GEOSPATIAL INVESTIGATION OF GROUNDWATER POTENTIAL ZONES IN KACHIA LOCAL GOVERNMENT AREA, KADUNA STATE, NIGERIA

BY

MARY EDWARDKUHIYOP

DEPARTMENT OF GEOGRAPHY
FACULTY OF SCIENCE
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA

AUGUST, 2016

GEOSPATIAL INVESTIGATION OF GROUNDWATER POTENTIAL ZONES IN KACHIA LOCAL GOVERNMENT AREA, KADUNA STATE, NIGERIA

BY

Mary EdwardKUHIYOP
B.Sc. Geology, UNIJOS (2009)
M.SC./SCI/5862/2011-2012

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER DEGREE IN REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

DEPARTMENT OF GEOGRAPHY
FACULTY OF SCIENCE
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

AUGUST, 2016

DECLARATION

I declare that the work entitled **"Geospatial Investigation of Groundwater Potential Zones in Kachia Local Government Area, Kaduna State, Nigeria"**has been carried out by me in the Department of Geography.The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this dissertation was previously presented for another degree or diploma at any other Institution.

Mary Kuhiyop EDWARD _____ _____

Signature **Date**

CERTIFICATION

This dissertation entitled **"GEOSPATIAL INVESTIGATION OF GROUNDWATER POTENTIAL ZONES IN KACHIA LOCAL GOVERNMENT AREA, KADUNA STATE, NIGERIA"** by Mary Kuhiyop Edward meets the regulations governing the award of the degree of Masters Degree in Remote Sensing and Geographic Information System of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Prof. E.O. Iguisi Chairman, Supervisory Committee	_____ (Signature)	_____ Date
Dr. B. Akpu Member, Supervisory Committee	_____ (Signature)	_____ Date
Dr. A.K. Usman Head of Department, Geography	_____ (Signature)	_____ Date
Prof. K. Bala Dean, School of Postgraduate Studies	_____ (Signature)	_____ Date

DEDICATION

I dedicate this dissertation to almighty god for giving me the grace, strength, and above all knowledge. Also to my late father Mr. Tanko Ibrahim without him, I would not become graduate today. May his soul rest in peace.

ACKNOWLEDGEMENTS

My sincere gratitude goes to the Almighty God for sparing my life and taking care of me up to this moment and ensuring that my research work meets the point of completion.

My gratitude goes to my able supervisors in persons of PROF E.O IGUISI and DR.B. AKPU for their professional advices, guidance and patience all through the period of my Research work. May God continue to bless you.My appreciation also goes to my beloved husband Engr.Edward Kuhiyop for his support financially, morally and spiritually. GOD bless you. I also want to appreciate my children Noka, Noyet and Nocham for their understanding and support during the period of this work.

I also will like to show my appreciation to my mother Mrs.Asabe Tanko for her support, encouragement not to give up and also for her prayers. I love you mama and God bless you. I also wish to appreciate my brothers and sister Gideon Tanko, Rachael Tanko and Dorathy Deh for their support and prayers. May Almighty God bless you all.

I wish to thank my sister in-law Patience Kuhiyop for your kindness in helping me take care of my children during this period of this research work, God bless you

Finally, my special appreciation goes to my course mate Paul Jobins, Shunom Baba who contributed to the success of this program. and I feel honored to have been a student of this prince less institution

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Water is a renewable resource which occurs in three forms liquid, solid, vapor (gaseous), all of which extremely useful to man.The water is not only essential for survival of human beings, but also for animals, plants and other living beings. The present study attempted to identify the groundwater potential zones in Kachia Local Government Area of Kaduna State, Nigeria using remote sensing and GIS techniques as well as electrical resistivity method for validation. The study made use of thematic maps like lineament, geology, land use and land cover, drainage, slope, elevation and soil map as GIS layers in geo-database and assigning weightages based on the pair-wise comparison of the factors that appear to be important in holding / processing recharge of water and ground water potential. By integration of weightages to acquire more effective score to demarcate the ground water potential zone in the present land units. The result of the study shows that topography, rainfall, drainage density, lineament density, geology, soil, slope steepness and landuse/landcover contribute significantly to groundwater prospects in the study area.Rainfall, soiland lineament density were identified as the highest factor contributing to ground water prospect with 34% and 24% respectively. The very good groundwater potential zones were identified in the eastern areas while the areas with low potential lie in the western areas.The result also shows that very good groundwater potential zones occupies a coverage of about 14.1%, good potential constitute 22.4%, moderate occupies 15.0% while fair and low constitute of 23.9% and 24.6% of the study area respectively. Kurmin Mata was identified to have a very high ground water potential within the study area. The result of the study also shows that the higher the aquifer thickness and depth the better the groundwater potential from both resistivity method and GIS and remote sensing. It is therefore recommended that ground water potential zones mapping should be carried out for the entire country to serve as guide for water resources agencies.

CHAPTER ONE :INTRODUCTION

1.1 Background to the Study

Water is one of the most indispensable ressource hence life is not possible on this planet without it. Recent research conducted by Yisa and Jimoh (2010) showed that there was an increase in the demand for freshwater worldwide due to rapid growth of population as well as the accelerated pace of industrialization in the last few décades in Nigeria. This demand has led to the use of ground water not only for its wide spread occurrence and availability but also for its constituent good quality which makes it ideal for drinking. The supply of fresh water to Nigerians has been inadequate and this has forced the inhabitants to resort to drinking water from wells(Sander, 2007). Today, more than half of the world's population depends on ground water for survival (Dawodu and Ipaiyeda, 2007). Groundwater has long been considered as one of the purest forms of water available in nature and meets the overall demand for rural and semi-rural people (Tyagi, Buddhi, Chaudhary and Sawhney, 2002). It was considered as the major source of water for human activities (consumption inclusive) especially in the rural areas (Fasunwon, Olowofola, Akinyemi and Akintokun, 2008).

Despite the considerable investment of governments in Nigeria over the years in provision of water for domestic, industrial, and agricultural purposes, a large part of the population still does not have access to water of adequate quantity and quality. It is estimated that only 58%of the inhabitants of the urban and semi urban areas of Nigeria and 39% of rural areas have access to potable water supply. In spite of these low figures, the average delivery to urban population is only 32 litres per capita, per day (Federal Ministry of Water Resources, 2000).

The ever increasing demand for water, especially for domestic purpose, has led to widespread and very intensive search of water in all parts of Nigeria, especially in the

crystalline complex where occurrence of groundwater are considerably low and generally to occur under the control of geological structures and weathered overburden. Most rural communities in the southern parts of Kaduna, especially in Kachia local government depend largely on groundwater through wells and boreholes for their water needs, since most surface source have been heavily polluted and expensive to develop(Olaniyan, Agunwamba, and Ademiluyi, 2010).

In realization of the need to providing potable water to rural communities such as Sabon Maro, Doka, Gidan Sani, Bahago, Gantan, Sabon-Gari Gantan, Kurmin Mata, Sabon-Gari Ankwa, Kachia, Sarahu, Angwan Ate and Asakwai etc. in Kaduna State, the Federal government in 1981 initiated the National borehole programme, marking a turning point in groundwater resources development in Nigeria. In addition to this, the Kaduna State water board, Local Government areas, Directorate for Food, Road and Rural Infrastructure (DFRRI), Water and Sanitation Agency of Nigeria (WATSAN), Kaduna State Agricultural Development Project (KADP), Petroleum Special Trust fund (PTF) and other organizations and private individuals, embarked on series of programmes for groundwater development. Despite the various efforts of Governments and private individuals, an appreciable result is yet to be achieved in the area of adequate groundwater development (Akintola, 2006).

The present failure rates of boreholes, variability of yields, maintenance problems of borehole and open wells in basement aquifers, frequent breakdown of pumps, especially the hand pumps, point to the need for greater understanding of the hydrogeological principles involved in the exploration and exploitation of the basement aquifer through borehole design and completion (Wright, 2006). It has been observed that these aquifers are particularly of importance in tropical and sub-tropical regions not only because of the widespread extent and accessibility, but there is often no readily available alternative source of water supply, particular for the rural population(Wright, 1992).

The occurrence, storage, and distribution of groundwater in Precambrian Basement Complex are influenced by different geological factors (Amadi and Olasehinde, 2010; Olurunfemi and Fasuyi, 1993). Most often, the occurrence of groundwater in Basement Complex terrains is localized and confined to weathered/fracture zones (Adiat, Nawawi and Abdullah*;*2009; Ariyo and Adeyemi, 2009). Test drilling and stratigraphy analysis are some reliable ways in determining the location of an aquifer and its characteristics. However, these methods are costly and time-consuming (Todd, 1980; Fetter, 1994; Adiat *et al*, 2013). As such, these methods are rarely used. An alternative technique for exploring groundwater resources that overcomes the above limitations (to a certain extent) is the use of geophysical methods such as the Electrical resistivity method. The failure in most groundwater development projects has mandated the use of geophysical surveys as a pre-requisite to any successful groundwater resources development (Dan-Hassan and Olurunfemi, 1999).

Electrical resistivity method is a geophysical method that has been successfully used by several researchers for groundwater investigations (Seaton and Burbey, 2002;Niwas and de Lima, 2003; Ako and Osondu 2006; Adeoti and Ishola 2008; Adiat *et. al.*, 2009). Other geophysical methods used to delineate groundwater potential zones include Geotechnical, Hydrogeological, Remote Sensing and Geographical Information Systems (GIS), (Adiat *et al*., 2012). However, some of these methods lack the precision of an in-situ analysis. The electrical resistivity method (non-invasive) is usually preferable because of the resistivity contrasts obtained when the groundwater zone is reached. Evidence shows that this technique has been successfully employed for delineating/mapping of geo-materials in the subsurface that guides exploration of groundwater resources (Anudu, Onuba and Ufondu, 2011; Emenike, 2001; Olorunfemi, Okhue, 1992; Oyedele, Adelusi, Ayuk, 2009).

Remote sensing with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas has become a very handy tool in exploring,

evaluating, and managing vital groundwater resources (Chowdhury,Roan and Sarma, 2003). The hydro-geologic interpretation of satellite data has been proved to be a valuable survey tool in areas of the world where little geologic and cartographic information exists or is not accurate (Engman and Gurney, 1991). Satellite data provide quick and useful baseline information about the factors controlling the occurrence and movement of groundwater like geology, lithology, geomorphology, soils, land use/cover, drainage patterns, lineaments, etc., (Babu, 2011). However, all the ground water controlling factors have rarely been studied together because of the non-availability of data, integrating tools and/or modeling techniques. Structural features such as faults, fracture traces and other such linear or curvilinear features can indicate the possible presence of groundwater. Similarly, other features like sedimentary strata (i.e., alluvial deposits and glacial moraines) or certain rock outcrops may indicate potential aquifers(Engman and Gurney, 1991).

The presence of ox-bow lakes and old river channels are good indicators of alluvial deposits (Farnsworth, Barret and Dhanju, 1984). Shallow groundwater could also be inferred by soil moisture measurements and by changes in vegetation types and pattern (Nefedov and Popova, 1972). In arid regions, vegetation characteristics may indicate groundwater depth and quality. Groundwater recharge and discharge areas in drainage basins can be detected from soils, vegetation, and shallow/perched groundwater (Todd, 1980).

In Kachia Local Government Area of Kaduna State, groundwater exploration is gaining greater attention due to increasing demand for water supply, especially in areas with inadequate pipe-borne and surface water. The drying up of some of the hand dug wells in the area worsens the problem. The problem is becoming progressively acute with growing population. As a result of inadequate supply of pipe burned water and drying of wells during dry season, these communities rely on self-water supply source such as unprotected wells, river, canal, and spring which play host to many diseases, such as typhoid fever, cholera,

dysentery, and infectious hepatitis, and as such, the people are vulnerable to these disease. There is therefore, need to explore the groundwater in order to meet the water demand of the people. Thus, this study focuses on the use of Remote Sensing and Geographic Information System techniques in investigating groundwater potential sites in Kachia Local Government Area of Kaduna State.

1.2 Statement of the Research Problem

In Nigeria as well as many other African countries, the provision of water for the teeming population is usually stated as one of the cardinal objectives of Government. In Kaduna State specifically, many water provision initiatives have been undertaken over the years and although achievements have been recorded in certain areas, water provision in the state cannot be described as a complete success story. It is estimated that there are currently about 1,805 boreholes constructed by the Ministry of Water Resources, covering all the 23 Local Government Areas in the state. In addition, the Rural Water Supply and Sanitation Agency (WATSAN) constructed an additional 400 boreholes. However in 2003, it was reported that only 20% of the boreholes in rural areas are active. As a result of high cost of geophysical exploration many boreholes are abandoned while some stop yielding water after sometime (WATSAN, 2006).

In Kachia Local Government Area, studies by WATSAN (2006) have shown that 50 boreholes were constructed from 2000-2010 but 80% has stopped yielding. The breakdown of the borehole has being attributed to poor maintenance and inadequate information on good ground water potential zone in the area. Since most geo-physical methods used in groundwater prospecting is time consuming and expensive, most water engineers tend to boycott the surveys process leading to poor yield and future break down of the boreholes.

