GROUNDWATER SURVEY IN BIDA BASIN, NIGER STATE NIGERIA USING ELECTRICAL RESISTIVITY DATA AND THREE-DIMENSIONAL GEOGRAPHICAL INFORMATION SYSTEM.

ISHAKU BASHIR YAKUBU

UNIVERSITI SAINS MALAYSIA

2014

GROUNDWATER SURVEY IN BIDA BASIN, NIGER STATE NIGERIA USING ELECTRICAL RESISTIVITY DATA AND THREE-DIMENSIONAL GEOGRAPHICAL INFORMATION SYSTEM.

by

ISHAKU BASHIR YAKUBU

Thesis submitted in fulfilment of the requirements for the degree of Master of Science

SEPTEMBER 2014

ACKNOWLEDGEMENT

The success of completing this research work lies in the hand of expert guidance supervisors: Dr Izham Mohamad Yusoff and Co Supervisor Assoc. Prof. Dr Main Rindam for provision of all reference materials needed for this research work, adequate support and evaluation, and persistence encouragement. I acknowledge and appreciate your efforts, support and encouragement towards the success of this research.

Without the study fellowship from Education Tax Fund (ETF) , it would have been difficult to achieve this degree. To this end, the kind gesture of the vice chancellor; Prof. Ibahim Adamu Kolo, the deputy vice chancellor administration; Prof. Baba Alfa, DVC. Academics Dr Mohammed Yakubu Auna, the university liaison officer, Mr. Godwin Ashituabe and the Management of Ibrahim Badamasi Babagida University Lapai, Niger State, Nigeria is greatly appreciated for this wonderful opportunity. I am also grateful to Ministry of Higher Education, Malaysia for financing some of my publication work via Fundamental Research Grant Scheme.

My gratitude goes to my parents' Mallam Ishaku Tomu Mindai and Mallama Jumai Ishaku for their parental and moral support. I am grateful and appreciate all your effort to ensure my success in life. Thank you. To my brothers: Ishaku Yunusa Yakubu, Dr. Usman Yakubu Danlami, Engr. Shehu M. Danlami, Hashiya Yakubu, Sufiyanu Yakubu, Madinat Yakubu, Zainab Yakubu and Karima Ishaku Yakubu and my cousins; Mohammed Doma, Bara'atu, Mustapha, Jemilu Saudatu and Lukman. My uncles: Ishaku Danlami Moses and his family, A.C Nata'ala Baba Mindai and family and the entire Mindai family. I will forever be grateful to all of you for your fervent prayers, support and encouragement. I will forever remain grateful and indebted to your endless scarifies towards my success in life.

My sincere gratitude's to the family of: Alhaji Ismaila Aliyu gabadna, Mallam Usman Saidu, most especially mallama Aisha Usman. Special and sincere thanks to: Hauwakulu Usman for your patience, understanding, support, prayers and encouragement at the time we needed each other most. I am sincerely sorry for the inconveniences; i might have cost you in my quest to succeed in life. mallam Lawal Gambo, Allahji Isah Maman lafiya and your wife Aisha Yakubu Aliyu of IBBU Lapai for your persistence encouragement and prayers.

I wonder how possible it would have been for me without the support and advice of my senior colleagues and friends; Dr Anthony Mogaji Kahinde, Abdullilahi Mohammed Baba, Ismaila Musa, Mr. Eugene Obiora Eugene, Uztaz Ajijolakewu Kamoldeen, Bashir Kayode Sodikpo, Saheed Ishola Kahinde, Alfa

Awolabi Abdulfatah, and Mr EN. Azizul Bin Ahmad of school of humanities. To my friends Mr. Emannuel Dogo Ishaku, Barister Sanni Ibrahim, Hajia Adama Ndayako, and mallam Musa of Niger state ministry of water resources.

My appreciation goes to professor Baba Alfa DVC administration, IBBU Lapai for providing the equipments required for sounding data acquisition, to Mr. Mathew Tsepav for preparing the equipment user manual, Mr Kure Isah Danjuma of IBBU Lapai for providing moral and Logistics during the field work and my friends Suleiman Ibrahim for assisting me throughout the period of data acquisition. My sincere appreciation goes to my lectures Dr. Manzur Bako Matazu, and Dr. Mohammed B. Y. of FUT Minna for advice and encouragement.

DEDICATION

This research work is dedicated to Allah almighty for providing me with knowledge strength and ability to carry out this research. To my late; grandfather Mr. Baba Mindai Jazun, Uncle Yakubu Baba Mindai and Mallama Zainab Ishaku Mindai

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ABBREVIATIONS	**MEANING**
%	Percentage
Ωm	Ohms Meter
˚C	Degree Celsius
2D	Two Dimensions
3D	Three Dimensions
3D-FDS	3D format data structure
AFTM	Audio Frequency Telluric Method
BHL	Borehole Lithology
B-Rep	Boundary Representation
CM	Centimetre
DEM	Digital Elevation Model
DTM	Digital Terrain Model
ER	Electrical Resistivity
ERT	Electrical Resistivity Tomography
ESRI	Environmental Systems Research Institute
FMWR	Federal Ministry of Water Resources
GIS	Geographical Information System
GPR	Ground Penetrating Radar
GPS	Global Positioning System
HEC-Geo HMS	Hydrologic Engineering Centre Geospatial Hydrologic Modelling Extension
IDW	Inverse Distance Weighting
IMF	International Monetary Fund
IP	Induced polarization
KM	Kilometre
M	Meter
MRS	Magnetic Resonance Sounding
NGS	Nigerian Geological Survey
NPC	National Population Commission
NRS	National Reference System
NSGN	Niger State Government of Nigeria
OO3D	Object Oriented 3D
SOMAS	Solid Object Management System
SSM	Simplified Spatial Model
TEN	Tetrahedron Network
TIN	Triangular Irregular Network
UDM	Urban Data Model
UNDP	United Nations Development program
UNICEF	United Nations Children Fund
UTM	Universal Transverse Mercator
VES	Vertical Electrical Sounding

