°
12	$271^\circ - 292.5^\circ$	6	13.3°
13	293.5° – 315°	3	6.6°
14	$316^\circ-337.5^\circ$	6	13.3°
15	$338.5^\circ - 360^\circ$	19	42°
	TOTAL	163	360 °

 Table 4.2: Statistical data for joint trends in the study area



Plate VI: Fine grained granite body with quartzo-feldsphatic veins at 09° 29' 35.6"N 006° 32' 19.6"E.

Medium grained granite bodies also outcropped (Plate VII).



Plate VII: Medium grained granite body at N09° 29' 53.7" E006° 32' 18.5"

Plates VIII, IX, X and XI are photomicrographs for the granite.



Plate VIII: PP Biotite granite

Plate IX: XP Biotite granite



Plate X: PP granite



Plate XI: XP granite

B= Biotite, Q= Quartz, ORTH= Orthoclase

Plate XII is the muscovite schist.



Plate XII: Muscovite schist at N09° 29' 58.9" E006° 32' 42.7"

Plate XIII is the amphibole schist.



Plate XIII: Amphibole schist at **N**09° 29' 17.0" E006° 32' 48.0."

Micrographs for the amphibole schist are plates XIV and XV.





 Plate XIV: PP Amphibolite Schist
 Plate XV: XP Amphibolite Schist

B= Biotite, Q= Quartz, ORTH= Orthoclase, A= Amphibole

The gneiss outcrop is shown in Plate XVI.



Plate XVI: Gneiss outcrop at N09° 29' 25.8" E006° 31' 19.9"

The gneiss has suffered the most deformation in the area. Part of its deformation are large isoclinal folding and strike slip faulting shown in Plate XVI above. By virtue of the deformation, gneiss is the oldest rock in the area. Micrographs for the gneiss are Plates XVII and XVIII.





Plate XVII: PP Gneiss

Plate XVIII: XP Gneiss

B= Biotite, Q= Quartz, ORTH= Orthoclase

The quartzite outcrop body is Plate XIX.



Plate XIX: Quartzite N09° 29' 39.3" E006° 32' 56.1"

The schist bodies strike N-S and dip 30° to $40^{\circ}E$

The geological map produced from the field outcrop observations is given as Figure 4.2



Plate XX: Joint sets in a medium grain granite 09° 29' 28.9"N, 006° 32' 28.3"E Joint sets (plate XX) are common in the granitic outcrops. The joints direction measurements are presented in appendix B. The rosette diagram for joint trends measured is shown in figure 4.3. Table 4.2 shows the statistical summary for joint trends measured in the field. The directions of the joint trends are NNE –SSW and NNW – SSE. These two constitutes a conjugate joint set. The NNE – SSW are strike joints, approximating the joints direction while the NNW – SSE are dip joints.



Figure 4.3: Rosette diagram for joint trends within the study area QuartzoFeldspathic veins are found cutting through many of the outcrop as seen in plate VI and plate XVI. The statistical summary in Table 4.2 was used to produce the above rosette diagram in figure 4.3.

4.2 Results of Groundwater Level Mapping

The field measurement data for groundwater level mapping is shown in Table 4.3.

Table 4.3:	Ground	lwater	level	mappi	ing c	lata
-------------------	--------	--------	-------	-------	-------	------

Location	Co-or	dinates	Altit	SWL	Depth	Hydraulic
			ude((m)	of well	Head (m)
			m)		(m)	
BKW 1	09°29'54.0"N	006° 32' 56.5"E	242	0.4	4.0	241.6
BKW 2	09°29' 28.3"N	006° 32' 04.5"E	217	0.3	1.5	216.7
BKW 3	09°29' 28.7"N	006° 32' 05.7"E	223	1.2	5.2	221.8
BKW 4	09°29' 31.7"N	006° 32' 05.7"E	223	2.8	4.1	220.2
BKW 5	09°29' 46.3"N	006° 31' 07.5"E	223	2.1	0.8	220.9
BKW 6	09°29' 43.8"N	006° 31' 17.9"E	227	1.33	5.7	225.67
BKW 7	09°29' 55.3"N	006° 31' 16.2"E	226	0.26	0.5	225.74
BKW 8	09°30' 00.0"N	006° 31' 26.8"E	215	4,8	5.2	210.2
BKW 9	09°29' 32.9"N	006° 31' 50.3"E	226	0.7	1.26	225.3
BKW 10	09°28' 59.2"N	006° 31' 45.0"E	249	4.15	4.4	244.85
BKW 11	09°28' 06.1"N	006° 32' 16.1"E	211	2.1	3.7	208.9



Figure 4.4: Groundwater flow direction map

The groundwater flow direction map produced from the data in Table 4.3, using the hydraulic heads values is shown in Figure 4.4. The map reveals that groundwater flow Southeastern and Northwestern directions within the study area.