Mogaji, Aboyeji and Omosuyi, (2011) mapped out lineaments for underground water targeting in Ondo state, Nigeria, using Remote Sensing and Geographic Information System

(GIS) techniques. The study used Landsat 7 ETM+ Imagery, ASTER digital elevations models (DEMs) and geological maps for mapping and analyses of lineaments in the Basement Complex region of Ondo State, Nigeria. The enhanced image, Normalized Difference Vegetation Index (NDVI) image and hill shaded relief image (processed ASTER DEM) were visually interpreted through GIS overlay operations for lineaments extraction through on-screen digitizing using ArcGIS 9.3. The extracted lineaments were statistically analyzed to determine their lengths, densities and intersections. The results obtained were used to generate lineament density, lineament intersection map and Rose diagram. The lineament/fracture analyses indicated that the area has numerous long and short fractures whose structural trends are mainly in the north-south and east-west directions. The cross-cutting lineaments are relatively high in areas around the central, north-eastern and south-western parts of the study area, and relatively low in the other areas. The research concluded that zones of high lineament intersection density are feasible zones for groundwater prospecting in the study area. The study has led to the delineation of areas where groundwater occurrences is most promising for sustainable supply and hence, further geophysical survey can be concentrated.

Pandian and Kumanan (2013)identified the groundwater potential zones using remote sensing and GIS inpart of Trichy and Karur district, Tamilnadu, India. The authors prepared thematic maps like lineament, geomorphology, land use and land cover, lithology and soil map and managing the GIS layers in Geo-database and assigning weightages based on the correlative factors that appear to be important in holding / processing of recharge of water and ground water potential content. The study of soil was added as an important theme/ data since it beholds the infiltration limitation through monsoon precipitation and in granulizing the effect of surface runoff based on their material content. The potentiality was delineated as moderate potential and some partswere classified as high potential zones, low and very low

potential zones and only few areas have been classified as very high groundwater potential zones.

Abubakar and Auwal (2012) used over forty Vertical Electrical Sounding survey to investigate groundwater potential of Dawakin Tofa Local Government Area of Kano state Nigeria. Results from the sounding data indicates that the area is generally underlain by five geoelectric or geologic section which include Lateritic top soil or Lateritic sand, Silty sand or Sandy clay, Weathered basement or Clay sand, fractured basement and fresh basement. Based on their results the fractured and the weathered basement make the aquiferous zone within the study area. The resistivities of the zones varies from 7.3 to 772 m with an average value of 178 m, while the thickness varies from a value of 1.66 to 28 m with an average value of 14.33 m. Depth to this zone varies from 5 to 31 m with an average value of 16 m. This series of studies provided adequate information about the groundwater occurrence of their study areas. This information will guide groundwater development in these areas.

It is a known fact that there is scarcity of water in the study area. Data on ground water in the study area is inadequate and there is no known study that investigated the ground water potential of the study area. These are gaps which this research intends to fill. This study therefore, focuses on the use of GIS and remote sensing in assessing groundwater potential in the study area

In order to achieve the purpose of the research, the following guiding questions or lines of inquiry are devised:

i. What is the characteristic of the ground water potential zones of the study area?

ii. Where are the groundwater potential sites in the study area?

iii. What is the areal coverage of the ground water potential zones?

iv. What are the reliability of GIS and Remote Sensing techniques in ground water potential zone mapping?

1.3 Aim and Objectives of the Study

The aim of this study is to apply geospatial technique in assessing ground water potential zones in Kachia Local Government Area, Kaduna State, Nigeria. The specific objectives are to:

i. examine the characteristics of the ground water potential zones in the study area.

ii. identify the ground water prospect zonesof the study area.

iii. determine the areal coverage of the ground water potential.

iv. validate the GIS and Remote Sensing result using vertical electrical sounding (VES) data of the study area.

1.4 Significance of Study

It is very important to know the groundwater potential of an area before embarking on any further exploration, as this will provide information on the water potential of the area, which in turn will prevent sudden dry up of boreholes during dry season and prevent minimal yield and supply from the boreholes.

Water scarcity in Kachia Local Government Area of Kaduna State warrants a detailed investigation of the groundwater potential characteristics of the area so that an exploration guide as well as sustainable groundwater management strategy can be developed.

The study will serve as a guide to the Government, and Non-Governmental Organizations and other stakeholders involved in water exploration. Also, the Kaduna State water board, Local Government Areas, Water and Sanitation (WATSAN), Kaduna State Agricultural Development Project (KADP), and other organizations and private individuals, involved in groundwater development will also benefit from this research.

1.5 Scope of the Study

This study was carried out for the entire Kachia Local Government Area, Kaduna State, Nigeria on Sabon Maro, Doka, Gidan Sani, Bahago, Gantan, Sabon-Gari Gantan, Kurmin Mata, Sabon-Gari Ankwa, Kachia, Sarahu, Angwan Ate and Asakwai. The study applied Remote Sensing and Geographic Information system technique in investigating ground water potentials zone in Kachia Local Government Area, Kaduna State, Nigeria using landsat imagery of 2014.The factors considered for the study include geology, drainage, rainfall, lineament, land-use/land-cover, slope/topography and soil as they are the available data and also the major factor contributing to the presence of ground water in an area.

CHAPTER TWO :CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 Introduction

This chapter presents general concepts relating to the origin, occurrence, movement, quantity, and quality of groundwater, including literature review.

2.2 Concept of Ground Water

2.2.1 Groundwater

Groundwater is a component of the hydrologic cycle, which describes locations where water mayoccur and the processes by which it moves or is transformed to a different phase. In simple terms, water orone of its forms—water vapor and ice—can be found at the earth's surface, in the atmosphere, or beneath theearth's surface(Griner, 1993). The hydrologic cycle is a continuum, with no beginning or end; however, it is often thoughtof as beginning in the oceans. Water evaporates from a surface water source such as an ocean, lake, orthrough transpiration from plants. The water vapor may move over the land and condense to form clouds,allowing the water to return to the earth's surface as precipitation (rain or snow). Some of the snow will endup in polar ice caps or in glaciers. Most of the rain and snowmelt will either become overland flow inchannels or will infiltrate into the subsurface. Some of the infiltrated water will be transpired by plants andreturned to the atmosphere, while some will cling to particles surrounding the pore spaces in the subsurface,remaining in the vadose (unsaturated) zone. The rest of the infiltrated water will move gradually under theinfluence of gravity into the saturated zone of the subsurface, becoming groundwater. From here,groundwater will flow toward points of discharge such as rivers, lakes, or the ocean to begin the cycle anew.This flow from recharge areas to discharge areas describes the groundwater portion of the hydrologic cycle (Griner, 1993)(See Figure 2.1).

The importance of groundwater in the hydrologic cycle is illustrated by considering the distribution of theworld's water supply. More than 97 percent of all earth's water occurs

as saline water in the oceans. Of the world's fresh water, almost 75 percent is in polar ice caps and glaciers, which leaves a verysmall amount of fresh water readily available for use. Groundwater accounts for nearly all of the remainingfresh water (USGS, 2002).

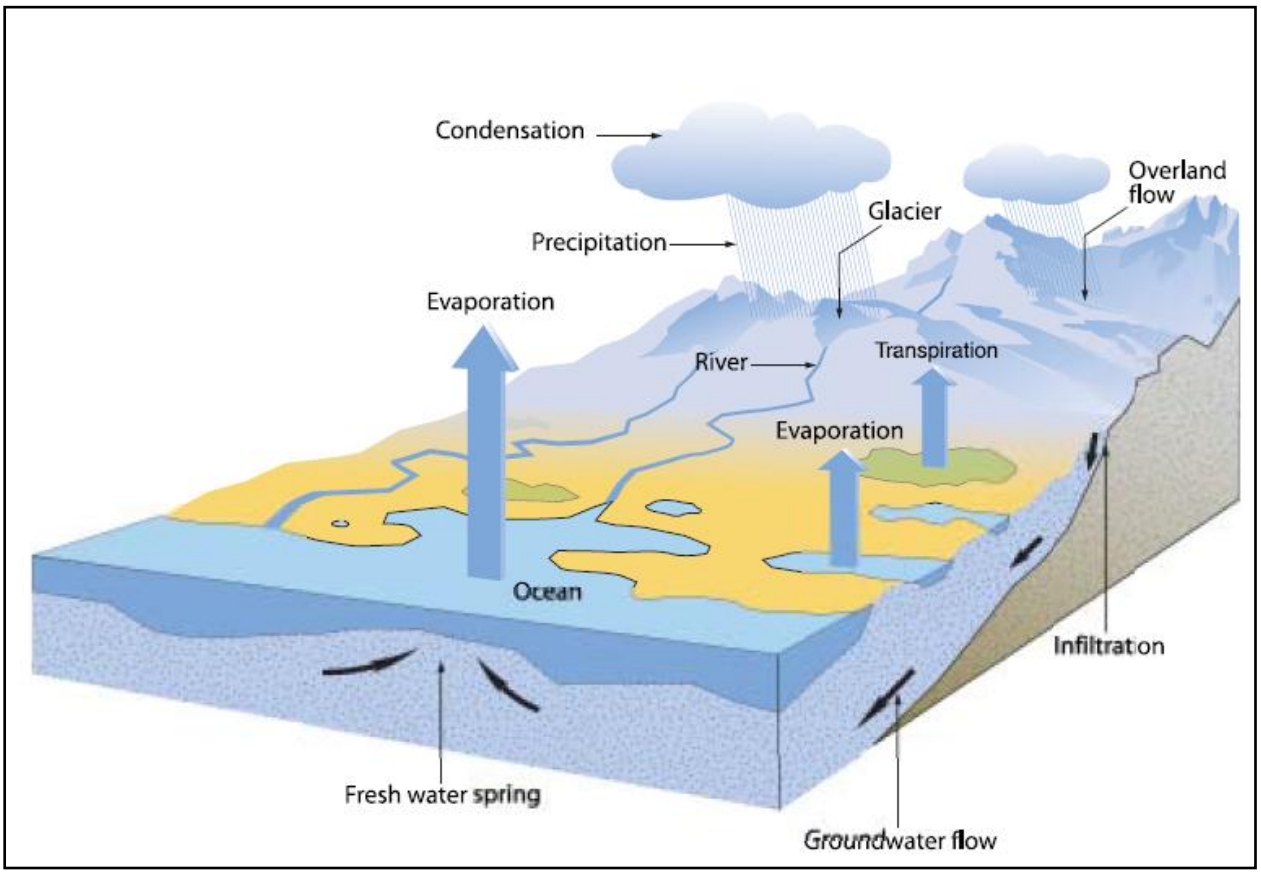

Figure 2.1: Hydrological Cycle
Source: USGS, 2002

2.2.2 Occurrence of Groundwater

Groundwater is the water occurring beneath the earth's surface that completely fills (saturates) the void spaceof rocks or sediment. Given that all rock has some open space (voids), groundwater can be found nearly any favorable location for its occurrence (Heath, 1983). Several key properties help determine whether the subsurface environmentwill provide a significant, usable groundwater resource. Most groundwater occurs in materialdeposited by streams, called alluvium. Alluvium consists of coarse deposits, such as

sand and gravel, andfiner-grained deposits such as clay and silt. The coarse and fine materials are usually coalesced in thin lensesand beds in an alluvial environment. In this environment, coarse materials such as sand and gravel depositsusually provide the best source of water and are termed aquifers; whereas, the finer-grained clay and siltdeposits are relatively poor sources of water and are referred to as aquitards. Groundwater basinsusually include one or a series of alluvial aquifers with intermingled aquitards. Less frequently, groundwaterbasins include aquifers composed of unconsolidated marine sediments that have been flushed by fresh water(Heath, 1983).

2.2.3 Aquifer

An aquifer is a body of rock or sediment that yields significant amounts of groundwater to wells or springs. In many definitions, the word “significant” is replaced by “economic.” Of course, either term is a matter of perspective, which has led to disagreement about what constitutes an aquifer.Coarse-grainedsediments such as sands and gravels deposited in alluvial or marine environments tend to function as the primary aquifers. Other aquifers, such as those found in volcanic, igneous intrusive rocks, and carbonate rocks are described briefly in the section Groundwater Source Areas.

2.2.4 Aquitard

An aquitard is a body of rock or sediment that is typically capable of storing groundwater but does not yield it in significant or economic quantities. Fine-grained sediments with low hydraulic conductivity, such as clays and silts, often function as aquitards. Aquitards are often referred to as confining layers because they retard the vertical movement of groundwater and under the right hydrogeologic conditions confine groundwater that is under pressure. Aquitards are capable of transmitting enough water to allow some flow between adjacent aquifers, and depending on the magnitude of this transfer of water, may be referred to as leaky aquitards (Heath, 1983).

2.2.5 Unconfined and Confined Aquifers

In most depositional environments, coarser-grained deposits are interbedded with finer-grained deposits creating a series of aquifers and aquitards. When a saturated aquifer is bounded on top by an aquitard (also known as a confining layer), the aquifer is called a confined aquifer (Figure 2.2) Under these conditions, the water is under pressure so that it will rise above the top of the aquifer if the aquitard is penetrated by a well.The elevation to which the water rises is known as the potentiometric surface. Where an aquifer is notbounded on top by an aquitard, the aquifer is said to be unconfined. In an unconfined aquifer, the pressure on the top surface of the groundwater is equal to that of the atmosphere. This surface is known as the water table, so unconfined aquifers are often referred to as water table aquifers. The arrangement of aquifers and aquitards in the subsurface is referred to as hydro-stratigraphy (Driscoll, 1986).