VGE	Virtual Geographic Environment
WGS	World Geodetic System
WHO	World Health Organization

PEMANTAUAN SUMBER AIR BAWAH TANAH DI EMPANGAN BIDA, NIGERIA MENGGUNAKAN DATA KEBERINTANGAN ELEKTRIK DAN SISTEM MAKLUMAT GEOGRAFI TIGA-DIMENSI

ABSTRAK

Permintaan masyarakat untuk air mudah alih menjadi terhad disebabkan oleh kekurangan bekalan sumber permukaan air, khususnya terhadap status kualiti air ternyahgred. Pengulangan hal ini kerap kali berlaku disebabkan oleh kerosakan alam sekitar yang tidak dapat dielakkan di lembangan Bida, Nigeria. Penerokaan kualiti sumber air bawah tanah secara semula jadi adalah penting untuk menambah baik kekurangan permukaan air dan memastikan keselamatan sumber air. Penyelidikan ini meneroka potensi peningkatan visualisasi dan kebergantungan atribut teknik Sistem Maklumat Geografi Tiga-Dimensi (3D GIS) dengan model data keberintangan elektrik dalam menilai potensi sumber air bawah tanah di lembangan Bida. Atribut 3D GIS meningkatkan ketepatan ramalan dalam proses membuat keputusan berbanding dengan teknik dua-dimensi (2D) GIS yang menjadi kebiasaan. Hasil data keberintangan elektrik yang ditafsirkan telah menggariskan tiga hingga lima unit litologikal, iaitu tanih liat, tanih berpasir, tanih liat berpasir dan batu pasir dengan pembentukan tanih liat berpasir dipetakan sebagai unit akuifer kebarangkalian tinggi di kawasan tersebut. Nilai-nilai keberintangan dan ketebalan unit litologikal adalah di antara 452Ωm hingga 934Ωm dan 10.27m hingga 54.10m di kawasan kajian masing-masing. Hasil agihan penyebaran spatial unit akuifer yang dipetakan melalui teknik aplikasi 2D GIS geostatistik menerbitkan kedalaman relatif menurun ke arah bahagian selatan lembangan Bida, pada purata 10m. Aplikasi dari 3D model

Tetrahedron Network (TEN), analisis litologikal 3D memberikan gambaran tentang pengaruh variasi spatial unit lithological terhadap penentuan potensi akuifer dalam lembangan. Hasil daripada penggunaan pendekatan 3D Lagrangian berdasarkan teori Darcy aliran air bawah tanah untuk simulasi lapisan litologi atas unit akuifer pada skala masa antara 30 minit hingga 4 jam membolehkan penilaian pengaruh beban lapisan tanah mempengaruhi potensi hasil aquiferous dalam kajian kawasan. Keputusan simulasi 3D diperolehi menunjukkan bahawa keberkesanan produktif terhadap potensi kawasan akuifer adalah berkadaran dengan sifat dan agregasi saiz partikel pembentukan yang berlebihan. Dengan yang demikian, pemanafaatan maklumat hidrologi terhadap teknik 3D GIS yang digunakan pada model data geoelectrical akan meningkatkan ketepatan ramalan zon potensi prolifik. Hal ini membawa kepada kebergantungan pembangunan sumber air bawah tanah pada kos yang minimum dan sangat berkesan.

GROUNDWATER SURVEY IN BIDA BASIN, NIGER STATE NIGERIA USING ELECTRICAL RESISTIVITY DATA AND THREE-DIMENSIONAL GEOGRAPHICAL INFORMATION SYSTEM.

ABSTRACT

Societal demand for portable water has been severely limited due to inadequacies of surface water sources of water supply with particular references to its degraded water quality status. Occurrences are often due to unavoidable environmental hazard across the Bida basin, Nigeria. Exploring the excellent natural quality of groundwater resources to improve the surface water inadequacies becomes imperative to ensure water resources security. This research explore the potential of volume visualization and reliability attributes of Three-Dimensional Geographical Information System (3D GIS) technique to model groundwater using electrical resistivity data in Bida basin. The 3D GIS attributes enhances its prediction accuracies in decision making process compared to the most often used 2D GIS technique. The interpreted results of the electrical resistivity data delineated three to five lithological units namely clay, sandy, sandy clay, clay sandy, sandstone with the sandy clay formation mapped as the most probable aquifer unit in the area. The resistivity and thickness values of these lithological units range between 452 Ωm to 934 Ωm and 10.27m to 54.10 m across the study area, respectively. The results of the spatial distribution of the mapped aquifer units via application of 2D GIS geostatistical technique established a relative depth of declining towards the southern part of Bida basin, at an average of 10m. With the application of the 3D Tetrahedron Network (TEN) model, the 3D lithological analysis gave an insight into determining the influence of spatial variation of the lithological units on the aquifer potential in the basin. The result of the applied 3D Lagrangian approach based on the Darcy's theory of

groundwater flow for simulation of lithologic layers above the aquiferous units on a time scale between 30 minutes to 4 Hours enabled evaluation of the overburden layer influence on the aquiferous yield potential in the study area. The obtained 3D simulation results shows that the productiveness of the area aquifer potential is proportional to the nature and aggregate of particle sizes of the overburden formation. Therefore, harnessing the hydrological information on the applied 3D GIS technique on modelling geoelectrical data will enhance prediction accuracy of prolific potential zones and thus leading to reliable development of groundwater resources at minimal cost and highly efficient.