4.3 Results of Physical Parameters Measurements

Figure 4.5, 4.6 and 4.7 are contoured maps of pH, TDS (Total Dissolved Solids) and EC (Electrical Conductivity).

LOC.	LAT.	LONG.	ELEV.	TEMP	pН	EC	TDS
CODE			(m)	(⁰ C)		(µS/c m)	(PPM)
BKW 1	09°29'54.0"N	006° 32' 56.5"E	217	25.2	6.62	355	178
BKW 2	09°29'28.3"N	006° 32' 04.5"E	223	24.8	6.72	798	398
BKW 3	09°29'28.7"N	006° 32' 05.7"E	223	26.0	6.24	1090	545
BKW 4	09°29'31.7"N	006° 32' 05.7"E	227	26.7	6.61	280	140
BKW 5	09°29'46.3"N	006° 31' 07.5"E	226	25.6	6.35	83	41
BKW 6	09°29'43.8"N	006° 31' 17.9"E	215	23.5	8.04	98	49
BKW 7	09°29'55.3"N	006° 31' 16.2"E	226	23.4	7.37	109	54
BKW 8	09°30'00.0"N	006° 31' 26.8"E	249	24.4	8.47	377	188
BKW 9	09°29'32.9"N	006° 31' 50.3"E	211	29.2	6.51	75	37
BKW 10	09°28'59.2"N	006° 31' 45.0"E	214	29.7	7.78	203	102
BKW 11	09°28'06.1"N	006° 32' 16.1"E	212	28.8	9.35	108	53.7

 Table 4.4: Results of measured physical parameters



The PH value is lowest at BKW 11, probably due to presence of an active mine.



Figure 4.6: TDS contoured map

The dissolved solids is highest around BKW 11 due to more solids released from the active mine and the slightly acidic environment.



Figure 4.7: EC contoured map

The EC values are highest around BKW 11 because of highest dissolved solids and lowest pH values there. All the physical parameters obtained are within the limits accepted by WHO (2011) and NSDWQ (2007) as shown in Table 4.4.

Elemental concentration values obtained for the toxic elements are shown in Table 4.6.

4.3.1 Temperature

The temperature of groundwater varies from place to place with respect to depth, the deeper the occurrence of groundwater the higher the temperature of the area. However, high temperature does not imply impurity. The temperature of surface water varied from 23.5 to 29.5°C while that of underground water is 23.5 30.7°C both surface and groundwater temperature has a mean average of 26.34°C which is consistent with the ambient temperature as recommended by both (WHO 2011) and (NSDQW 2007).

4.3.2 pH

This is the degree of acidity or basicity of an aqueous solution. It is required by the NSDWQ (2007) and WHO (2011) that the pH of a safe drinking water should range between (6.5 - 8.5 and 7 - 8.5) respectively. Out of the eleven samples analyse only three are slightly acidic ranging within 6.22, 6.24 and 6.31 in BKW 2, BKW 3 and BKW 5 while the remaining falls within the required limit set by both (WHO 2011) and (NSDQW 2007).

4.3.3 Electrical Conductivity

This is the ability of water to conduct electric current or it can be a measure of the salinity or level of impurity in water sample. It has a standard of 1000μ S/cm and all the eleven sample analyse falls below the minimum standard required for drinking quality water by both (NSDWQ 2007) and (WHO, 2011). The mean average of the eleven samples is 297.57 μ S/cm.

 Table 4.5: Comparing physical parameters data analysed with WHO (2011) and NSDWQ (2007) standard

Physical parameter	BKW 1	BKW 2	BKW 3	BKW 4	BKW 5	BKW 6	BKW 7	BKW 8	BKW 9	BKW 10	BKW 11	WHO (2011)	NSDWQ (2007)
TEMP(^o c)	25.0	28.8	26	26.7	25.6	23.5	23.4	24.4	29.2	29.7	28.8	VARIABLE	VARIAB LE
рН	6.62	6.22	6.24	6.61	6.31	8.04	7.37	7.47	6.51	7.78	7.01	7 - 8.5	6.5 - 8.5
EC(µS/cm)	355	798	850	280	83	98	109	377	75	203	108	1000	1000
TDS(PPM)	178	398	545	140	41	49	54	188	37	102	53.7	1000	500

4.3.4 Total Dissolve Solids

This comprise of both the inorganic salt and small amount of organic and natural matter that have dissolve in water. TDS in drinking water comes from natural option, sewage, surface run off and industrial spends water. The mean average of the TDS in the study area is 148.55 mg/l while the permissible standard limit is 500 mg/l and 1000 mg/l by both (NSDWQ, 2007) and (WHO, 2011).