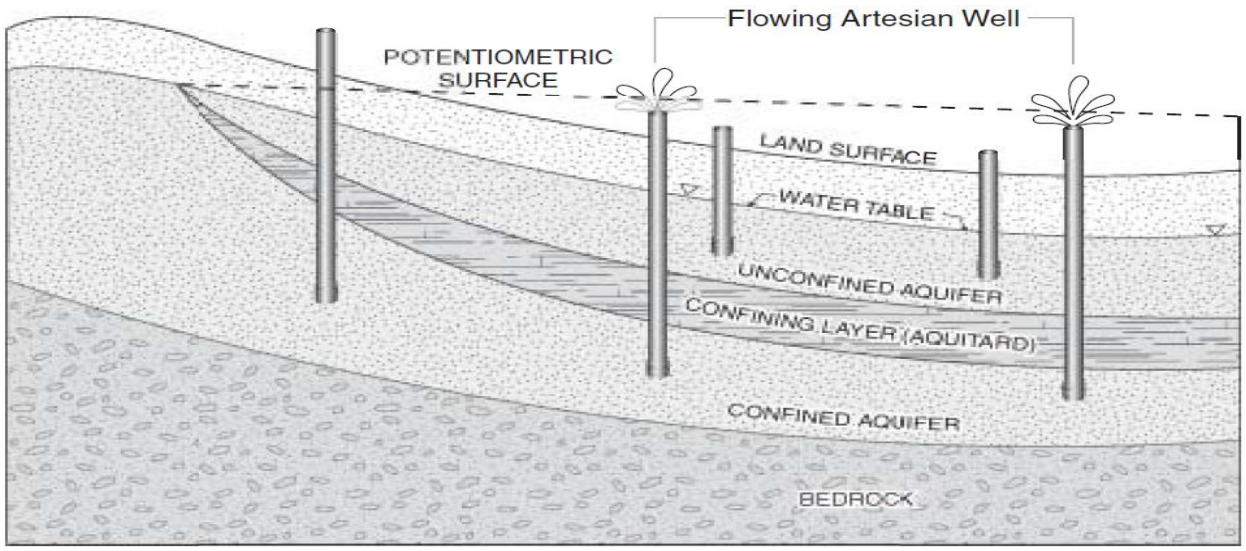

Figure 2.2: Interbedded aquifers with confined and unconfined conditions
Source: Driscoll, (1986).

In some confined aquifers groundwater appears to defy gravity, but that is not the case. When a wellpenetrates a confined aquifer with a potentiometric surface that is higher than land surface, water will flow naturally to the surface. This is known as artesian flow, and results from pressure within the aquifer. The pressure results when the recharge area for the

aquifer is at a higher elevation than the point at which discharge is occurring. The confining layer prevents the groundwater from returning to the surface until the confining layer is penetrated by a well. Artesian flow will discontinue as pressure in the aquifer is reduced and the potentiometric surface drops below the land surface elevation (Heath, 1983).

2.2.6 Aquifer Properties

The degree to which a body of rock or sediments will function as a groundwater reservoir depends on manyproperties, some of which are discussed here. Two of the more important physical properties to consider areporosity and hydraulic conductivity. Transmissivity is another important concept to understand whenconsidering an aquifer's overall ability to yield significant groundwater. Throughout the discussion of theseproperties, keep in mind that sediment size in alluvial environments can change significantly over shortdistances, with a corresponding change in physical properties. Thus, while these properties are oftenpresented as average values for a large area, one might encounter different conditions on a more localizedlevel. Determination of these properties for a given aquifer may be based on lithologic or geophysicalobservations, laboratory testing, or aquifer tests with varying degrees of accuracy(Driscoll, 1986).

a) Porosity

The ratio of voids in a rock or sediment to the total volume of material is referred to as porosity and is ameasure of the amount of groundwater that may be stored in the material. Porosity is usually expressed as a percentageand can be classified as either primary or secondary. Primary porosity refers to the voids present when thesediment or rock was initially formed. Secondary porosity refers to voids formed through fracturing orweathering of a rock or sediment after it was formed. In sediments, porosity is a function of the uniformityof grain size (sorting) and shape. Finer-grained sediments tend to have a higher

porosity than coarsersediments because the finer-grained sediments generally have greater uniformity of size and because of thetabular shape and surface chemistry properties of clay particles. In crystalline rocks, porosity becomesgreater with a higher degree of fracturing or weathering. As alluvial sediments become consolidated,primary porosity generally decreases due to compaction and cementation, and secondary porosity mayincrease as the consolidated rock is subjected to stresses that cause fracturing(Driscoll, 1986).

Porosity does not tell the entire story about the availability of groundwater in the subsurface. The porespaces must also interconnect and be large enough so that water can move through the ground to be extractedfrom a well or discharged to a water body. The term "effective porosity" refers to the degree ofinterconnectedness of pore spaces. For coarse sediments, such as the sand and gravel encountered in most countries, alluvial groundwater basins, the effective porosity is often nearly equal to the overall porosity.In finer sediments, effective porosity may be low due to water that is tightly held in small pores. Effectiveporosity is generally very low in crystalline rocks that are not highly fractured or weathered(Driscoll, 1986).

While porosity measures the total amount of water that may be contained in void spaces, there are tworelated properties that are important to consider: specific yield and specific retention. Specific yield is thefractional amount of water that would drain freely from rocks or sediments due to gravity and describes theportion of the groundwater that could actually be available for extraction. The portion of groundwater that isretained either as a film on grains or in small pore spaces is called specific retention. Specific yield andspecific retention of the aquifer material together equal porosity. Specific retention increases with decreasinggrain size. Sand and gravel, having much lower porosity than clay,make excellent sources of groundwater because of the high specific yield, which allows the groundwater to

flow to wells. Rocks such as limestone and basalt yield significant quantities of groundwater if they are well-weathered and highly fractured(Driscoll, 1986).

b) ***Hydraulic Conductivity***

Another major property related to understanding water movement in the subsurface is hydraulic conductivity.Hydraulic conductivity is a measure of a rock or sediment's ability to transmit water and is often usedinterchangeably with the term permeability. The size, shape, and interconnectedness of pore spaces affecthydraulic conductivity (Driscoll 1986).

Hydraulic conductivity is usually expressed in units of length/time: feet/day, meters/day, or gallons/day/square-foot. Hydraulic conductivity values in rocks range over many orders of magnitude from a lowpermeability un-fractured crystalline rock at about 10-8 feet/day to a highly permeable well-sorted gravel atgreater than 104 feet/day. Clays have low permeability, ranging from about 10-3 to 10-7 feet/day (Heath, 1983).

c) Transmissivity

Transmissivity is a measure of the aquifer's ability to transmit groundwater through its entire saturatedthickness and relates closely to the potential yield of wells. Transmissivity is defined as the product of thehydraulic conductivity and the saturated thickness of the aquifer. It is an important property to understandbecause a given area could have a high value of hydraulic conductivity but a small saturated thickness,resulting in limited overall yield of groundwater (Heath, 1983).

2.2.7 Geophysical Investigation

Crystalline basement complex rocks area relatively impermeable and have little or no storage capacity. Consequently, the groundwater resources in such terrain are therefore limited. It is therefore very important to know that the overall success of groundwater supply in such area can often depend on borehole siting. The greater, the siting success, the fewer boreholes that have to be drilled to achieve a project objective, thereby keeping the project

costs to a minimum. Borehole siting success has improved and become more cost effective in recent years with the introduction of new geophysical technology, providing instrumentation with greater resolution and rapidity of field measurements and allowing comprehensive interpretations of field data to be obtained with computers.

Groundwater exploration in the basement complex requires good degree of accuracy in locating productive borehole site. Unlike in the sedimentary areas where aquifers could be extensive and consistently underlying the entire area. Consequently, the identification of sizeable fractures and deep weathered ones, which provide good aquifers by means of surface geophysical investigation, is highly desirable. The main objectives of geophysical investigations are:

a. determining the geo-electric parameters, such as resistivities and thickness of the subsurface layers and their hydrogeological implications.

b. Mapping the bedrock relief (estimation of depth of basement rocks) and other subsurface structural features.

Clark and Jones (1985) observed that deeply weathered sites and fracture zones could be identified from aerial photographs. However, the use of remote sensing techniques is, in general, restricted to regional study. A location error of less than 1.0-5.0m can make a huge difference between a productive borehole and a dry one (abortive), due to the great variability and the unpredictability of the nature of the basement aquifer (Palacky, Ritsema and De Jong, 1981). For this reason, a ground geo-physical survey is often very necessary.

In the study reported herein, the electrical resistivity and electromagnetic methods were employed to investigate and assess the subsurface of the area. Two important physical properties of the geological section that can be determined from the above geophysical survey techniques area the electrical resistivity and magnetic susceptibility. Details of the surveying techniques based on these properties are outlined below.

a. Electrical Resistivity Method

Electrical resistivity methodfor a very long time now, the electrical techniques have enjoyed monopoly of use in groundwater explorationwith the electrical resistivity being mostly used. It is often regarded as the geophysical techniques most suited to the problems encountered in groundwater prospecting since the observed resistivity values are dependent on rock type, the degree of saturation, the chemistry of the saturating fluid and because it is comparatively rapid and cheap (Ako and Osondu, 1986).

The factors, which control the electrical resistivity of rocks, include the porosity of the rock, degree of saturation, water salinity, the matrix conductivity and the resistivity of the rock grains (Telford, Geldert, Sheriff, and Keys, 1976). Under ideal conditions, the resistivity of a water bearing formation decreases as the amount of water increases presence of secondary porosity by jointing and fracturing further reduces the resistivity.

The electrical resistance (R) of, example, a piece of wire is defined by ohm's law as the potential difference (ΔV) across it divided by the current (I) flowing through it (Telford *et al*, 1976). The expression is given as,

$R = \Delta V/I$ ---------- (2.1)

Since resistance is a function of the dimensions of the wire (length L, and cross-sectional area, A) and the resistivity (p) of the material of which it is made,

$R = Pl/a.$ ---------- (2.2)

If Eqs. (4.1) and (4.2) are combined to provide a definition of resistivity, we have.

$P = A\Delta V (LI).$ ---------- (2.3)

Resistivity is defined for practical purposes as being numerically equal to the electrical resistance of a block of material of unit dimensions. The most commonly used dimensions are meters and hence resistivity is usually expressed in ohm-maters.

In making resistivity surveys, a commutated current or very low frequency current is introduced into the ground via two electrodes. The potential difference is measured between a second pair of electrodes. If the electrode is arranged in any of the several possible patterns, the current and potential measurements are used to calculate the resistivity (P) using Eq. (4.4) (Telford *et al.*, 1976).

$P = K\Delta V/I$ …….. (2.4)

Where k is the geometric factor of the electrode arrangement. The resistivity is called apparent (p) because each resistivity value is a weighted combination of the resistivities of the various different materials that make up the subsurface earth below the point of measurement (Todd, 1980; Telford *et.al*, 1976).

b. Electrode Configuration

The electric sounding technique gives detailed information of the vertical succession of different conducting zones or formations and their individual thickness and true resistivities below a given point on the earth's surface. The commonly used electrode configurations are the Wenner and Schlumberger spread. The schlumberger array uses a potential electrode spacing that is much less than the current electrode spacing; each potential electrode spacing is used for a range of current electrode spacing.

The offset wenner array uses, 5 equally spaced electrodes, and 5 reading are taken using different combinations of 4 electrodes. This is made practicable by the use of a special multicore cables and a switchbox. One major advantage of the offset Wenner array is that it is less affected by moderate lateral variations in resistivity (Barker, 1981).

c. Resistivity traversing

Apart from the electromagnetic (EM) method used for some traversing, the resistivity method using Wenner array was also employed. Traversing provides a means of studying

lateral variations in the resistivity of the ground. In its simplest form, shifting the array by a distance equal to the electrode spacing between successivereadings carries out a traverse.

d. Electromagnetic Surveys

The basic principle is that an alternating current is passed through a transmitter coil to generate an alternating electromagnetic field, which is detected by a receiver coil at some distance from the transmitter (Groundwater research department (GWRD) report, 1994). A reference cable connects the transmitter and the receiver, with both coils in the same plane. Two types of electromagnetic (EM) survey equipment were used. These are the slingram, developed by ABEM/Swedish geological company and the geonics EM34-3 (fig. 4.2). This EM equipment (em34-3 and slingram) were used as a rapid reconnaissance tool in identifying high conductivity anomalies. Such anomalies are often further investigated by vertical electrical soundings (VES) in order to provide more quantitative information on the geo-electrical profile through the weathered profile through the weathered zone as an aid in borehole siting (Palacky *et al*, 1981; Olayinka and Olorunfemi 1992).

e. Geonics EM .34

Electromagnetic measurements carried out with a Geonic EM 34 ground conductivity meter. This instrument provided a direct reading of apparent were used. These are the 20m and 40.0m, each providing a different depth of investigation. Both vertical dipole and horizontal dipole mode of reading were carried out.

The base concept of this method entails probing the subsurface by means of an artificially produced magnetic field generated by an alternating current through a wire loop in search of conductive zones that are fractures and water bearing.

2.3 Literature Review

2.3.1 Movement of Groundwater

The movement of groundwater in the subsurface is quite complex, but in simple terms it can be described as being driven by potential energy. At any point in the saturated subsurface, groundwater has a hydraulic head value that describes its potential energy, which is the combination of its elevation and pressure. In an unconfined aquifer, the water table elevation represents the hydraulic head, while in a confined aquifer the potentiometric surface represents the hydraulic head. Water moves in response to the difference in hydraulic head from the point of highest energy toward the lowest. On a regional scale this results in flow of groundwater from recharge areas to discharge areas. Pumping depressions around extraction wells often create the discharge points to which groundwater flows. Groundwater may naturally exit thesubsurface by flowing into a stream, lake, or ocean, by flowing to the surface as a spring or seep, or by being transpired by plants(Flockhart, Sham and Xiao, 1993)

The rate at which groundwater flows is dependent on the hydraulic conductivity and the rate of change of hydraulic head over some distance. In the mid-19th century, Henry Darcy found through his experiments on sand filters that the amount of flow through a porous medium is directly proportional to the differencebetween hydraulic head values and inversely proportional to the horizontal distance between them (Fetter, 1994). The conclusions extend to flow through aquifer materials. The difference between hydraulic headsdivided by the distance between them is referred to as the hydraulic gradient. When combined with thehydraulic conductivity of the porous medium and the cross-sectional area through which the groundwaterflows, Darcy's law states:

Q = KA(dh/dl) (volume/time)

Where:

Q = flow discharging through a porous medium

K = hydraulic conductivity (length/time)

A = cross-sectional area (length2)

dh = change in hydraulic head between two points (length)

dl = distance between two points (length)

This version of Darcy's law provides a volumetric flow rate. To calculate the average linear velocity atwhich the water flows, the result is divided by the effective porosity. The rate of movement of groundwateris very slow, usually less than 1,000 feet per year because of the great amount of friction resulting frommovement through the spaces between grains of sand and gravel(Flockhart Sham and Xiao, 1993).