CHAPTER ONE

INTRODUCTION

1.1 General Introduction

Access to clean water is a fundamental need of every society and ultimately it is a responsibility of the government. According to the World Health Organization (WHO) and United Nations Children's Fund (UNICEF) Joint Monitoring Programme for water supply and sanitation estimates, 1.1 billion people live without improved water sources (Voigt *et al.*, 2012; Mohammed *et al.*, 2013). Rapid population growth has triggered water demand for drinking, agriculture and industrial uses. It is predicted that by 2025, about 1.8 billion people will be living in regions with absolute water scarcity, and two-third of the world's population could be under water stressed conditions (Hanasaki *et al.*, 2013).

While water demand increases with rapid population growth, surface water is considered unreliable and unsustainable; due to vulnerability to adverse weather condition, pollution and presence of pathogens necessitating the need to explore groundwater resources as an alternative for reliable, quality and sustainable water supply (Adiat *et al.*, 2012). Globally, groundwater is generally considered most suitable in terms of excellent quality, low vulnerability to contamination and low exploration cost thus, making it suitable for human consumption, industrial uses and irrigation purposes (Hoques *et al.*, 2009). The quantity available for exploration is estimated to be about 0.06 percent and made up of 98 percent of fresh water confined within soil/rock void. But despite the abundant reserve and resource commitment, groundwater resource exploration has remained below the substantial level due to lack of capability in previous groundwater survey techniques to accurately infer groundwater potential areas. Difficulties in reliable groundwater survey is due to the confinement of the groundwater resources to beneath the earth's crust, making it impossible to be directly seen on the earth surface thereby, making mapping of the resources potential area difficult to quantify in both time and space (Lee *et al.*, 2012).

Successful groundwater resource development largely depends on the pre-drilling information survey. As such, varieties of geophysical techniques such as seismic refraction, electromagnetic induction, ground penetrating radar, audio frequency telluric method among others, have been explored in groundwater survey with the view of inferring groundwater potentials in an area. However, electrical resistivity (ER) survey method is prompt, cost effective and viable in identifying subsurface information that has direct bearing on groundwater availability (Park *et al.*, 2012) making it most preferable among several geophysical techniques. According to Rubin and Hubbard (2006), the ER method has proved to be the most efficient in groundwater survey. However, the application of ER in groundwater survey is deficient in regional analysis in such a way that temporal, spatial, spectral analyses etc for assessing groundwater resources in both accessible and inaccessible areas are its limitation. Hence, the hybrid application of Geographical Information System (GIS) with ER method can greatly resolve the above mentioned ER limitations in groundwater survey.

GIS is a system that allows for the capture, storage, retrieval and processing of information regarding geographical space and also display the processed information in a visual format that support decision making (Longley, 2005). GIS enables the storage and processing of heterogeneous data about resources, event, ecosystem and human impact. GIS has an advantage of analysis and visualisation of voluminous data which can be processed to facilitate decision-making at both local and regional scale.

GIS technique has been implemented along with spatial data regarding the subsurface and other information that can be correlated to infer groundwater development on a regional scale. However, the results implemented are often in two dimensions (2D) as a thematic layer map. In recent years, many researchers have implemented three-dimensional (3D) GIS technique with high efficiency in groundwater survey in terms of complex decision making and estimation of groundwater parameter. The availability of 3D modelling and visualisation capability as well as data mining from 3D GIS data models, enhances its application in groundwater survey and development. But existing studies have not been able to integrate a true subsurface data into its analysis, hence results from such studies may be deviant from real subsurface parameter thus affecting groundwater development in practice.

1.2 Problem Statement

Water is regarded as a unique resource required for sustaining human life, for maintaining of ecosystems and for achieving sustainable development (Topfer, 1998). In Bida basin, Nigeria, the surface water which is the major source of potable water supply is not often available at the point of use. Moreover, it is highly vulnerable to environmental hazard such as climate change impact and the effect of human anthropogenic activities; hence its quality status is often degraded. By contrast, groundwater is characterised by unique attributes including excellent quality, constant temperature, low vulnerability to pollution etc. Hence, its use in many countries such as India, USA etc particularly in rural communities for poverty reduction has been well facilitated compared to surface water.

The voluminous estimate of groundwater resources in Nigeria has been established to be about 52 billion cubic meters (Cloutier & Rowley, 2011). Despite these abundances, estimate shows that only 58% of the inhabitants of urban and, semi-urban areas and 39% in rural areas, have access to potable drinking water (Eduvie, 2006). Efforts at all tiers of government in Nigerian (i.e. federal, state and local governments) in the provision of adequate water to meet demand, have been evidence in many water planning projects since 1917. This ranges from setting up of Nigerian Geological Survey (NGS), the Federal Ministry of Water Resources (FMWR), River Basin Development Agencies and state water boards to manage and oversee water projects in Nigeria (FMWR, 2000). In terms of financial commitment, between 2011 to 2013 alone, over USD 0.8billion have been expended by the government, while local and foreign organisations such as the United Nations Development Program (UNDP), the United Nations Children Fund (UNICEF), the International Monetary Fund (IMF), Global 2000 and World Bank, among several others, have donated over USD 1.8 million between 1996 to 2001 (Omole, 2013). But despite the huge investment, water provision has not been able to meet the yearning of societies for quality and clean water.

The responsible factors for under-utilisation of groundwater resources development has been attributed to poor hydrogeological survey to accurately infer and identify viable groundwater potential areas (Ibrahim, et al 2012). The complexity of geological settings characterising the country is another responsible factor for the spate of failure of boreholes drilled for groundwater resources development. In order to maximize the optimal exploration of groundwater for the purpose of solving the problem of water resource crisis, there is need for detailed hydrogeophysical investigation coupled with application of geospatial technology for maximizing the potential of groundwater resources both at the local and regional scale analyses.