4.4 **Results of Elemental Concentration Analysis for Toxic Elements**

Heavy	BKW	BKW	BKW	BKW	BKW	BKW	BKW	BKW	BKW	BKW	BKW
metal (ppm)	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11
Fe	6.27	13.17	14.86	8.09	120.67	2.14	3.33	1.22	33.66	38.07	8.34
Со	0.07	0.11	0.50	0.17	0.05	0.17	0.24	0.16	0.02	ND	0.11
Zn	ND	0.03	ND	ND	ND	ND	0.01	0.13	0.01	0.14	ND
Cd	0.15	ND	0.17	0.21	0.08	ND	ND	ND	0.05	0.09	0.07
Mn	0.11	1.49	ND	ND	0.33	1.06	0.72	1.57	0.43	1.38	0.90
Cu	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.002	ND
Ni	0.67	ND	0.85	0.06	0.30	0.09	0.08	0.67	0.02	ND	ND
Cr	0.63	ND	3.75	1.18	2.14	1.03	0.49	0.79	0.75	0.82	0.64
Pb	ND	ND	ND	ND	0.03	0.02	ND	ND	0.07	0.10	0.08
As	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

 Table 4.6: Concentration values for the potentially toxic elements

ND= Not detected

Heavy	BKW	BKW	BKW	BKW	BKW	BKW	BKW	BKW	BKW	BKW	BKW	Mean	WHO	NSDWQ
metal	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11		(2011)	(2007)
(ppm)														
Fe	6.27	13.17	14.86	8.09	120.67	2.14	3.33	1.22	33.66	38.07	8.34	22.71091	0.2	0.3
Со	0.07	0.11	0.5	0.17	0.05	0.17	0.24	0.16	0.02	0.00	0.11	0.145455		
Zn	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.13	0.01	0.14	0	0.029091	5	0.3
Cd	0.15	0.00	0.17	0.21	0.08	0.00	0.00	0.00	0.05	0.09	0.07	0.074545	0.003	
Mn	0.11	1.49	0.00	0.00	0.33	1.06	0.72	1.57	0.43	1.38	0.9	0.726364	0.5	0.2
Cu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.002	0.00	0.000182		1
Ni	0.67	0.00	0.85	0.06	0.3	0.09	0.08	0.67	0.02	0.00	0.00	0.249091	0.02	0.02
Cr	0.63	0.00	3.75	1.18	2.14	1.03	0.49	0.79	0.75	0.82	0.64	1.110909	0.05	0.05
Pb	0	0	0	0	0.03	0.02	0	0.1	0.07	0.10	0.08	0.0372	0.01	0.01
As	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01

Table 4.7: Comparing toxic element concentration values, with WHO (2011) and NSDWQ (2007)



Copper (Cu) is an essential substance to human life, but in high concentrations it can cause anaemia, liver and kidney diseases in addition to stomach and intestinal disorder. The permissible limit of copper intake in water is 1.0mg/l by WHO (2011). In the study area copper does not constitute a public health risk for now because there is no concentration exceeding the above standard.



Figure 4.9: Concentration map for zinc (ppm)

Zinc (Zn) concentration in water and soil is a function of the composition of parent rock, as well as anthropogenic activities such as mining, agriculture and domestic waste. Zinc is an essential element for growth for both plants and animals and can be toxic at an elevated concentration which could result in to phyto-toxicity. Acute zinc intoxication could also lead to nausea, vomiting, severe anaemia and renal failure. The concentration of zinc ranges between 0 - 0.14ppm and a mean value of 0.029ppm respectively and when correlated to the standards sets by both WHO (2011) and NSDWQ (2007) of 5 and 0.3mg/l, it falls below the maximum permissible limit.

The concentration of both metals (copper and Zinc) decreases southwards in same direction as groundwater flow due to dilution effect. The concentration for the metals is within acceptable limits in the water. Figures 4.10 and 4.11 are concentration maps for cobalt and nickel respectively.



Figure 4.10: Concentration map for cobalt

Cobalt (Co) is carcinogenic and the health effects include Bronchitis and inflammation of tissue. The concentration of cobalt ranges from 0ppm to 0.5ppm with an average mean value of 0.15ppm respectively. The WHO (2011) and NSDWQ (2007) has no standard for cobalt.



Figure 4.11: Concentration map for nickel (ppm)

Nickel (Ni) concentration in water samples analysed has a range of 0 ppm – 0.85 ppm, under a set standard of 0.002mg/l by both WHO (2011) and NSDWQ (2007). Nickel has been a major component in the production of stainless steel, non – ferrous alloys and super alloys. Concentration of Cobalt and Nickel decrease southwards. The southward decrease is upset by the presence of active mine near BKW11 ($6^{\circ}32'6.5$ "E; 9°29'25"N). Nickel concentration is above accepted limits at BKW 1, BKW 3, BKW 5, BKW 7 and BKW 8.