2.3.2 Quantity of Groundwater

Because groundwater is a precious resource, the questions of how much there is and how more can be madeavailable are important. There are many terms and concepts associated with the quantity of groundwateravailable in a basin, and some controversy surrounding their definition. Some of these include groundwaterstorage capacity, usable storage capacity, groundwater budget, change in storage, overdraft, and safe yield.

2.3.3 Groundwater Storage Capacity

Total storagecapacity seems easy to understand. It can be seen as how much physical space is available for storinggroundwater. The computation of groundwater storage capacity is quite simple if data are available: capacityis determined by multiplying the total volume of a basin by the average specific yield. The total storagecapacity is constant and is dependent on the geometry and hydrogeological characteristics of the aquifer(s) (figure 2.3)(Flockhart, Sham and Xiao, 1993)

Estimates of total groundwater storage capacity are staggering. Previous estimates of totalstorage range from 850 million acre-feet (maf) to 1.3 billion acre-feet (DWR 1994). However,due to incomplete information about many of the groundwater basins, there has

never been an accuratelyquantified calculation of total storage capacity statewide. Even if such a calculation were possible, the utilityof such a number is questionable because total storage capacity might lead to overly optimistic estimates ofhow much additional groundwater development can contribute to meeting future demands.Total groundwater storage capacity is misleading because it only takes into account one aspect of thephysical character of the basin. Many other factors limit the ultimate development potential of agroundwater basin. These limiting factors may be physical, chemical, economic, environmental, legal, and institutional. Some of these factors, such as the economic and institutional ones, can change withtime. However, there may remain significant physical and chemical constraints that will limit groundwaterdevelopment (DWR, 1994).

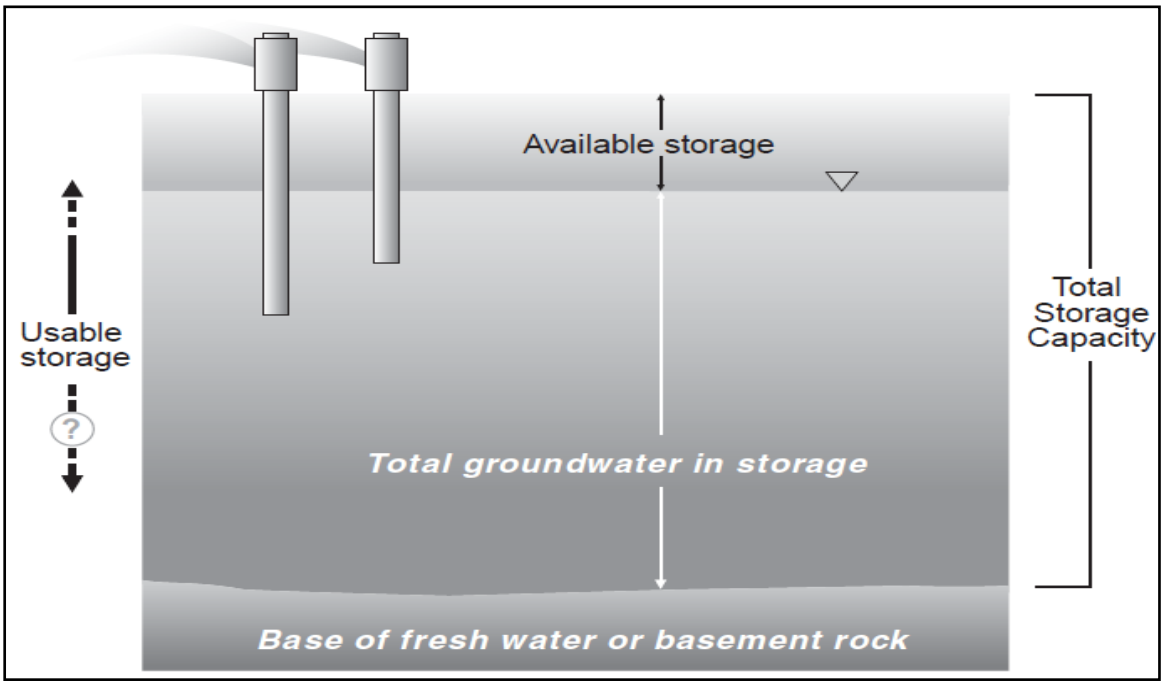

Figure 2.3: Schematic of total, usable, and available groundwater storage capacity
Source: (DWR, 1994)

2.3.4 Quality of Groundwater and Uses

All water contains dissolved constituents. Even rainwater, often described as being naturally pure, containsmeasurable dissolved minerals and gases. As it moves through the

hydrologic cycle, water dissolves andincorporates many constituents. These include naturally occurring and man-made constituents.Most natural minerals are harmless up to certain levels. In some cases higher mineral content is preferable toconsumers for taste. For example, minerals are added to many bottled drinking waters after going through afiltration process. At some level, however, most naturally occurring constituents, along with thoseintroduced by human activities, are considered contaminants. The point at which a given constituent isconsidered a contaminant varies depending on the intended use of the groundwater and the toxicity level ofthe constituents.

2.3.4.1 Beneficial Uses

For this report, water quality is a measure of the suitability of water for its intended use, with respect todissolved solids and gases and suspended material. An assessment of water quality should include theinvestigation of the presence and concentration of any individual constituent that may limit the water'ssuitability for an intended use.

Instead, water quality criteria for two of the most common uses—municipal supply (referred to as publicdrinking water supply in this report) and agricultural supply—is described below.

a. Public Drinking Water Supply

Standards for maximum contaminant levels (MCLs) of constituents in drinking water are required under the federal Safe Drinking Water Act of 1974 and its updates. There are primary and secondary standards.Primary standards are developed to protect public health and are legally enforceable. Secondary standardsare generally for the protection of aesthetic qualities such as taste, odour, and appearance, and cosmeticqualities, such as skin or tooth discoloration, and are generally non-enforceable guidelines. However, the secondary standards are legally enforceable for all new drinking water systems and new sourcesdeveloped by existing public water suppliers (DWR 1994). Under these primary and

secondary standards,the U.S. Environmental Protection Agency regulates more than 90 contaminants, and the California Departmentof Health Services regulates about 100.

b. Agricultural Supply

An assessment of the suitability of groundwater as a source of agricultural supply is much lessstraightforward than that for public water supply. An evaluation of water supply suitability for use inagriculture is difficult because the impact of an individual constituent can vary depending on many factors,including soil chemical and physical properties, crop type, drainage, and irrigation method. Elevated levelsof constituents usually do not result in an area being taken entirely out of production, but may lower cropyields. Management decisions will determine appropriate land use and irrigation methods.

There are no regulatory standards for water applied on agriculture. Criteria for crop water have beenprovided as guidelines. Many constituents have the potential to negatively impact agriculture, includingmore than a dozen trace elements (Ayers and Westcot 1985). Two constituents that are commonly consideredwith respect to agricultural water quality are salinity—expressed as total dissolved solids (TDS)—and boronconcentrations.

2.3.5 Geographic Information System and Remote Sensing in Groundwater

The full potential of remote sensing and GIS can be utilized when an integrated approach is adopted. Integration of the two technologies has proven to be an efficient tool in groundwater studies (Saraf and Choudhury 1998). For effective groundwater exploration and exploitation it is important to study the different parameters in an integrated approach. The integration of multiple data sets, with various indications of groundwater availability, can decrease the uncertainty and lead to ‘safer’ decisions (Sander, Chesley, and Minor, (1996). The Geographic information system offers spatial data management and analysis tools that can assist users in organizing, storing, editing, analyzing, and displaying positional and attribute information about geographical data (Burrough 1986). Remote sensing data provide

accurate spatial information and can be economically utilized over conventional methods of hydrogeological surveys. Digital enhancement of satellite data results in extraction of maximum information and an increased interpretability. GIS techniques facilitate integration and analysis of large volumes of data. Whereas field studies help to validate results further. Integrating all these approaches can offer a better understanding of groundwater controlling features in hard rock aquifers.

Rampal and Rao (1989) used MSS Landsat data of the Doddaguni area in Karnataka, Indiafor targeting groundwater potential zones. The groundwater targeting was dependent on theidentification and mapping of fractures, lithologic units and regional geology of the studyarea. They developed computer programs to enhance images using histogram equalization,combination and rationing of bands, and high and low-pass filtering. Using the variousenhanced images, a geological map of the area was prepared and a relationship between thelithologic units and estimated water features was developed. The validity of the methodologywas checked and found very encouraging in classifying the study area according to thegroundwater potential. The study also reveals that lithology contribute about 40% to groundwater potential in the study area.

Bobba, Bukata,and Jerome (1992), using the digital radiance Landsat data of Big Creek and Big OtterCreek basins in southern Ontario (Canada), delineated principal groundwater regimes accordingto the proximity of water table to the surface, i.e., discharge, recharge and transitionareas. They reported that during the spring, the modulating influence of groundwater on thenear-surface temperature could be detected only using the near-infrared band of the satelliteimagery. However, during summer months, the presence of phreatophytic vegetation throughoutthe watershed required the visible energy band in conjunction with the near-infrared datato affect such a classification scheme. They concluded that the digital satellite data provedto be very useful in delineating groundwater flow systems, which are

valuable input to thehydrological modeling, non-point source modeling, and the selection of solid-waste disposalsites.

Salama, Tapley, Ishii, Hawkes(1994) used aerial photographs and Landsat (TM) data to prepare the mapsof geomorphology, geology and structures of the Salt River System of Western Australiafor classifying the units that control the mechanisms of groundwater recharge and dischargein the area. The hydrogeologic interpretation of geomorphologic patterns and the classifiedhydrogeomorphic units from the TM analysis were used to identify recharge and dischargezones. They inferred that the permeable areas around the circular granitic plutons and thehighly permeable areas of sand plains were good for recharge. Groundwater discharge wasprimarily found along the main drainage lines, on the edge of the circular sand plains, indepressions, and in lakes.

Kamaraju, Bhattacharya, Reddy, Rao, Murthy and Rao (1995) evaluated the groundwater potential in West Godavari Districtof A.P., India using GIS. They used the existing maps and records as input data whichwere in different forms and scales, and created a GIS database using ArcInfo software. Thedescriptive information was converted into "groundwater favorability index" by rating thevarious groundwater-controlling characteristics according to their weightings to the output.The groundwater potential map thus generated showed three major hydrogeologic conditionswith distinct groundwater prospects. They emphasized that the GIS technique is very timeandcost-effectiveand could be employed successfully in the planning stage of a groundwaterexploration programme.

Krishnamurthy and Srinivas (1995) used remote sensing and GIS for demarcating groundwaterpotential areas in the Marudaiyar basin of Tamil Nadu, India. They prepared the maps oflithology, landforms, lineaments and surface water bodies from the remotely sensed data, andthose of drainage density and slope from SOI (Survey of India) toposheets. Thethematicmaps were integrated and analyzed using a model developed with logical

conditions in aGIS. Finally, the groundwater potential zone map thus developed was verified with fielddata, which indicated a good agreement.

Sander, Chesley and Minor 1996) developed better well-siting strategies for the violtanian Sedimentarybasin in central Ghana using remote sensing, GPS and GIS. Remote sensing data usedwere from Landsat TM, SPOT, and infrared aerial photographs. These data were interpretedfor lineament, vegetation, drainage and bedrock features to evaluate groundwater potential. Lineaments were also examined in the field and integrated with the information from severalGPS-positioned boreholes. GPS improved the spatial accuracy of various data integrated in the GIS.The study concluded that though GIS proved to be an effective integration tool for analyzing spatialdata and developing well-siting strategies, the implementation of a GIS in a groundwaterproject requires careful planning to avoid costly and unnecessary data acquisition and entry.

Edet,Okereke,Teme, and Esu, (1998) applied remote sensing technique for delineating the areas expectedto be suitable for future groundwater development in the Cross River State of southeasternNigeria. Radar imagery and aerial photographs were used to define some hydrologic andhydrogeologic features in parts of the study area. Lineaments and drainage patterns wereanalyzed using length density and frequency. The results were then used to delineate the areasof high, medium, and low groundwater potential. They found good correlations between thelineament and drainage patterns, lithology, water temperature, water conductivity, well yield,transmissivity, longitudinal conductance, and the occurrence of groundwater.

Travaglia and Ammar (1998) proposed a methodology for the integration dataextracted from satellite imagery with traditionally-gathered data. Based on the analysis ofthese data and selected field investigations, it was revealed that in the basaltic terrain ofsouthern Syria, the groundwater movement along faults and features occurred mainly due

totectonic movements. The statistical analysis of the lineaments interpreted from the LandsatTM data indicated two major directions of fracturing, which was considered as “open”for groundwater storage and transmission. It was concluded that the developed methodologycould be applied in other parts of Syria as well as in other countries with similar hydro geologicconditions.