In hydrogeophysical surveys (use of geophysical measurements for estimating parameters and monitoring processes that are important to groundwater studies, such as those associated with water resources, contaminant transport, ecological and climate investigations), several researchers have applied ER method for groundwater potential mapping with appealing results (Emenike, 2001; Oseji *et al.*, 2005; Mohammed *et al.*, 2007; Al Saud, 2010). An improvement in the ER application with the use of GIS technique has enabled the generation of 2D model map usable for regional groundwater productivity potential mapping (Ruby *et al.*, 2010; Srivastava *et al.*, 2012; Nwachukwu *et al.*, 2013), thus, overcoming the limitation of ER method confined to local analysis. However, the produced 2D model, based on the 2D GIS approach, is limited in terms of volume visualisation which can be inimical to accurate decision making. The knowledge of target volume and size are vital criteria for optimising the exploration of subsurface natural resources. Hence, the introduction of 3D GIS technique to give an insight into determining the volume and size of prospective aquifer unit will greatly enhance decision making in exploring groundwater resources, though, some recent studies have applied 3D GIS model approach in groundwater survey (Nebiker, 2003; Zhiyong *et al.*, 2005; Fei *et al.*, 2008). However, these prior studies used the surface data sets in their modelling. According with Todd and Mays (2005); Jha and Peiffer

(2006); Meijerink (2007), these surface factors are indirect indicators of groundwater existence. Rare references have explored the potential of subsurface data set which according to Jha *et al.* (2010) have direct bearing to groundwater existence in an area. Hence, this study will explore the potential of 3D GIS to subsurface data set obtained with the application of ER method of geophysical prospecting.

In conclusion,the conventional GIS approach of groundwater survey lack 3D and volume representation of the subsurface geologic features that can enhance optimal exploration of groundwater resources in an area. The aim of the research therefore, is to study the hydrogeology of Bida basin Nigeria through the integration of ER data and 3D GIS technique for the purpose of enhancing groundwater resource survey to meet communities' demand for quality, clean and safe water. The research proposes a 3D GIS modeling of ER data that can effectively address the deficiencies of the 2D GIS approach in grounndwater survey with a view of maximising groundwater resource exploratiom in an area.

1.3 Research Objectives

a) To identify groundwater reservoir nature and extent using ER data acquired in the study area.
b) To produce aquifer characteristics spatial map using GIS technique.

c) To model the 3D visualisation of the delineated lithological units using 3D Tetrahedron Network data model.

d) To evaluate the aquifer yield potential for the area groundwater development via 3D simulation model and Darcy's theory of groundwater flow application.

1.4 Research Scope

The scope of the research is to study the distribution, flow and quality of underground water (hydrogeology) of Bida basin in North Central Nigeria, in order to understand the aquiferous system with the view of enhancing effective and reliable groundwater survey to meet water needs of the locality. The study uses primary data namely: ER data collected from the field; Digital Elevation Model (DEM) data; locational data, and secondary data including geological map, borehole logs from Niger State Rural Water Sanitation (RUWASAN), and government documents. The research provides knowledge that gives an insight to the understanding of types of lithological formations found and their affinity to store and yield water in the study area. 3D TEN data model is adopted because of its capability of representing continuous spatial field. It has the advantage of representing continuous field in spatial space due to availability of spatial partitioning of 3D X,Y as normal grid while partitioning along Z direction varies according to characteristic attributes of the object described by the Z Dimension (Wu, 2004). The application of 3D GIS using 3D TEN data model and its simulation functionality to the delineated formations with the view of visualising the pattern of groundwater flow within each of the delineated geological units, for the purpose of evaluating groundwater potentials in Bida basin is another scope covered in this study.

1.5 Limitation of the Study

All available resources of both primary and secondary data were fully utilised in this research to achieve the aim and objective s of the research in enhancing groundwater survey in the study area through the incorporation of 3D GIS technique. However, aspects of infiltration processes, prediction of recharge and discharge rate of the aquifer were absolved from the scope of this research. In addition, literature conducted has shown that, the rate of groundwater recharge and discharge, to a larger extent, is a function of materials that constitute the subsurface as they determine the magnitude of infiltration into the aquifer i.e. reservoir. Therefore, 3D modelling and simulation of the subsurface lithology were given optimum priority as other aspects of groundwater process were left out based on the designed objective of this research.

1.6 The Significance of the Research

The significance of this research is itemised below:

a) It promotes the understanding of different geological units that constitutes the subsurface in the study area. The properties and characteristics of the aquifer, overburden material nature and spatial extent of the geological units. The influence of the delineated layers on groundwater prospecting enables reliable groundwater exploration to meet demand in the study area.

b) The 3D modelling and analysis of the inferred subsurface geological (i.e top soil, clay, clay sand, sandy and sandy clay etc) units in Bida basin was able to visualise the different layers in a near world setting using the 3D TEN data model. This has enhanced the understating of water yield capacity of an aquifer function of the nature of material that constitutes the aquifer and overlying layers.

c) The likely aquifer potential in the study has been evaluated from 3D groundwater simulation of the subsurface lithological units. The evaluated aquifer yield potential, to a larger extent, can enhance appropriate siting of borehole with high precision and reliability to meet societal demand.

Several methods that have been used in groundwater survey include, but are not limited to, ER, seismic, magnetic, remote sensing, electromagnetic and GIS. Out of these methods, ER is most effectively used for locating productive site due to accuracy attributed to moisture, ER relationship, ease of operation, cost effectiveness, less time consumption (Robinson *et al.*, 2008) and unlimited depth of probing to depend on electrode spread (Adiat *et al.*, 2012). ER survey has been adopted in groundwater exploration and has helped in revealing the geology of the subsurface layer. The objective of ER is to deduce the variation of resistivity with depth below a given point and correlate it with available geological information to infer groundwater depth while determining the layer of a promising well. Hence, ER is able to delineate the different lithology of subsurface and determe groundwater depth (Yadav & Singh, 2007; Sikandar *et al.*, 2010; Song *et al.*, 2012). GIS, on the other hand, has enabled the representation, analysis and visualisation of multilayer information (as thematic layer map) on a regional scale for enhancing identification of groundwater potential areas.