Figures 4.12 and 4.13 are concentration maps for cadmium and manganese.



Figures 4.12: Concentration map for cadmium

Cadmium (Cd) solubility increase under low pH, and form soluble complex which greatly increase its mobility and could lead to absorption of cadmium by the soil colloids, hydrous oxides and organic matter. At high pH values greater than 6, cadmium is absorbed by the soil solid phase or is precipitated and the solution concentration of cadmium is being reduced. Cadmium concentration in the groundwater analysed varied between 0ppm - 0.21ppm.



Figure 4.13: Concentration map for manganese

Manganese (Mn) is essential for plant and animal growth and development. Manganese can be absorb by soil and the extend of adsorption depend on the organic content and cation exchange capacity of the soil The concentration of manganese in the water samples analysed range from 0ppm – 1.57ppm.

The southward decrease is interrupted by the active mine near BKW11 (6°32'6.5"E; 9°29'25"N). Cadmium concentration is above accepted limits at BKW 1, BKW 3, BKW 4, BKW 5, BKW 9, BKW 10 and BKW 11. Manganese concentration is above accepted limits at BKW 2, BKW 6, BKW 7, BKW 8, BKW 10 and BKW 11.

Concentration map for lead is given as Figure 4.13. The concentration generally decreases southwards.



Figure 4.14: Concentration map for lead

Lead (Pb) concentration in groundwater analysed range between 0ppm and 0.11ppm with a mean value of 0.04ppm approximately. Toxicity due to lead exposure is called lead poisoning. Lead poisoning is mostly related to the gastrointestinal tract and central nervous system in children and adults. Lead poisoning can be either acute or chronic.

Exposure to elevated levels of lead can cause the plasma membrane of the blood brain barrier to move into the interstitial spaces leading to edema. Also, lead exposure can disrupt the intracellular second messenger systems and alter the functioning of the central nervous system. Developing fetuses and children are most vulnerable to neurotoxic effects due to lead exposure. Although lead poisoning is preventable, it still remains a dangerous disease as it can affect most of the organs of the body (Godwill *et al*, (2019).)

Lead concentration is above accepted limits at BKW 5, BKW 6, BKW 9, BKW 10 and BKW 11.



Figure 4.15: Concentration map for chromium (ppm)

The minimum and maximum values of chromium ranges from 0ppm - 3.75ppm and a mean of 1.1ppm. This shows much more concentration around Gado village. Chromium compounds can result in the formation of ulcers such as nasal septum ulcer which are very common in chromate workers. Exposure to higher amounts of chromium compounds in humans can lead to the inhibition of erythrocyte glutathione reductase,

which in turn lowers the capacity to reduce methemoglobin to hemoglobin (Godwill *et al*, (2019).

The general southward decrease of this concentration is upset by the active mine near BKW11 (6°32'6.5"E; 9°29'25"N). The concentration is above accepted limits at BKW 1, BKW 3, BKW 4, BKW 5 BKW 6, BKW 8, BKW 9, BKW 10 and BKW 11. The concentration map for iron is shown in Figure 4.16.



Figure 4.16: Concentration map for iron (ppm)

The concentration is above accepted limits at all the locations. Iron is one of the most abundant elements on earth. Rain water dissolves it mainly because it infiltrates the soil to the underlying geological formations. Although iron is not hazardous to the health, it is considered a secondary or aesthetic contaminant. Iron is essential for good health as it helps transport oxygen in the blood. Iron cause test and odor problem in water and may result in red water coloration when it exceeded the maximum permissible limit of 0.3mg/l by Nigerian standard NSDWQ (2007) and 0.1mg/l for WHO (2011) standard. The study area has a minimum and maximum value of 1.22ppm and 120.67ppm respectively, Iron concentration in all the water samples analysed is generally high but it

is higher in sample locations BKW 2, BKW 5, BKW 9 and BKW 10 respectively this anomalous concentration of iron in the water sample of the entire study area may be due to the geology of the underlying rocks in the study area which are predominantly schistose in nature and even amphibolitic that are showing weathering to some extent and are also rich in iron bearing mineral and it could be due to the chemical weathering of rocks and lateralization. The concentration of iron is shown in the figure above. Table 4.8 shows the data for MPI estimation