Goyal, Bharadwaj, and Jugran, (1999) used a multi-criteria evaluation technique (MCET) to evaluate theinter class and inter-map dependencies for groundwater evaluation in the Rawasen and Piliwatersheds of Uttar Pradesh, India. They developed various thematic maps such as land use,geomorphology and lineament maps from satellite images and aerial photographs. Adrainagemap was prepared using the Survey of India (SOI) toposheets. The slope map was obtainedby creating DEM after interpolating spot elevation and contours in GIS. For integration, allthe maps were converted into digital formats in the GIS environment, which were then usedfor the zonation of groundwater availability in the Rawasen and Pili watersheds.The study concluded that slope had the highest influence to groundwater potentiality contributing 36% followed by geomorphology with 15%.

Musa, Juhari Mat, and Abdullah, (2000) used an integrated remote sensing and GIS system to produce variousthematic maps for classifying groundwater potential zones in Langat Basin, Malaysia. Theyused Landsat TM data, topographic map, soil map and other relevant field data for preparing various thematic layers such as annual rainfall, lithology, lineament density, drainage density,land use, land elevation, slope steepness and soil type, and combined all the layers using a modified DRASTIC (Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone media, and aquifer hydraulic Conductivity model. The polygons ineach of the thematic layers were categorized depending on their suitability/relevance to thegroundwater potential, and suitable weights were assigned to them. Finally, all the thematiclayers were integrated using a groundwater potential model

to derive the final layer. It wasconcluded that the integrated assessment of thematic maps using a GIS-based model provedto be the most suitable method for groundwater potential zoning in hard-rock terrains.And also groundwater potential was significant in areas of high lineament density (40%).

Lachassagne *et al*. (2001) developed a newmethodology for delineating favorable prospectingzones of a few square kilometers within basement areas of several hundred square kilometersfor the purpose of siting high-yield water wells. The methodology adopts a functionalapproach to hard-rock aquifers using a conceptual model of the aquifer structure and of thefunctioning of the main aquifer compartments: the alterites (weathered and decayed rock),the underlying weathered-fissured zone, and the fractured bedrock. It involves an economicallyfeasible method of mapping the thickness and spatial distribution of the alterites and theweathered-fissured zone, on which the long-term exploitation of the water resource chieflydepends. The potential groundwater resources were mapped by GIS multi-criteria analysisusing various parameters characterizing the structure and functioning of the aquifer. It wasconcluded that the developed methodology involves a coherent process of downscaling that,through applying methods that are increasingly precise but also increasingly costly, enablesthe selection of sites with diminishing surface areas as the work advances.

Shahid and Nath (2002) analyzed the hydrogeological data obtained from remote sensingand surface geophysical techniques for evaluating the groundwater condition in a soft-rockterrain of Midnapore District, West Bengal, India. The IRS LISS-II data were used for generatingthe thematic map of geology. Vertical electrical sounding (VES) survey was conductedat 139 locations in the study area, and the data were interpreted using genetic algorithm andRidge Regression techniques. The aquifer resistivity and thickness thus obtained were usedto prepare the corresponding thematic maps. Weights were assigned to different ranges ofresistivity and thickness values based on their position on the geological

map. Finally, theweighted maps were integrated using a GIS-based aggregation method to identify groundwaterpotential zones in the study area.

Singh and Prakash (2002) combined remote sensing, geophysics and GIS techniques todemarcate groundwater potential zones in the hard-rock region of India. They prepared hydro geomorphologicaland lineament maps from IRS LISS-III data by using visual interpretation.The topographic informationwas obtained from the SOI toposheets of 1:50,000 scale and TINwas generated from elevation contours. Slope maps were prepared from TIN, and the surfacedrainage maps were prepared from the topo-sheets and satellite data. Electrical resistivitysurveys were also conducted to investigate the lithology and the horizontal and vertical extentof aquifer systems. A groundwater potential map was developed by integrating the relevantlayers (i.e., hydro-geomorphology, lineament, slope, drainage, and overburden thickness) inArcInfo GIS environment, and then assigning appropriate weights to each layer based ontheir relative contribution to the existence of groundwater. The verification of the developedgroundwater potential map indicated that the demarcated groundwater potential zones are infair agreement with the well-yield data.

Singh, Raviprakash, Mishra, Singh (2002) used remote sensing, geoelectrical and GIS techniques for groundwaterexploration in Sonebatra, Mirjapur and Chaundali districts of Uttar Pradesh, India. They usedIRS LISS-II data for preparing hydro-geomorphological and lineament maps. The groundwaterpotential was assessed through the integration of relevant layers in the ArcInfo gridenvironment, which included hydro-geomorphology, slope, lineament, aquifer thickness, andclay thickness. The generated groundwater zone map was verified with the well-yield dataand a good correlation was found.

Srivastava (2002) integrated the remote sensing data with the hydrologic data in orderto investigate subsurface details, aquifer geometry and groundwater quality in Ken Graben,Uttar Pradesh, India. He used IRS LISS-I/II data to explore the geological,

geomorphologicaland structural aspects of the terrain. Buried channels and two different types of basementdepressions were identified in the study area which affected the aquifer geometry, groundwaterpotential and quality. The variations in tone and texture associated with vegetationand geological features, coupled with the inferred groundwater migration pattern in the areaenabled the delineation of brackish groundwater pockets, which was in close agreement withthe field observation. Furthermore, an overlay of the enhanced image on the digital terrainmodel of the study area revealed the exact surface geometry of aquifers and their relationshipto the surficial geomorphic features.

Hadithi, Shukla, Israil (2003) evaluated the groundwater potential in the Ratmau-Pathri Rao watershedin Haridwar district, India using geo-electrical, remote sensing (RS) and GIS techniques.They integrated various thematic maps, viz., geology, hydro-geomorphology, drainage density,slope, aquifer thickness, and depth to water table in a GIS framework. Then appropriateweights were assigned to various factors affecting the occurrence of groundwater to evaluate groundwater potential in each segment of the study area. They found that the categorizationof groundwater potential by RS and GIS techniques was in agreement with the availablewell-yield data. It was also observed that areas with aquifer thickness greater than 35m were areas with good groundwater potential.

Sikdar, Chakraborty, Adhya, Paul (2004) used remote sensing and GIS techniques to explore the land use/landcover changes and to delineate groundwater potential zones in and around Raniganj coalmining area of Bardhaman District, West Bengal, India. They used IRS LISS-III data andToposheets to identify land use/land cover changes from 1972 to 1998 in the area. It wasfound that the land covered by vegetation and settlement has decreased during this period atthe expense of mining activities. Various thematic layers namely geomorphology, lithology,drainage texture, slope, lineament density and current land-use pattern were considered todelineate groundwater potential zones. These thematic layers were

prepared using ILWISGIS package, and ranked in a scale of 0 to 5 depending upon their suitability for groundwateroccurrence. The rank of each map was then converted to a probability weight using Bayesianstatistics and finally a multi-criteria overlay analysis was used to find groundwater potentialzones. The groundwater abstraction structures (i.e., dug wells, mini-deep tubewells or deep tubewells) feasible in each of the delineated potential zones were also suggested.

Elango and Arrikkat (1998) integrated and analyzed various thematic layers related to groundwaterrecharge using GIS for the identification of recharge sites in parts of Ongur sub-basin,south India. Seven thematic layers were prepared using both remotely sensed and conventionaldata. These layers were ranked, reclassified, and overlaid in ArcInfo GIS. Basedon the GIS analysis, the study area was divided into four zones viz., 'very good', 'good','poor', and 'very poor' according to the potential for natural recharge. The unfavorable areaswere further classified into four classes on the basis of potential for artificial recharge. It wasconcluded that remotely sensed data, conventional data, and GIS overlay analyses provide apowerful and practical approach to identify groundwater recharge areas in a basin.

Ramlingam and Santhakumar (2002) used remote sensing and GIS techniques to exploresuitable recharge areas and structures to augment an aquifer system in Tamil Nadu, India.The thematic maps such as geomorphology, geology, soil, slope, land use, drainage density, lineament density, runoff, depth to weathered zone, depth to basement, groundwaterlevel fluctuations and the water quality were used in this study. These maps were preparedusing IRS LISS-III satellite data and other collateral information obtained from the field.The ArcInfo GIS package was used to identify suitable artificial recharge areas. They used1-sigma criteria to divide the rechargeable area into various categories namely 'highly favorable','moderately favorable', 'less favorable' and 'poor'. Suitable recharge structures

wereproposed depending on the terrain condition and favorable zonation. They concluded that thezonation created using GIS as well as the type and location of water-harvesting structuressuggested were agreeable, and the success rate was more than 90%.

Vasanthakumaran, Shyamala, and Sridhar, (2002) used remote sensing and GIS techniques for selecting suitablesites for artificial groundwater recharge in the rocky terrain of Southern India. They usedtoposheets and satellite data for preparing soil, lineament, and drainage density maps. Thedeveloped themes were integrated using ArcView and ArcInfo GIS software and appropriateweights were assigned to each theme, which resulted in the identification of suitable artificialrecharge sites.

Fayer, Gee, Rockhold, Freshley, and Walters (1996) estimated the areal distribution of natural recharge at the Hanford Site insoutheastern Washington State to serve as input to a groundwater flow and transport model.A GIS was used to identify all possible combinations of soil type and vegetation and assignto each an appropriate estimate of recharge. The strategy was to assign estimates based onfield data and supplement with simulation results only when necessary. The estimated rates varied from 0.7 to 127.1 mm/yr.The GIS software was used to estimate the annual rechargevolume attributable to specific soil-vegetation combinations and to construct a recharge map.The recharge map showed the impact of a 1984 fire on increasing recharge; it also illustratedthe higher recharge rates associated with disturbed soils in the waste storage areas.

Stone, Moomaw, and Davis (2001)presented a method to estimate the distribution of groundwater rechargewithin hydrographic basins in the Great Basin region of the southwestern United States onthe basis of estimated runoff from high mountainous areas and subsequent infiltration inalluvial fans surrounding the inter-montane basins. It involves a combination of GIS analysis,empirical surface-runoff modeling, andwater-balance calculations. The method addresses theneed to develop and incorporate constraints on the

distribution of recharge in regional-scalegroundwater flow modeling of arid and semiarid environments. The conceptual approach and methodology were developed for Crescent Valley, Nevada and it was demonstrated that themethod resulted in a more accurate representation of actual recharge conditions.

Brunner, Khan, Kinzelbach,(2004) presented a methodology for obtaining the recharge map for two sites in Botswana, South Africa. The relative distribution of recharge was obtained from remotely sensed data using surface water balance method, which was calibrated with local recharge values determined by Chloride Method. The Meteostat-5 satellite data (5-km spatial resolution) were used to estimate rainfalls, which were validated against the measured rainfall data collected from four stations.Asimpleralgorithmwas used to estimate ET which involved multiplication of daily net radiation and evaporative fraction. The daily net radiation datawere obtained from the satellite imagery and astronomical data using a simple algorithm andthe evaporative fraction was obtained from the satellite imagery for each pixel value. Finally, correlation coefficients between the recharge estimates obtained by the water balance model and those by Chloride Method were determined. Based on these correlation coefficients, a scaled recharge mapwas developed. The study inferred that if the assumptions of the surface water balance and Chloride Method are satisfied and the precipitation as well as chloride data is available in the required resolution, the methodology could easily be adapted to other arid or semi-arid regions.

Cherkauer (2004) estimated natural groundwater recharge in watersheds of varying sizes using a distributed parameter model and GIS. This procedure simplifies the PRMS calibration observed streamflow hydrographs by reducing degrees of freedom from dozens to four. For seven watersheds (60 to 500 km2), the GIS-aided calibrations had average errors of 5% on recharge and 2% on total streamflow, verifying the accuracy of the process. Recharge was also calculated for 63 local-scale sub-watersheds (average size 37 km2), and the

calculated recharges were found to average 11 cm/yr. The model was extended to un-calibrated watersheds where GIS and climatic information were known. It reproduced total annual discharge and recharge to within 9 and 10%, respectively, indicating the process can also be used to calculate recharge in ungauged watersheds.

Many literature have discussed the application of GIS and Remote Sensing forexploration and assessment of groundwater resources, selection of artificial recharge sites andestimation of ground water natural recharge distribution in several study areas. This research was built upon past research and evidence from other literature to apply Geo-spatial technique in assessing ground water potential zones and also to validate this technique using the vertical electric sounding (VES) data in Kachia Local Government Area, Kaduna State, Nigeria.

CHAPTER THREE :STUDY AREA AND METHODOLOGY

3.1 Introduction

This chapter discussedthe study area in terms of the location, drainage climate, economic activities, soil and vegetation. It also describes the data sources, method of data collection and the techniques used for data analysis.

3.2 The Study Area

3.2.1 Location and Size

Kachia Local Government Area is one of the 23 Local Government Areas of Kaduna State, Nigeria. It is bounded by latitudes 09^{o} $32^{'}$ and 10^{o} $10^{'}$N of the equator and longitudes 07^{o} $14^{'}$ E and 08^{o} $04^{'}$E. Kachia Local Government Area is bordered to the north by Chikun and Kauru L.G.As, to the west by Niger State, to the East by Zangon Kataf L.G.A. and to the south by Kagarko and Jaba Local Government Areas. Kachia Local Government Area has its headquarters in the town of Kachia. It has an area of 4,632 km² and a population of 244,274 at the 2006 census (Akintola, 2006) (See Figure 3.1).