The existing 3D data modelling: (grid modelling), volume base (TEN model) and hybrids by Gong *et al.* (2004) has enabled representation of rigid and dynamic aspect of hydrogeological features. Rigid features such as soil and rocks could be represented using the grid modelling while fluid-like features such as fire and water could be represented using the tetrahedron and hybrid data models. 3D data model has enabled researchers to address problems of urban runoff (Izham & Rindam, 2012), fluid simulation groundwater simulation (Gue *et al.*, 2008; Nasib, 2012) urban and city planning (Moser & Albrecht, 2010); emergency response planning (Whey-Fone, 2012), mineral exploration (Wilford, 1999) and hazards assessment point (Ding *et al.*, 2012). The successful use of 3D data model was made possible by the ability of GIS to accumulate large volume of geographical data and manipulation of the information to produce a desired result.

The integration of ER and GIS in groundwater prospecting employed the advantage of large geodata base of GIS by storing information related to groundwater inference parameter such as thickness, depth of the water table, and layer resistivity. The aforementioned data are analysed in terms of spatial extent using the different geostatistical algorithm of interpolation such as: inverse distance weighting, kridgin, polynomial etc of GIS to enhance regional analysis including inaccessible location or points.

To this end, the integration of 3D GIS and ER in groundwater survey enables representation and visualisation of hydrogeological dynamics of subsurface geology in 3D. Unlike in previous researches where the results are often in 2D and attributes of 3D becomes discrete leading to abstraction from reality. Implementing 3D from resistivity survey data, processing of spatial and discrete data using 3D GIS technique and analysis in 3D environment allow for efficient and reliable representation of subsurface layers. Simulation of dynamic field within the lithology layers enhances visualisation in 3D groundwater movement within the different layers of the subsurface thus, enables evaluation of aquifer yield potential in an area. Deducing from the simulation results, areas with promising well, have been earmarked. This establishes a leading 3D GIS technique improvement over the existing 2D GIS application in groundwater research domains.

1.7 Location of the Study Area

The study area of the research is Bida basin in Figure 1.1, North Central Nigeria. Nigeria is located between latitude 4°N to 14ºN and longitude 3°E to 15º East of the Greenwich meridian located in the North Eastern hemisphere of Africa. It is located in the western part of Africa. The is bounded to the north by Niger republic, to the South by the Atlantic Ocean, to West by the Republic of Benin and to the East by the Republic of Cameroon and Chad respectively. Its coast in the south lies on the gulf of Guinea on Atlantic Ocean.

The basin lies between longitudes 4˚45'E to 6˚10'E and latitudes 8˚47'N to 9˚10'N as depicted in Figure 1.1. Bida is bounded to the North by Paiko, Bosso, Gbako, Lavun and Mashegu local governments. To the South is a Niger River, Kwara and Kogi state. To the West is Borgu local government and to the East is the federal capital territory Abuja, Nigeria. The Bida basin is drained by two major rivers, namely; river Chanchaga and Gbako, and some smaller drainages that empty into the Niger River.