S/ Para **COORDINATES** Ci MACi [Ci MPI /(Mac)i] Ν mete rs 1 Fe N09°29' 54.0" 006°32'56.5" 22.7109 0.3 75.703 2 Co N09°29' 28.3" 006°32'04.5" 0.1455 0.01 14.55 3 Zn N09°29' 28.7" 006°32'05.7" 0.0291 0.3 0.097 4 Cd N09°29' 31.7" 006°32'05.7" 0.0745 0.02 3.725 5 Mn N09°29' 46.3" 006°31'07.5" 0.7264 0.20 3.632 6 Cu N09°29' 43.8" 006°31'17.9" 0.0002 1.0 0.0002 7 Ni N09°29' 55.3" 006°31'16.2" 0.2491 0.02 12.455 8 Cr N09°30' 00.0" 006°31'26.8" 1.1109 0.05 22.218 9 Pb N09°29' 32.9" 006°31'50.3" 0.0312 0.01 3.12 10 As N09°29' 59.2" 006°31'45.0" 0 0.01 0 135.5002

Table 4.8: MPI estimation data

The MPI value of 135.5002 shows that the groundwater is very highly polluted due to cumulative multi-metal effect

4.5 Results of Geo-electrical Resistivity Measurements

The geo-electrical sounding data obtained is given in Table 4.9.

Schlumberger configuration for vertical electrical sounding (VES) was employ to ascertain the pattern of resistivity variation with depth and the maximum electrical spacing employed was 50m. A total of twelve VES was conducted within the study area both around the mines and along river channels to ascertain the resistivity variations within the study area for both aquifer and pollution plume evaluation.

Table 4.9: Results of geo-electrical data

AB	MN	VE	VE	VE	VE	VE	VE	VE	VE	VE	VES	VES	VES
/2	/2	S 1	S2	S 3	S4	S5	S 6	S7	S 8	S 9	10	11	12
1	1	41	39	135	88	386	765	142	842	251	390	225	110
2	2	18	47	53	52	142	530	130	623	324	257	300	107
3	3	16	43	42	51	84	324	123	521	349	239	180	91
5	4	18	34	56	109	67	206	128	322	365	205	200	92
6	5	17	32	52	137	61	195	122	319	433	162	247	108
8	6	25	32	53	201	57	198	125	322	367	110	362	135
10	7	28	36	54	280	55	210	126	324	245	85	502	212
15	8	55	49	36	385	77	231	138	333	188	98	581	276
20	9	71	63	40	315	101	247	150	342	153	116	681	370
30	10	108	104	50	305	150	270	170	368	126	142	832	435
40	11	137	143	62	375	201	325	200	402	137	175	923	477
50	12	161	167	68	431	236	340	194	428	183	198	958	578

The sounding curves are given in Appendix C.


Figure 4.17: Iso – resistivity map for the regolith

The regolith resistivity generally shows decreases in the NW, NE and SE ward in conformity with the general groundwater flow and TDS directions.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusions

Surface geological mapping and thin section analysis reveals the dominant lithology units to be granite and schist, other lithologic unites are gneiss, quartzites and amphibolites.

The groundwater level mapping reveals that groundwater flow Northwestern and southeastern directions within the study area.

All physical parameters such as pH, Electrical conductivity and total dissolve solids falls within the permissible standard set by WHO (2011) and NSDWQ (2007) except for pH in BKW 2, BKW 3 and BKW 5.

The AAS result reveals that concentration of cadmium, manganese, lead and iron are above WHO (2011) and NSDWQ (2007) accepted limits.

Metal pollution index (MPI) of 135.5002 indicates the groundwater is very highly polluted in the study area due to multimetal effects.

The toxic elements concentration generally decrease southward due to dilution effect.

The isoresistivity map indicates Northwestern and southeastern decrease resistivity in the direction of groundwater flow.

The Northwestern and Southeastern decrease in toxic element concentration is disturbed at location of active mining site, there by indicating mining related groundwater pollution.

5.2 Recommendation

Potable water can be obtained from the SSW portion of the study area. Subsequently, studies of this type and more should be carried out in feature to check the portability of water within the study area. Proper regulation of the mining activities within and around the study area must be regulated by the government to avoid groundwater contamination.