Farming is the traditional occupation with main emphasis on cultivation of crops and keeping of livestock. Important crops grown include maize, sorghum, millet, rice, soya bean, groundnut, yam, cassava, sweet potato, ginger, pepper and tomato. Cattle are reared by the nomadic Fulani people. Sheep, goats and poultry are kept on free range basis. This shows the extent to which the people are dependent on land and water for their livelihood. The major source of water are from dams, rivers, hand dug wells and boreholes.

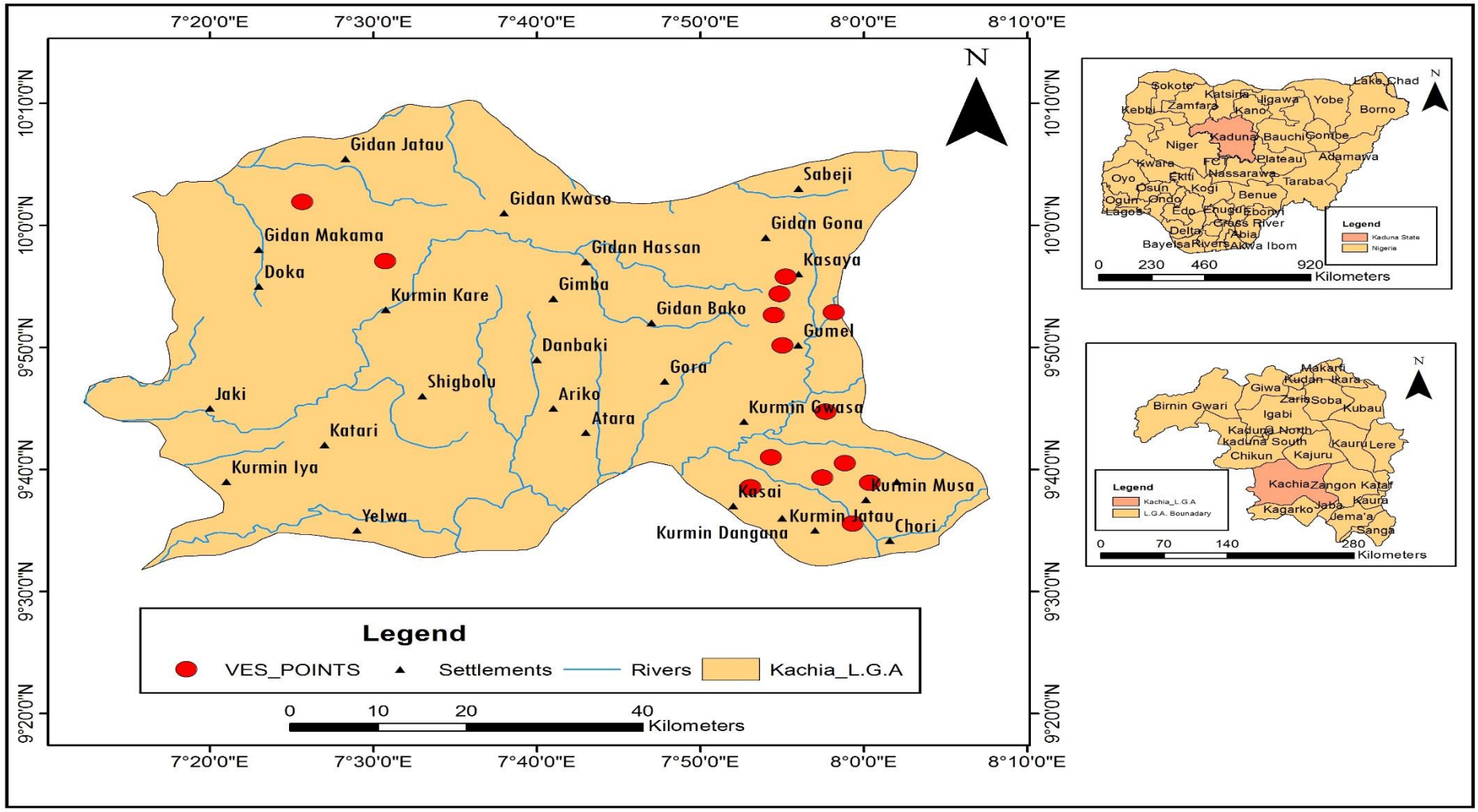

Figure3.1: Kachia Local Government Area

Source: Modified from the Administrative Map of Kachia L.G.A

3.2.2 Climate

Kachia has a tropical continental climate type characterized by wet and dry season. The tropicalcontinental is more pronounced in the dry season particularly in December and January. The dry season is dominated by the north-east trade wind called Harmattan which prevails between November-February. The dry season is also rainless from October to April. The wet season is dominated by the tropical maritime trade wind which starts around May to October. The area has a mean daily temperature showing a major peak in April. As such, temperatures are hot all year round except for the dry cool and dusty months of harmattan in November to February. The maximum temperature seldom falls from about 36°C as in April to about 27°C in the heart of rain season (August-October). The annual rainfall is about 1000mm (Ayoade, 1988). These seasons arecontrolled by the apparent movement of an imaginary line known as the inter-tropical discontinuity (ITD), which is in turn dictated by two dominated trade winds; are the tropical continental and the tropical maritime. While according to Thornwaites moisture index the climate of Kaduna falls under the dry sub-humid type (Ayoade, 1988).

3.2.3 Vegetation

The natural vegetation of the study area is that of the Northern GuineaSavannah with grass dominating and scattered trees hardly higher than 4.6m with broad leaves. Meanwhile, the seasonal character of rainfall in the study area has influenced the vegetation which turns evergreen during the wet season and pale brown in the dry season respectively. Thus, the dominant true species are *IsoberlinaDoka, Dodoneaspp,* and grass communities consist of *Hyperhenia* and *Andropgon* species. In the city proper the vegetation is characterized by Silk cotton, Baobab and other protected trees. However, man has greatly affected the vegetation formation in the area, through his activities like; bush burning, cultivation ofcrops, grazing, lumbering, urbanization and industrial activities among others. Thevegetation formation

varies and associated with distinct ecological site with particularregard to the nature of the soil (Oguntoyinbo, 1983).

3.2.4 Soils

The soils in the study area have been classified according to Hoores classification schemefor Africa as tropical ferruginous soil. They are zonal soils developed under climaticregimes with appreciable but seasonal rainfall of 500-1200mm and cover nearly half ofNorthern Nigeria (Oguntoyinbo, 1983). The soil material consists of several feet ofdeposited silt sand overlaying sedimentary decomposed rock. The soil is poorly drainedbecause of the high percentage of fine textured materials in the upper layers, which resultsto water logging especially during the rainy season and tends to dry out and cracks during dry season. Alluvial soil is formed a long riversides (fadama). It is made up of several feet ofgrey white loamy coarse sand with layers of grey heavy molten occurring at varyingdepths within the profile. The alluvial soils are usually under intensecultivation ofsugarcane and vegetables year-in year-out and as a result in farmers resort to usingfertilizers to improve soil fertility (Ayoade, 1988).

3.2.5 Geology

The geology of the study area is part of the basement complex geology of northcentral Nigeria. The region is underlain by older granitic crystalline, metamorphic rocks of Precambrianto low Paleozoic age (Oguntoyinbo, 1983). The metamorphic rocks consists of gneisses which has suffered intense weathering andhave remained stable for millionsof years. The prolonged weathering under tropical bioclimatic condition has produced rolling plains dotted with residuals of different origin.

The study area lies on the high plains of Hausa land, with elevation ranging from 550 to 750meters above mean sea level showing a general regional slope to the south and a relative relief of 30 to 45 meters. The plains on which the area is situated are parts of the vast,

gently undulating plains scenery; which extends almost unbroken from Sokoto to Lake Chad and beyond, from South of Kaduna to the Tidueddi Scarp near Agades. At first sight, they seem remarkable only for their usual monotony and apparent geomorphic simplicity. However, a closer field examination reveals considerable variation inboth surface form and composition(Oguntoyinbo, 1983).

The southern parts of Kaduna in the north central Nigeria forms a part of the west mobile zone which extends from east to west from Nigeria, Ghana where it is 'sutured' to the west African craton by the pan African Dahomeyan (or Beninaian) belt (Mbonu,1989). Is shown in fig. 2.1 the whole ensemble or rocks in this zone has undergone an extensive episode of "remobilization and reactivation' during the pan-African thermotectonic event some 600my ago (McCurry, 1970, 1976; Oawoye, 1970; Macleod, *et al*, 1971; and Mbonu, 1989). Oyawoye (1970) and McCurry(1976).Reported that the oldest rock of the area is the gneissess and older metasediments believed to be Birrimian age (about 2500my). Through the process of metamorphism, migmatization that occurred within at least two tectno-metamorphic cycles, the rocks were largely transformed into migmatites and granite-gneisses; with some relics of the original gneisses. The basement complex was later intruded by series of intermediate and acid plutonic rocks during the pan African orogeny (McCurry, 1976), the plutonic intrusions formed what is now known as the older granites. The major rock units mapped based on existing literature and field work is summarized as follows (figs.2.2 and 2.3): migmature gneiss complex, metasedimentray series, the older granite series, the Jurassic younger granites, the newer basalts and laterites.

3.2.5.1 Migmatite-Gneiss complex

The migmatite-gneiss complex constitutes the largest group of rocks occurring in the study area. It consists of migmatites, biotite and granitic gneisses. The Migmatite gnesiss complex represents reactivated older metasediments (Oluyide, 1995; Dada, 1993): hence,

they are characterized by a variety of structures and textures. Oluyide (1995) also reported that the migmatites are impregnated by numerous pegmatites and quartzo-feldspathic veins. The migmatite-gneiss complex could be further grouped into two units based on field observation of their lithologic characteristics and age as reported by McCurry (1976). These include the migmatites and the gneisses.

a. Migmatites

These rocks constitute the prominent rock in the study area and the most diverse in composition and features. The migmatites commonly show granoblastic textures and swirted foliation with large blocks of banded gneiss. Being a heterogeneous mixture of other rocks, its components can be found as distinct rock types within the same outcrop. These are granite, pegmatite, gneiss and schist.Migmatites outcrop as flat-lying bodies, medium sized domes, ridges, whale-backs and high rising escarpments. Where the dominant components are gneisses and or schists, the outcrops maintain a low to average relief. However, in outcrops dominated by granite especially the porphyritic granites, the forms are high ridges hills and sharp crested escarpments (GSN, 1970 report).

In some locations –Iri station, Jura and Kachia areas, the Migmatite is dominated by porphyroblastic granite exhibiting augens of feldspar around which flow thin mica plates. In some outcrops, Pegmatites are found within the Migmatites –gneiss complex.

b. Gneisses

The gneisses occur in various sizes ranging from low-lying isolated outcrops to large bodies which sometimes form extensive ridges. They also vary in texture from being medium, even rained to coarse porphyroblastic. The outcrops are pinkish to grey in colour, strongly foliated and sometimes have variable joint directions with quartz mineralization. They are composed essentially of feldspars, quartz and Biotite minerals.

c. Meta-Sedimentary Series

These series consists of schist, including gneiss, finegrained flaggy quartzite and pegmatites. These are metamorphosed sedimentary and meta-volcanic rocks, which predominantic in the southern parts of the project area. For example-Kubacha, Western parts of Kurmin Dangana, Koka, and Kurmin biri near Kachia. Most of these schists occur as isolated narrow bodies within the migmatite-gneiss complex. These metasediments host about 90% of the mineral occurrences, namely; gold iron talc, Kyanite, graphite and others (Oluyide, 1995). There is remarkable variation in the composition of the schist. It changes from politic to quartzitic schist in the north of Kaduna. The outcrops of the pelitic schist are only restricted to the northern part s of the study area. The outcrops are of moderately low ridges or whale backs with long axes in the general direction of strike. Generally, they are hard, compact, and sometimes occur as boulders. Most of these politic schists are dark, solid, finely foliated with very fine streaks of concordant light colored quartzofeldspathic material. Prominent grains as reported by okezie (1970) include; quart, mica and brownish garnet with grain size ranging from very fine to medium. Biotite apparently dominates over muscovite.

d. Older Granite Series (The Pan African Granites)

The granitoids constitute the second largest group of rock in the study area. They are characterized by loftly topography and inselberges (Oluyide,1995). These rocks are very prominent around Kafanchan-Kagoro range of hills in the southern parts of the project area. The lithological varieties of the rock formation believed to have been emplaced during the early Palaeozoic era (550±100my) (oluyide, 1995, McCurry, 1972, 1976), include coarse- grained porphyritic granite, biotite hornblende granite and fine-grained granites and fayalite-quartz monzinite. In the field, the prophyritic granite consists of large white and pink prismatic phenocrysts of microcline. The rock is pinkish grey in

appearance and Porphyntic in texture. The medium grained granite is generally grayish brown, medium grained, fairly uniform in texture, weakly foliated and massive. The rock is highly jointed and strikes mostly in the N-S and sometimes E-W directions. It is composed of feldspar s, quartz and biotite as the major minerals.

e. Laterites

Lateritic capping occurs in most of the study area. These are probably erosional remains of Pliocene laterite sheet covering an extensive peneplain described by Du Preez (1949). They are reddish brown with ferruginous concretions. The laterites are sometimes highly consolidated especially at the surface and weathered into lateritic nodules mixed with silty and sandy clays. In generals, the concretion and vesicular types of laterites are present in the study area. Adanu (1989) reported the depositional sequence drawn up by Wright and McCurry (1970) as comprising scattered exposures of sometimes gravelly laterite which either underlies or overlies alluvium, locally discontinuously laterite, marked by layers of quartz fragments, and an ancient drainage channel, filled by stream deposits and are now re-exposed in present day erosion gullies.

f. Weathering of Rocks

Metamorphic and magmatic rocks were emplaced under conditions different from those prevailing on the surface under which they are exposed. Under the surface conditions that prevail in the study area, characterized by dry and wet seasons, high rainfall and temperatures, crystalline rocks are subjected to intense weathering (Mbonu, 1988). In fact, the ultimate of weathering is a remobilization of a compact fresh rock into a disintegrated, porous and detrital mantle, constituted essentially of quartz and clays whose relative proportion is largely influenced by the nature of the parent rock. Granite-gneissic rocks do produce more of the quartz than clays whereas Schists are characterized by more of the clays than quartz. It is for this reason that detailed description of the

various rock types in the study area are high lighted above. In general, rocks of the basement are aquiferous only when they are weathered and or fractured, otherwise, they are sterile as it concerns storage and transmission of groundwater.

g. Structures

The geological and structural map of the study area is shown in fig. 2.3 lineaments; statistically analyzed by frequency distribution of accumulative lineament length and strike directions is presented in fig. 2.4 as windrose diagram. The prominent structural trends are the NS, NE/SW, AND NW/SE. these lineaments relate well to the fracture directions of the regional geologic structure in the basement complex (oluyide, 1988). Ductile and brittle structures are found in the basement rocks. They include joints, faults, fold, schistosities and lineation. Very often the outcrops trend in the same direction as the foliation. The intensity of the foliation varies greatly from one gneissic body to the other. The dip directions varied closely with the strike of the foliations. The dip directions measured are generally moderate and ranged from 19^0 to 27^0 and values below 10^0 were common. In the gneisses, the outcrops are massive and ridge like, and occasionally, tubular bodies with bedded outcrops are quite common. Shear faults are seen displaying both sinisterly and dextral relationship especially at Gwantu, Kagoro and Kajuru; where some shear faults have been filled with quartz mineralization. All these structures identified, play important role in the movement of groundwater. Joint systems, which are widespread, form good channel.