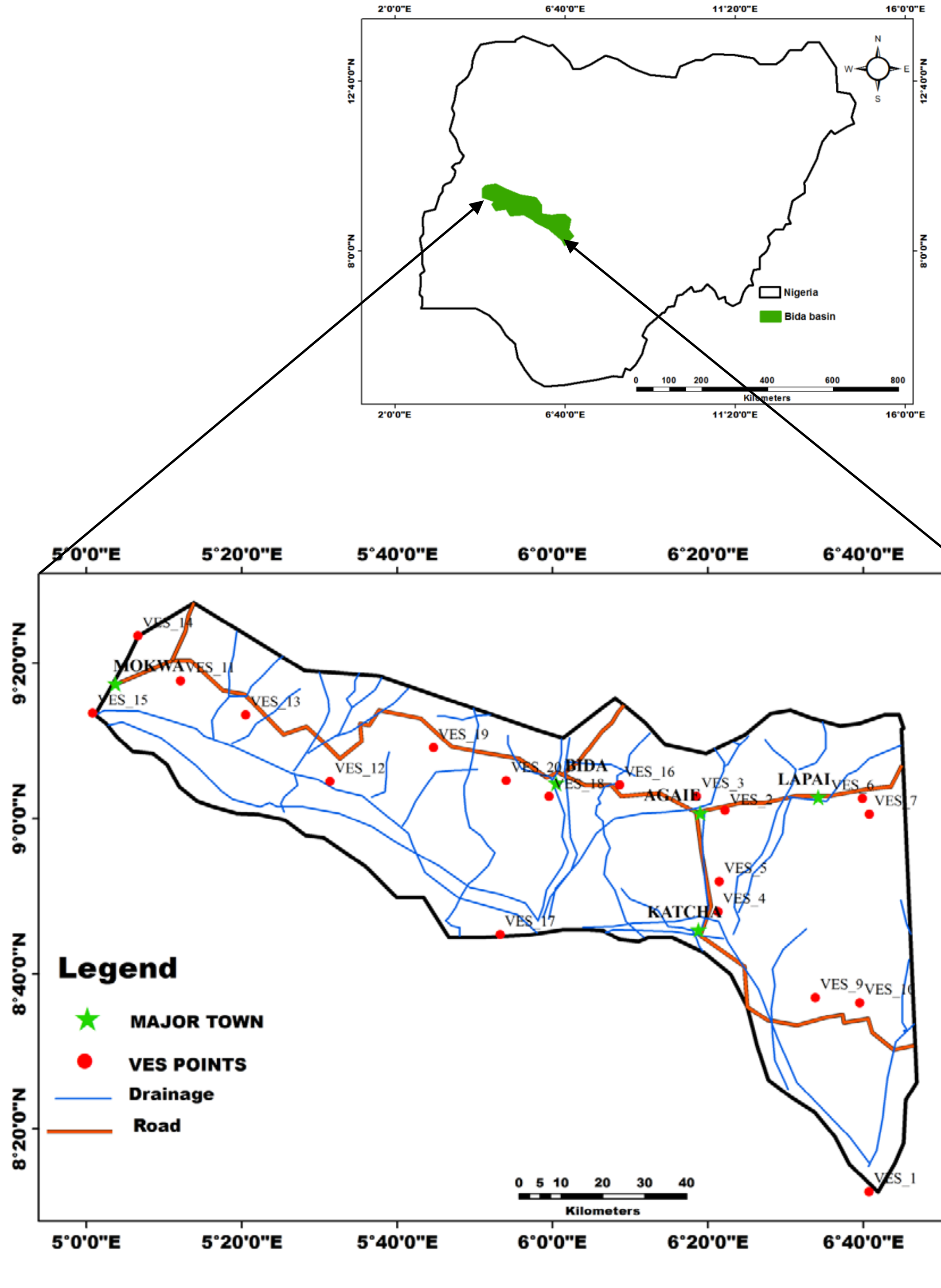

Figure 1.1 : Map of of Bida basin.

The major means of transportation is by road, railway and some navigable rivers. The major road divides the study area almost into two linking Mokwa, Bida, Agaie and Lapai to other parts of Niger state. Railway line passes through Mokwa to Baro linking the southern part to the Northern part of Nigeria by rail. The railway line was mainly used for groundnut pyramid and cotton boom during the colonial period before it was abandoned with the discovery of petroleum. These three modes of transportation are the most dominant in the studied area where goods and services are transported.

Bida basin was chosen for the research because of its complex interwoven geological features characterised by sedimentary and basement formation. In addition, the study area host various settlements that perform different functions, including education, administrative, commercial and agricultural functions leading to inflow of population. This situation has increased water needs and caused water stress conditions on the existing water supply system or sources; thus, the development of hybrid technique of groundwater survey aimed at enhancing groundwater exploration to meet demand for this large population becomes imperative.

1.7.1 Weather and Climate of the Study Area

Climate describes the average weather condition of a place over a long period of time while weather is the atmospheric condition of a place over a short period of time. The climate and weather condition of the study area is due to the influence of tropical continental (cT) air mass, tropical Maritime (mT) and equatorial easterlies. The tropical continental air mass originate from a high pressure belt of North of the Tropical of Cancer while the maritime air mass originates from the southern high pressure belt located off the coast of Namibia (Odekunle, 2006). The tropical continental air mass and tropical maritime air mass meet to form a zone of inter tropical convergence/divergence zone that brings precipitation and dry season in Bida basin depending on dominant air mass. The inter tropical continental air mass pickup little moisture along its path and thus is dry, bringing dryness condition i.e. dry season while tropical air mass prevalence brings about wet condition due to its ability to pick large moisture along the coast through which it flows and shading precipitation along the continental part of the country (Odekunle & Adejuwon, 2007; Abaje *et al.*, 2012). When tropical maritime air mass prevails, it marks the onset of rainy season usually between April to October and dry season between November to March (Adefolalu, 1988; Omotosho *et al.*, 2000; Odekunle, 2004). The length of rainy season has been consistent between 7 to 8 months with three months as most rain and rain peak shifting between August to July. The Mean annual rainfall of 1000mm to 1,500mm(Ayoade, 1974; Adefolalu, 1988), while the dry season lasts between 5 to 6 months (Odekunle, 2006). The mean annual temperature of the study area is between 26.5^{o}C to 27.8°C with maximum temperature between March and June while the minimum is between December and January. Rainfall is the major source of recharge; it determines the amount of water that would be available for percolation into the earth groundwater system.

1.7.2 Geology of the Study Area

Bida basin as shown in Figure 1.2 is filled with mainly Santonia to Maestrichtian sediments of sandstones, siltstones and superficial alluvial deposits (Obaje, 2009a). The lithology of these formations are weathered literate, sandy clay and clay sand (Bello & Makinde, 2007). The southern part of the study area is characterised by secondary permeability with the following formations; weathered laterite, sandy clay/clayey sand, fractured basement and fresh basement rocks. Generally the rock units in this region are suggested to be highly characterised by alternating of clay, siltstone, silt, clay and weathered bedrock (Braide, 1990; Akande *et al.*, 2005). These geological materials are liable to form aquifer and permeable zones to the bedrocks in both the sedimentary terrain and the crystalline basement complex existing in the area. In areas underlain by crystalline rocks, presence of structures like fractures, fissures, veins, joints and such other structural deformations of the basement complex, controls the flow of groundwater and also influences the rate of recharge and discharge of the main aquiferous (Idornighie & Olorunfemi, 1992; Akande *et al.*, 2005; Bello & Makinde, 2007).

The thematic layer in Figure 1.2 of Bida basin show four main soil types-coarse sandy, clay, sandy silt, and fine sand. Sand silt dominated a major portion of the study area, followed by fine sand and clay. A very thin lens of clay exists in the North West region of the study. From groundwater point of view, sandy and clay sand are considered as most important soil that indicate high groundwater potential due to it well connected network of voids and relatively large void that allow for infiltration and subsequent storage of water for exploration and subsequent exploitation.