REFERENCES

- Abdulahi, S. (2014). Effect of artisanal gold mining on surface and groundwater at Maiwayo and Gada-Eregi village, Minna-Bida road North-central Nigeria.
- Adegoke, J. A., Agbaje, W. B. & Isaac, O.O. (2009). Evaluation of toxic element status of water and soil at Ikogosi warm Spring, Ondo State of Nigeria. *Ethiopian Journal of Environmental Studies and Management*, 2(3). 81-83
- Adekoye, J. A. (2003). Environmental effect of solid minerals mining, *Journal of Physical Science*, 21(9), 625-640
- Adler, R. & Rustler, J. (2007). A strategy for the management of acid mine drainage from gold mines in Gauteng. Contract Report for Thutuka (Pty) Ltd. Submitted by the Water resources governance systems research group, csir: Pretoria. Report No. CSIR/NRE/PW/ER/2007/0053/C
- Ajusa, J. (2003). A review of refractory ore process, A & B Metallurgical Consultants, Kwekwe, Zimbabwe. *Journal of Earth Sciences* 23, 42-50.
- Akabzaa, T. M. (2000). Impact of mining sector in Ghana: A study of the Tarkwa mining region. report submitted to SPAPRI, Ghana, 175.
- Akankpo, A. O., & Igboekwe, M. U. (2011). Monitoring groundwater contamination using surface electrical resistivity and geochemical methods. *Journal of Water Resource and Protection*, 3(5). 12-14.
- Akhilesh, J., Savita, D & Suman, M. (2009). Trace elements investigation in groundwater of Bhopal and Sehore district in Madhya Predesh, India. *Journal of Apply Science and Environmental Manage*, 13, (4), 47-50.
- Amadi, A. N. (2011). Quality assessment of Aba River using toxic element pollution index. American Journal of Environmental Geology, (1) 1-5.
- Amadi, A. N. & Nwankwala, H. O. (2013). Evaluation of toxic element in soil from Enyimba dumpsite in Aba, south eastern Nigeria using contamination factor and geo accumulation index. *Energy and environmental research*, 3 (1), 125-134.
- Dada, S. S. (2006). Proterozoic evolution of Nigeria. In: Oshi O (Ed.), The basement complex of Nigeria and its mineral resources (A Tribute to Prof. M. A. O. Rahaman), (29-44.). Ibadan: Akin Jinad & Co.
- Darcy, H. (1856). *Les fontaines publiques de la ville de Dijon: exposition et application.* Victor Dalmont, 1856.

- European Environmental Bureau, (EEB, 2000). The environmental performance of the mining industry & the action necessary to strengthen European legislation in the wake of the Tisza Danube pollution EEB, 16, 16-21.
- Falconer, J.D. (1911). *The geology & geography of Northern Nigeria*. London, Macmillan and Company Limited.
- Grant, N. K. (1978). Structural distinction between a meta-sedimentary cover and an underlying basement in the 600 Ma old Pan-African domain of North-western Nigeria. *Geological Society of America, Bulletin*, 89, 50-58.
- Godwill, A. E., Paschaline, U. F, Friday, N. N. & Marian N. U (June 19th 2019). Mechanism and health effects of toxic element toxicity in humans, Poisoning in the Modern World: <u>https://www.intechopen.com/books/poisoning-in-the-modernworld-new-tricks-for-an-old-dog-/mechanism-and-health-effects-of-heavy-metal</u>
- Hanaa, M., Salem, A. Eweida, E. & AzzaFarag. (2000). Heavy metals in Drinking Water and their environmental impact on human health. *ICEHM* 2000: 542-556.
- Harter, T. (2003). Basic concepts of groundwater hydrology. UCANR Publications, 279.
- Henriet, J. P. (1976). Direct applications of the Dar Zarrouk parameters in ground water surveys. *Geophysical prospecting*, 24(2), 344-353.
- Human Right Watch (2012). Report on Zamfara State's Lead & Mercury poisoning due to artisanal gold mining activities within the communities affected. *Journal of environment*, *34*, 193-198.
- Larceda, L. D. (1997). Global mercury emissions from gold and silver mining water, air, soil pollution, 97, 209 221.
- Maillet, R. (1947). The fundamental equations of electrical prospecting. *Geophysics* 12(4), 551-556.
- Martins, O. (2001). Water resource management and development in Nigeria *Issues* and Challenges in a New Millennium.11-20.
- McCurry, P. (1976). The Geology of the Precambrian to lower Palaeozoic rocks of Northern Nigeria. A review In: Kogbe C.A. (Ed.). *Geology of Nigeria*. Lagos: Elizabethan Publishers, 15–39.
- NSDWQ (2007). Nigerian Standard for Drinking Water Quality. Standard Organization of Nigeria. Retrieved from: http://www.unicef.org/Nigeria/ng publication Nigeria Standard for Drinking Water Quality pdf.
- Nigerian Metrological Agency (NIMET, 2010). Summary of climatic condition of Minna from 2002 2012.