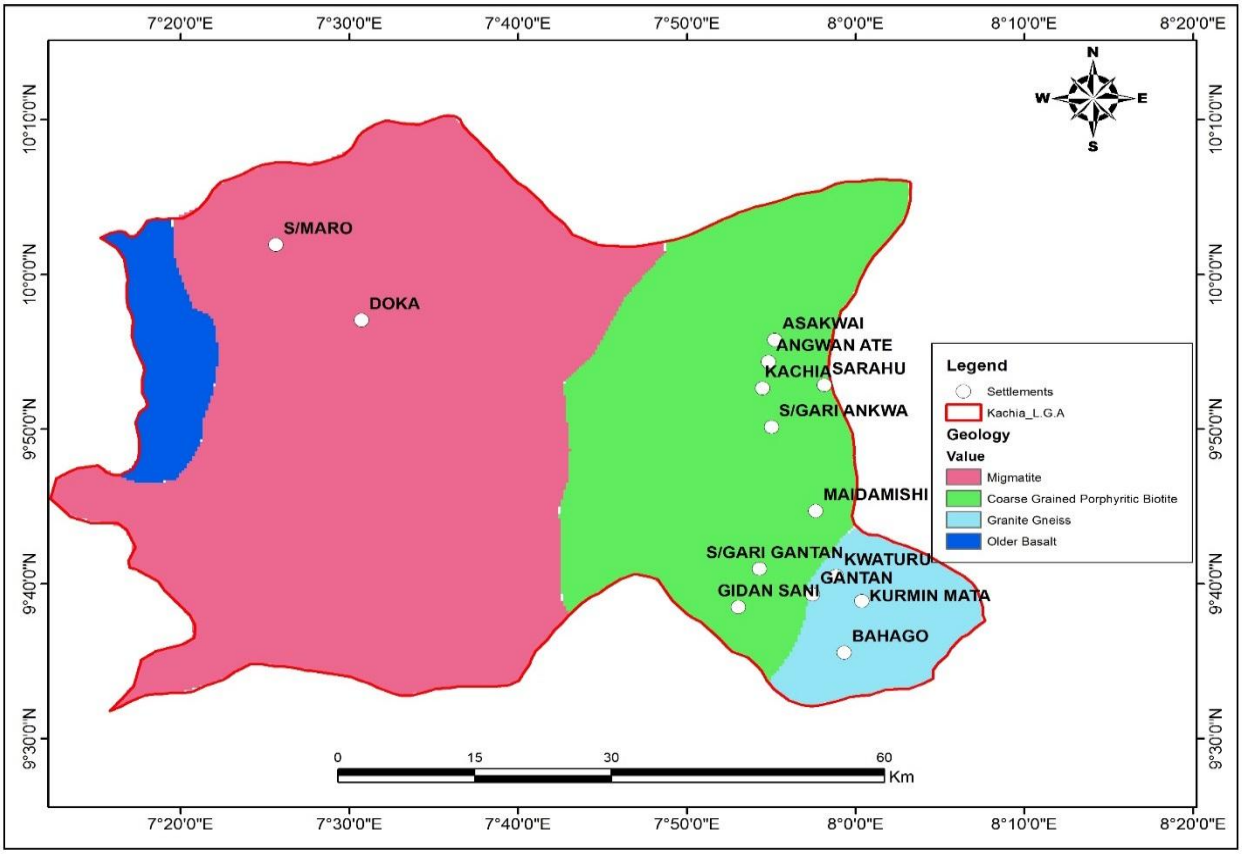

Figure 4.10: Geology Map of Kachia L.G.A.

Source: Geology Map of Nigeria.

3.2.6 Hydrology

The area is drained by river Kaduna and characterized by high stream frequencies anddrainage density. The river drains mostly during the raining season, and characterized byseasonal and ephemeral attributes. It takes its source from the highland of Jos. It is a greatresource for various water usage (Oguntoyinbo, 1983).

3.3 Methodology

3.3.1 Reconnaissance Survey

A reconnaissance survey and physical field observation of the study area was undertaken, in order to have adequate knowledge of the study area. It also helped the researcher to gain good knowledge on water problem in the study area.

3.3.2 Types of Data and Sources

i. Drainage Density data

Drainage pattern gives an idea about the joints and faults in the bedrock which in turn indicates the presence or absence of groundwater. High drainage density indicates unfavorable site for groundwater existence, Moderate drainage density indicates moderate groundwater potential and less/no drainage density indicates high groundwater potential(Chowdhury, *et. al.* 2003).

ii. Slope data

In relation to groundwater flat areas where the slope amount is low are capable of holding rainfall, which in turn facilitates recharge whereas in elevated areas where the slope amount is high, there will be high run-off and low infiltration (Chowdhury, *et. al.* 2003)

iii. Land use/Land cover

One of the parameters that influence the occurrence of sub-surface groundwater occurrence is the condition of land cover and land use of the area. The effect of land use / cover is manifested either by reducing runoff and facilitating, or by trapping water on leaves. Water droplets trapped in this way go down to recharge groundwater. Land use/cover may also affect groundwater negatively by evapotranspiration, assuming interception to be constant (Chowdhury, *et. al.* 2003)

iv. Lineaments

Lineaments are the results of faults and fractures. They infer that they are the zone of increased porosity and permeability, which in turn has greater significance in groundwater occurrence and distribution (Chowdhury, *et. al.* 2003)

v. Topography

The local and regional relief setting gives an idea about the general direction of groundwater flow and its influence on groundwater recharge and discharge (Chowdhury, *et. al.* 2003).

Both primary and secondary data were utilized in thisstudy. Primary data that were use are satellite imageries (LANDSAT and Shuttle Radar Topographic Mission, SRTM) and the secondary data include rainfall data and existing geological map of Kaduna state. Other literature were sourced from newspaper, journal, textbooks etc.

Table 3.1: Types and sources of data

S/no	Type of Data	Source	Purpose
1	SRTM-30	Global Land Cover Facilities, University of Maryland Website	For DEM creation, topography and Slope map
2	LANDSAT 7 (2014)	Global Land Cover Facilities, University of Maryland Website	Production of Land use/ land cover and lineament map
4	Geological Map 1:50000	Nigeria Geological Survey Agency.	Geology of the area
5	Rainfall data (2004-2014)	Nigeria Metrological Agency (NIMET).	Production of Rainfall map

3.3.3 Software

The following software wereused for the underground water potential zones in the study area:

i. ERDAS IMAGINE: For image processing and classification.

ii. ArcGIS for digitizing and Groundwater analysis.

iii. PCI Geomatica v10.0 for lineament extraction.

iv. Microsoft Excel for graphical representation of charts.

3.3.4 Data Processing

3.3.4.1 Image processing and classification

The LANDSAT 7 was utilized to obtained different layers and the layer was stacked together using ERDAS Imagine 9.2 software; subset of the study area were obtained using the ERDAS imagine software subset tool. ERDAS imagine was used for the pixel-based classification. Supervised classification was carried out using maximum likelihood classifier since it is a land-use/land cover classification which will produce the output raster layer. This method of classification involves the procedure of identifying pixels possessing the same spectral features. ERDAS Imagine software was used in digitally processing and identifying the spectral signatures of different features. Maximum likelihood algorithm was used to classify the images and the digital numbers of the pixels will be grouped with pixels arranged and organized otherwise known as land cover classes built-up, vegetation, bare land, agricultural area, water bodies as suggested by U.S.G.S classification system (Anderson's Classification, 1971).

3.3.4.2 Processing of thematic maps

a. **Annual rainfall map**

An annual rainfall map of the study area was prepared by the Inverse Distance Weighting (IDW) interpolation method using the annual rainfall measured at the NIMET meteorology stations bordering Kachia Local Government Area.

b. **Drainage map**

Drainage is one of the most important indicators of underground water, because drainage pattern, texture and density are controlled in a fundamental way by the underlying lithology. The drainage pattern is a reflection of the rate that precipitation infiltrates compare with the surface runoff. The drainage map will be digitized from the SRTM data and

topographic map. The Drainage density map will be produced using the ArcGIS Spatial Analyst Tool.

c. **Topographic/Slope map**

Topographic data is a vital element in determining the water table elevations. The Digital Elevation Model (DEM) from the SRTM data was used to produce the contours and slope map for the study area. Steps followed to prepare the slope amount of the project area are described:

i. DEM from SRTM.

ii. Importing into ArcGIS environment

iii. Derivation of Slope Amount was done using Spatial Analysis and reclassification into appropriate classes.

d. **Land use/Land cover map**

The landuse/landcover for the study area was characterized by a mixture of built-up, vegetation, bare land, agricultural area, water bodies. The land-use/land-cover will be interpreted from the landsat satellite imagery by using visual interpretation. Unsupervised classification and supervised classification was carried out using the appropriate bands combinations. Unsupervised classification was used to have a general idea of the study area and supervised classification were used for production of the final land-use map.

e. **Lineaments map**

Lineaments give a clue to movement and storage of groundwater (Subba *et al*. 2001) and therefore are important guides for groundwater exploration. Recently, many groundwater exploration projects made in many different countries have obtained higher success rateswhen sites for drilling were guided by lineament mapping(Teeuw, 1995). The lineament map will be derived from landsat imagery by image enhancement and digitizing.

f. **Geology map**

The geological map for the study area was digitized from an existing geology map of Kaduna state and then converted into raster in ArcGIS environment.

3.3.5 Techniques for Data Analysis

3.3.5.1 Examination of the characteristics of the ground water potential zones.

Prior to integration of the data sets, individual class weights and map scores were assessed based on Satty's and Vargas (1991) Analytic Hierarchy Process (AHP); in this method the relative importance of each individual class within the same map were compared by each other by pair-wise and eight importance matrices were prepared for assigning weight to each class.The AHP was used to characterize the zones into very good, good, moderate, low and very low. These zones were characterized based on the aquifer properties, soil type, geology and topography. Table 3.2 shows the processes involved in weight assignment using AHP and Table 3.3 shows the criteria used for the reclassification of Slope, Geology and Lineament according to Solomon (2003).

Table 3.2: Procedure of Assigning Weightages in Analytical Hierarchy Process

Scale	Degree of preference	Explanation
1	Equal importance	Two elements contributes equally to the objective
3	Moderate importance	Experience and judge slightly favor one element over another
5	Strong or essential importance	Experience and judgment strongly favor one element another
7	Very strong importance	One element is favored very strongly over. It dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8	Values for inverse comparison	Can be used to express intermediate values

Source: Saaty and Vargas (1991).

Table 3.3: Values assigned for different groundwater control parameters

Parameter		Value	Parameter		Value
Geology			***Slope***		
				(VeryGood)	
Alluvium	(Very Good)	80	0 -3^o		80
Basalt	(Very Good)	80	4 -7^o	(Good)	70
Foliated met.	(Good)	70	8 -11^o	(Moderate)	60
Metasediments	(Good)	70	12 -15^o	(Low)	40
Granite (syntectonic)	(Moderate)	60	> 15^o	(Poor)	10
Granite (posttectonic)	(Moderate)	60			
Nonfoliated met.	(Moderate)	50			
Gneiss (Low)		40			
Laterite	(Low)	40			
Kaolinized Granite	(Poor)	10			
Lineament Density					
0 -50 m	(Very Good)	80			
50 –100 m	(Good)	70			
100 -150 m	(Moderate)	60			
150 -200 m	(Low)	40			
200 -250 m	(Poor)	10			

Source: Solomon (2003)

Table 3.4 shows the criteria used for the reclassification of the soil map and LULC and according to the criteria used by Pandian *et al.* (2013) while the elevation, rainfall, drainage density were classify based on Tewodros (2005) criteria.