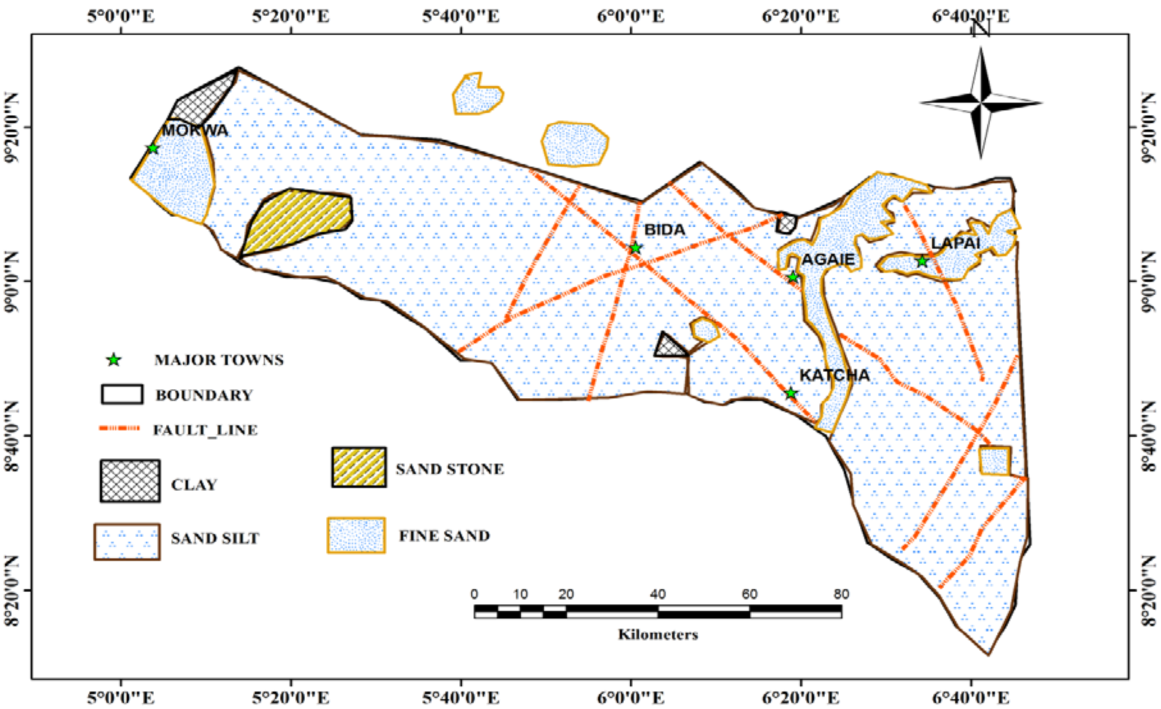

Figure 1.2 : Geological map of Bida basin.

1.7.3 Drainage pattern of the study area

The drainage system of an area is largely a function of the slope, nature and altitude of the underlying bedrock, regional and local fracture pattern. Drainage system in an area reflects the prevalent lithology and obtainable geological structures in the area. The less the permeability of a given environment, the less is the rate of infiltration and consequently the well developed and fine the drainage system (Adiat *et al.*, 2013).

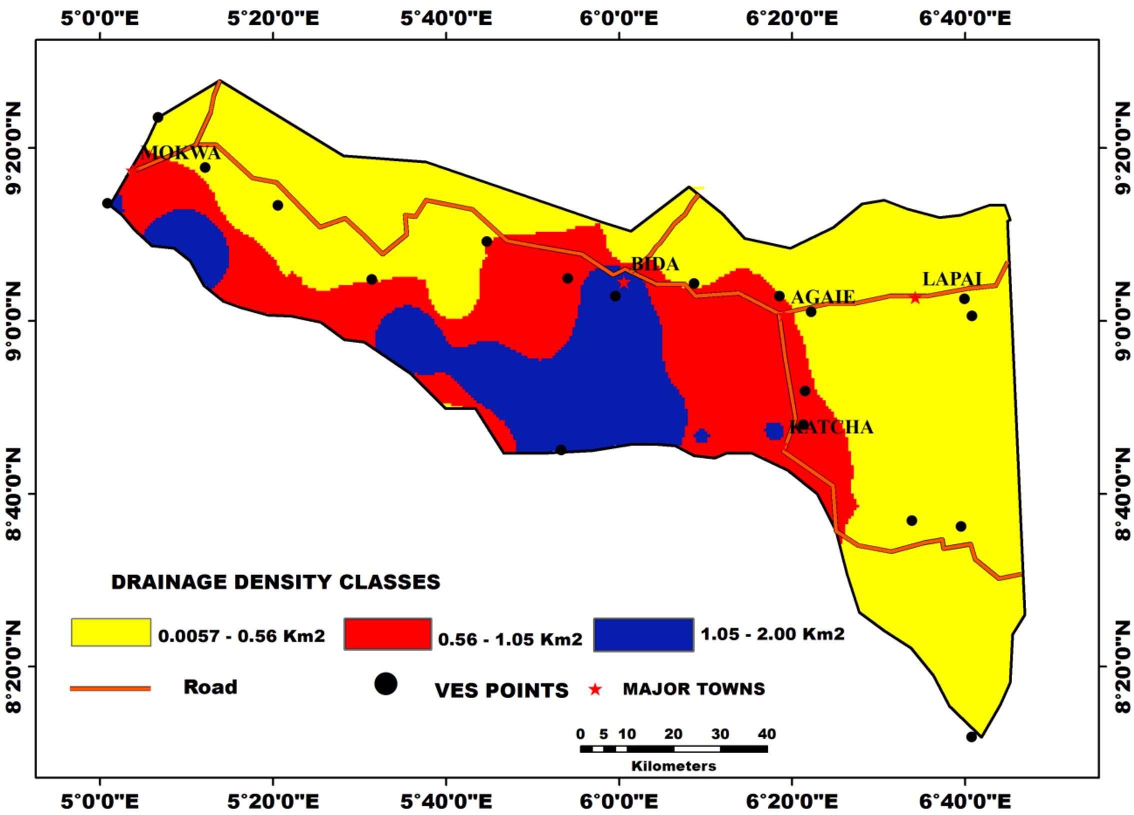

Figure 1.3 : Drainage density map of Bida Basin.