- Niwas, S. & Singhal, D. C. (1981). Estimation of aquifer transmissivity from Dar-Zarrouk parameters in porous media. *Journal of Hydrology*, 50, 393-399.
- Obaje, N. G. (2009). *Geology and mineral resources of Nigeria*. Berlin: Springer-Verlag, Heidelberg. 221.
- Olade, M. A. & Elueze A. A. (1979). Petrochemistry of the Ilesha Amphibolite and Precambrian crustal evolution in the Pan-African domain of SW Nigeria. *Precambrian Research*, 8, 303–318.
- Olarewaju, V.O. (2006). The charnockitic Intrusive of Nigeria. In: Oshi O. (ed.) The basement complex of Nigeria and its mineral resources (A Tribute to Prof. M. A. O. Rahaman). Ibadan: Akin Jinad & Co. 45–70.
- Oyawoye, M. O. (1972). The basement complex of Nigeria. In: *African geology* (T.F.J. Dessauvagie & A. J. Whiteman, Eds.). Ibadan University Press, Ibadan. 67-99.
- Prasad, B., Kumari, P. Bano, S. & Kumari, S. (2014). Groundwater quality evaluation near mining area and development of heavy metal pollution index. *Applied Water Science*, 4(1), 11-17.
- Rahaman, M. A. (1981). Recent advances in the study of the Basement Complex of Nigeria. *First Symposium on the Precambrian Geology of Nigeria*.
- Rahaman, M. A. (1988). Recent advances in the study of the Basement Complex of Nigeria In: Geological Survey of Nigeria. *Precambrian Geology of Nigeria*, 11– 43.
- Rahaman, M. A. & Lancelot J. R. (1984). Continental crust evolution in SW Nigeria, constraints from U/Pb dating of Pre-Pan-African gneisses In: Rapport d'activite 1980–1984. Documents et Travaux du Centre Geologique et Geophysique de Montpellier, 4, 41.
- Rahaman, M. A. & Ocan, O. (1978). Relationships in the Precambrian migmatitegneisses of Nigeria. *Nigerian Journal of Mining and Geology*, 15, 23–32.
- Singovszka, H., Magdalena, B. Stefan, D. & Petra, P. (2017). Metal pollution indices of bottom sediment and surface water affected by acid mine drainage. Faculty of civil engineering, institute of environmental engineering Technology, University of Kosice, Vysokoskolska Kosice, Slovakia. *Journals of Metals* 7 (8).
- Singh, P. K., Verma, P. Tiwari, A. K. Sharma, S. & Purty, P. (2015) Review of various contamination index approaches to evaluate groundwater quality with Geographic Information System (GIS). 67-83
- Taylor, S. R., & Mclennan, S.M. (1995). The geochemical evolution of continental crust. *Journal of Applied Geophysics*. 33(2), 241-265.

- Tijani, M. N., Okunlola, O. A. & Abimbola, A. F. (2006). Lithogenic concentrations of trace metals in soils and saprolites over crystalline basement rocks: A case study from SW Nigeria. *Journal of African Earth Sciences*, 46(5), 427-438.
- Todd, D. K. & Mays, L. W. (2005). Groundwater hydrology edition. New Jersey: Wiley. 89 - 90.
- Tubosun, I. A., Lancelot, J. R. Rhaman, M. A. & Ocan, O. (1984). U-Pb Pan-African ages of two chearnockite granite associations from Southwestern Nigeria, contributions to mineralogy and petrology, 88 (188-195).
- Unuevho, C. I., Ancho, M. Amadi, A. N. Onuoha, K. M. and Ogunbanjo, M. I. (2016). Application of geosciences Technique for the assessment of dumpsite leachates and groundwater pollution in regolith aquifers. *Journal of Hydrological sciences* 4(1), 161-180.
- Water Aid (2006). Curbing water borne diseases in Nigeria: waterfront magazine, 18(1), 26-27.
- World Health Organization (2010). Guide lines for drinking water quality 1, Geneva, Netherlands.
- WHO (2011). World Health Organisation, Guidelines for Drinking Water Quality (4th Edition) World Health Organisation, Geneva.
- Yusuf, A., Olasehinde, A. Mboringong, M. N., Table, R. P & Danel D. (2017). Evaluation of toxic element concentration in groundwater around Kashere and its environs, upper Benue through, Northeastern Nigeria.

Zohdy, A. A. (1974). Use of Dar Zarrouk curves in the interpretation of vertical electrical sounding data. *United States Geological Survey Bullet*.35-42.

S/N	Strike	Dip	S/N	Strike	Dip	S/N	Strike	Dip
1.	175 ⁰	68 ⁰	21.	333 ⁰	-	41	108 ⁰	-
2.	088^{0}	38 ⁰ -	22.	109^{0}	68^{0}	42	110^{0}	-
3.	073 ⁰	25 ⁰ -	23.	60^{0}	-	43.	148^{0}	-
4.	030 ⁰	44 ⁰	24.	308 ⁰	-	44.	114 ⁰	84^{0}
5.	36 ⁰	44 ⁰	25.	12^{0}	-	45.	109 ⁰	72^{0}
6.	77^{0}	70^{0}	26.	182^{0}	-	46.	111^{0}	-
7.	52 ⁰	71 ⁰	27.	98 ⁰	81 ⁰	47.	181^{0}	16 ⁰
8.	14 ⁰	75 ⁰	28.	239 ⁰	-	48.	15 ⁰	50^{0}
9.	60^{0}	45 ⁰	29.	125^{0}	60^{0}	49.	134 ⁰	-
10.	40^{0}	82^{0}	30.	150^{0}	36 ⁰	50.	241 ⁰	-
11.	40^{0}	68 ⁰ -	31.	188^{0}	45 ⁰ -	51.	147 ⁰	-
12.	22^{0}	68 ⁰	32.	340^{0}	-	52	186 ⁰	75 ⁰ E
13.	010 ⁰	78 ⁰ -	33.	323 ⁰	28^{0}	53	014 ⁰	64 ⁰
14.	240^{0}	44 ⁰ -	34.	308 ⁰	78^{0}	54	77^{0}	70^{0}
15.	188^{0}	-	35.	108^{0}	46^{0}	55	36 ⁰	52 ⁰
16.	239 ⁰	-	36.	185^{0}	-	56	193 ⁰	34 ⁰
17.	273 ⁰	-	37.	71^{0}	-	57	260^{0}	75^{0}
18.	209^{0}	40^{0}	38.	51 ⁰	67 ⁰ -	58	171^{0}	82 ⁰
19.	303 ⁰	76 ⁰	39.	180^{0}	69 ⁰	59	078^{0}	61 ⁰
20.	230^{0}	66 ⁰	40.	290^{0}	70^{0}	60	62 ⁰	56 ⁰
61	85 ⁰	51 ⁰	62	73	25^{0}			

APPENDIX A

Strike and dip values of joints on Rocks of Bariki and environs

APPENDIX B

180°, 037°, 197°	098°, 073°, 110°	354°, 143°, 321°	146°, 354°, 139°
182°,130°, 184°	056°, 032°, 132°	180°, 198°, 278°	170°, 139°, 142°
130°,021°, 087°	144°, 181°,101°,	118°, 356°, 290°	341°, 359°, 156°
026°, 095°, 042°	115°, 092°, 047°	330°, 360°, 241°	293°, 331°, 213°
042°, 120°, 082°	321°, 180°, 180°	250°, 352°, 344°	229°,171°, 151°
101°, 076°, 172°	330°, 230°, 284°	354°, 339°, 355°	141°, 320°, 197°
188°, 170°, 070°	270°,267°, 345°	274°, 358°, 171°	130°, 183°, 170°
026°, 095°, 042°	179°, 156°, 341°	111°. 212°, 241°	028°, 182°, 182°
021°, 084°, 087°	042°, 042°, 042°	036°, 024°, 032°	012°, 082°, 058°
010°, 017°,101°	087°, 026°, 170°	032°, 120°, 036°	026°, 120°, 295°
182°, 172°, 132°	101°, 180°, 340°	036°, 358°, 311°	188° , 354°, 024°
050°, 170°, 060°	165°, 024°, 058°	026°, 172°, 017°	027°, 032°, 162°
120°, 192°, 154°	340°, 270°, 123°	280°, 191°, 320°	342°, 276°, 050°
173°, 087°, 120°	042°, 170°		

FRACTURES RECORDED WITHIN THE STUDY AREA

APPENDIX C

Log – Log Graph of Apparent resistivity versus Current electrode spacing AB/2 of VES Stations in Bariki and its environs



ER.1. 09⁰29'55.7"N, 006⁰32'42.9"E. (234M)



ER.2. 09⁰29'39.5"N, 006⁰32'44.0"E. (227M)



ER.3. 09°29'31.6"N, 006°31'54.3"E. (213M)



ER.4. 09º29'26.4"N, 006º31'31.5"E. (210M)



ER.5. 09⁰29'14.2"N, 006⁰32'00.6"E. (212M)



ER.6. 09⁰30'07.7"N, 006⁰31'38.3"E. (233M)



ER. 7.09⁰29'08.9"N, 006⁰31'03.6"E. (195M)



ER.8.09⁰29'20.7"N, 006⁰31'34.4"E. (200M)



ER.9.09⁰29'06.1"N, 006⁰32'06.1"E. (207M)



ER. 10.09⁰29'46.3"N, 006⁰31'07.3"E. (226M)



ER.11.09⁰29'59.2"N, 006⁰31'45.0"E. (214M)



ER.12.09°30'00"N, 006°32'18.7"E. (253M)