Surface drainage density in Bida Basin ranges from 0.0057 to 2 km^2 as depicted in Figure 1.3. Based on the surface drainage density, the study area can be grouped into three classes: (1) 0.0057- 0.56 km^2, (2) 0.56-1.05 km^2 and (3) 1.05 – 2 km^2 as illustrated in Figure 1.5. The basin is dominated mainly by a drainage density of 0.0057-0.56 km^2. The surface drainage pattern in the study area is a reciprocal of permeability in such a way that the less the permeability of the material that constitute the subsurface, the less the infiltration rate, and hence more surface runoff and low infiltration rate. In terms of groundwater prospect, the three classes could be considered as high, medium and low, respectively.

1.7.4 Population and Cultural Activities in the Bida basin

According to GOVERNMENT (2006), Bida, Mokwa, Agaie and Lapai has a total population of six hundred and seventy six thousand, one hundred and fifty two persons (676,152) sparsely distributed across the study area, except in the administrative and commercial centres where the population is more concentrated. The break down as depicted in Figure 1.4 shows that Mokwa is the most populated settlement with a total population of two hundred and forty four thousand, nine hundred and thirty seven persons, followed by Bida with a total population of one hundred and eighty eight thousand, one hundred and eighty one. Agaie has a total population of one hundred and thirty two thousand, nine hundred and seven; while Lapai has a total population of one hundred and ten thousand, one hundred and twenty seven persons.

Modern Bida is well known for crafts, notably brass and copper goblets, other metal products, glass beads and bangles, raffia hats and mats, and locally dyed cotton and silk cloth (Encyclopædia, 2013). The craftsmen work by hand in their own premises in distinctive wards and are organszed into close-knit guilds. Most of the town's predominantly Nupe population live in mud houses that are grouped into customary compounds. The town is the main collecting point for the swamp rice cultivated in the floodplains of the Niger and Kaduna rivers. Bida also trades in yams, sorghum, millet, sheanuts, tobacco, cotton, peanuts (groundnuts), palm oil and kernels, onions, indigo, sugarcane, fruits, goats, sheep, and pottery (Encyclopædia, 2013).

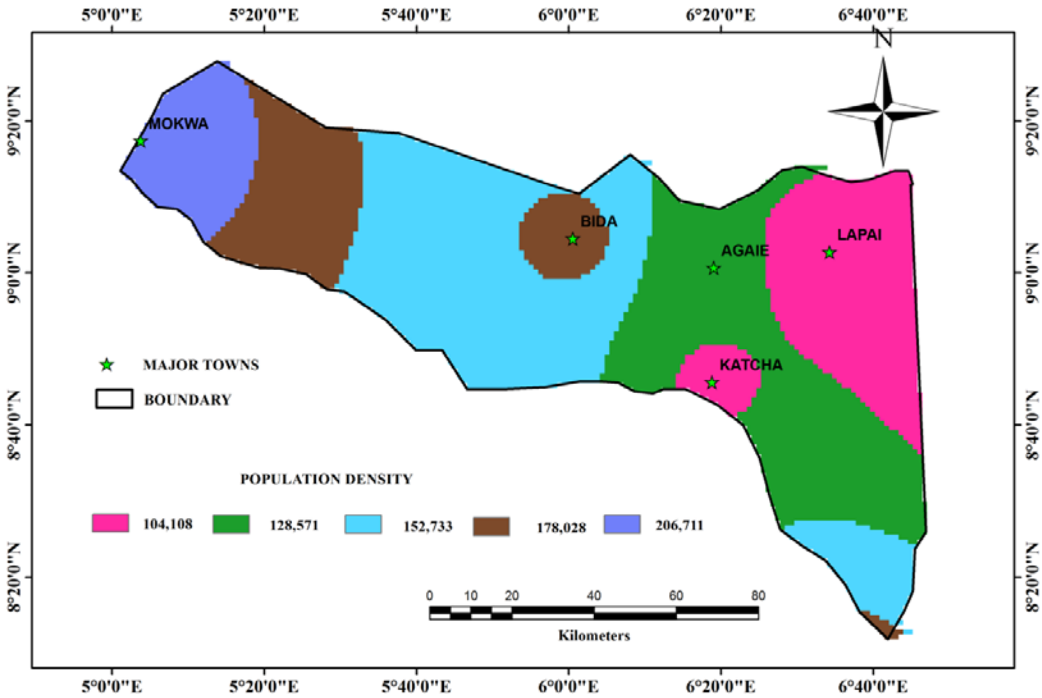

Figure 1.4 : Population density map of Bida basin.

From groundwater point of view, this high population density could exert pressure on existing water sources in the study area when considered in terms of water demand for domestic, industrial and agricultural purposes. In addition projection of increase of population, economic, administrative, agricultural and educational function of these settlements will lead to teaming population, and will continue to exert more pressure on water resources leading to water stress condition. Thus couple with complex geological nature of the study area (i.e. sedimentary and basement complex), there is need to develop new and improved method of groundwater survey technique that has high yield of reliability and low cost to meet societal demand for water.

1.8 Thesis Structure

This thesis is structured into five (5) chapters as follows:

Chapter One: This chapter presents the introduction of the study under various subtitles namely: general introduction of the research, problem statement of the research, research objectives, research scope, justification of the research, importance and contribution of the research to knowledge, location and description of the study area including; weather, climate, geology, drainage density, population and cultural activities and finally the importance of efficient, effective, accurate and reliable