Table 3.4: Values assigned for different groundwater control parameters

Soil	Weight ages	Rank
sandy Loam, Sandy Clay Loam, Gravelly Sandy Clay	1	High
Sandy Clay, Loam, Gravelly Clay Loam, Kankar Bed	2	
sandy clay loam	2	Medium
clay loam	3	Low
Clay	3	

Source: Pandian *et al*. (2003)

Table 3.5: Values assigned for different groundwater control parameters

Land Cover	Weightages	Rank
Crop land	1	
Waterbodies	1	
Plantation	1	High
Wet logged	1	
Landwith scrub	1	
Builtup land	2	Medium
Barren Rocky	3	
Fallow land	3	Low

Source: Pandian *et al*. (2003)

Table 3.6: Values assigned for different groundwater control parameters

Drainage Density	Weightages	Rank
0-0.9	1	Low
1.9-2.9	2	Moderate
2.9-3.9	3	High
>3.9	4	Very High
Rainfall		
852-915	2	Low
915-979	3	Moderate
979-1042	4	High
1042-1105	5	Very High
Elevation		
1760-2134	5	Very High
2134-2509	4	High
2509-2883	3	Moderate
2883-3257	2	Low
3257-3631	1	Poor

Source: Tewodros (2013)

3.3.5.2 Estimation of the areal coverage of the underground water potential zones.

Each layer (i.e. the very good, good, moderate, fair and low zones) from the ground water potential zones raster map was converted individually to geo-database file format using the conversion toolbox in ArcGIS version 10.1. Theseprocess of conversion to geo-database file format automatically calculates the area of each of the groundwater potential zones.

3.3.5.3 Identification the ground water prospect zones from the thematic maps

Integration of the thematic maps was carried out in ArcGIS 10.1 using the weighted overlay in spatial analysis tool by using a formula after(Mogaji *et al.*, 2011).

Underground water potential zones = GL+RF+LD+DD+SL+LU+TP---------- (1)

Where:

GL= Geological map

RF= Rainfall map

LD= lineament density map

DD= Drainage Density map

SL= Slope map

LU= Landuse Map

TP= Topographic Elevation map.

3.3.5.4 Validationof the groundwater potential zones using Resistivity survey of geophysical investigation.

The geophysical investigations made use of the resistivity method comprising mainly of Vertical Electrical Sounding (VES) at various strategically located and potentially anomalous points in the area under survey. Vertical electrical sounding investigates the way in which the resistivity of the ground varies with depth and it's often related to strength and conductivity of the formation.

CHAPTER FOUR :RESULTS AND DISCUSSION

4.1 Introduction

This chapter is concerned with the presentation of results and related discussions.

4.2 Characteristics of Groundwater Potential Zones

In an attempt to examine the groundwater potential zones in the study area, the groundwater controlling factors were classified and mapped by digitizing of existing data such as the soil and geological maps. The rainfall map was produced by Inverse Distance Weighting Interpolation (IDW) technique. The drainage and slope were generated from the DEM and finally the lineament and LULC map were extracted from the satellite imagery (Landsat 7). The rankings/weightages of factor contributing to groundwater prospects in the study area were evaluated by pair wise comparison using Analytical Hierarchy Process (AHP).The thematic maps of the groundwater controlling factor were produced in ArcGIS 10.1 environment and the results are presented in Figure 4.1 to Figure 4.10 while the weightages of the factors are represented in Tables 4.1 to Table 4.7

4.2.1 Topography or Elevation

The Digital Elevation Model (DEM) was generated from the shuttle radar topographic mission (SRTM-90) data.Figure 4.1 shows the Digital Elevation Model (DEM) used to build the topographic elevation factor values and Table 4.1 represents the reclassified elevation based on Tewodros (2005) criteria and the weight of elevation and potentiality for groundwater prospects in the area of study.

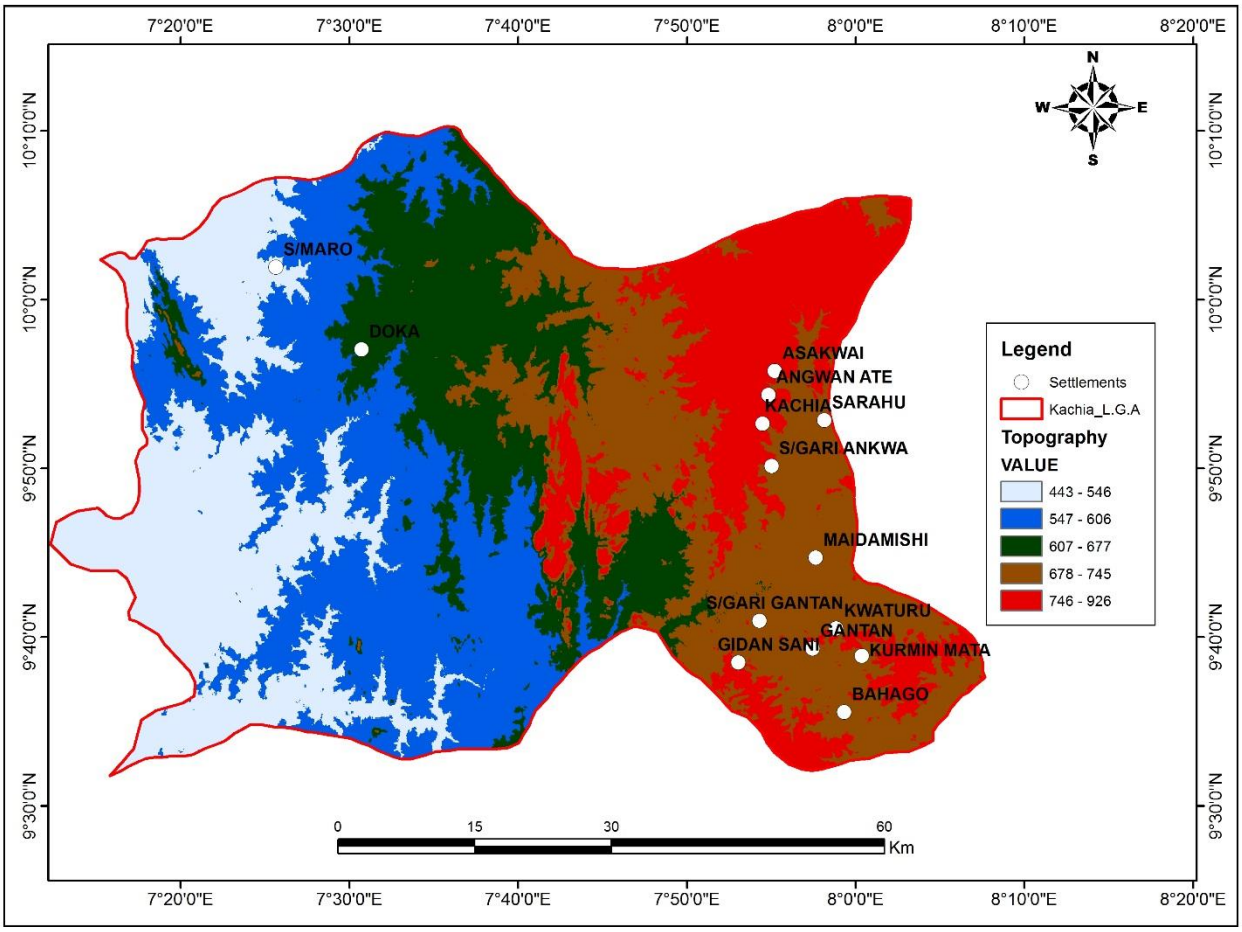

Figure 4.1: Digital Elevation Model (DEM) of Kachia L.G.A.

Source: Author's Analysis, 2015

Table 4.1: Groundwater Potential for Topography in Kachia L.G.A.

Elevation	443-566	547-606	607-677	678-745	746-926	Weightage	Potential
443-566	1	3	4	5	7	0.49	Very Good
547-606	1/3	1	1	3	5	0.20	Good
607-677	1/4	1	1	3	5	0.19	Moderate
678-745	1/5	1/3	1/3	1	3	0.08	Fair
746-926	1/7	1/5	1/5	1/3	1	0.04	Low

Consistency Ratio=0.04

Table 4.1 shows that areas with low elevation values have very good groundwater potential and places on high elevation have low water potential.Places on low elevation then will give more chance for groundwater accumulation (Solomon, 2003). Topographic data is a vital element in determining the water table elevations (Sener, Davrazand Ozcelik, 2005).

The combination of fractures with topographically low ground can also serve as the best aquifer horizon (Subba, 1992).

4.2.2 Average Annual Rainfall

The amount of rainfall is one of the major factors that contribute to groundwater recharge. In Figure 4.2, the mean annual precipitation ranges between 925-963mm in the western areas where the elevation is high and in eastern areas where the elevation is low, rainfall appears to be high ranging between 1,050 – 1,099mm. A pair wise comparison and reclassification was carried outbased on Tewodros (2005) for the mean annual precipitation of the study area using AHP and the result is presented in Table 4.2.

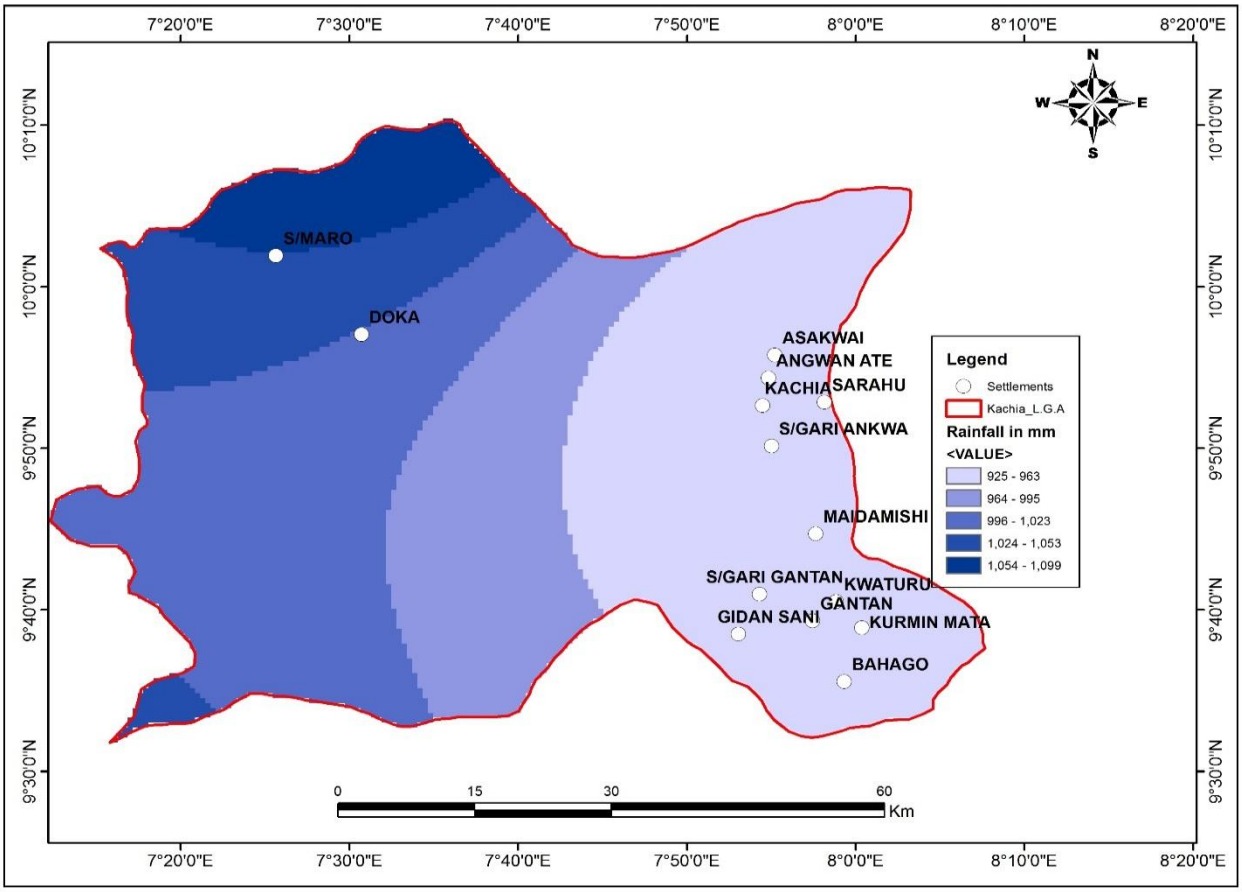

Figure 4.2: Average Annual Rainfall of Kachia L.G.A.

Source: Author's Analysis, 2015

Table 4.2: Groundwater Potential for Rainfall in Kachia L.G.A.

Rainfall	925-963	964-995	996-1023	1024-1053	1054-1099	Weightage	Potential
925-963	**1**	2	2	2	2	0.11	Low
964-995	1/2	**1**	2	2	2	0.14	Fair
996-1023	1/2	1/2	**1**	2	2	0.19	Moderate
1024-1053	1/2	1/2	1/2	**1**	2	0.24	Good
1054-1099	1/2	1/2	1/2	1/2	**1**	0.32	Very Good

Consistency Ratio=0.01

These precipitation values were weighed to reflect the influence of perception on groundwater. As we have more precipitation, more water will be available for surface runoff and infiltrations will naturally recharge thegroundwater. Table 4.2 shows that the higher the precipitation the higher the potential of the groundwater.

4.2.3 Slope

Slope which is one of the factors that influence groundwater in the study was generated from the DEM and is shown in Figure 4.3 and the weight of the slope map was reclassified according to Solomon (2003) criteria and is presented in Table 4.3.

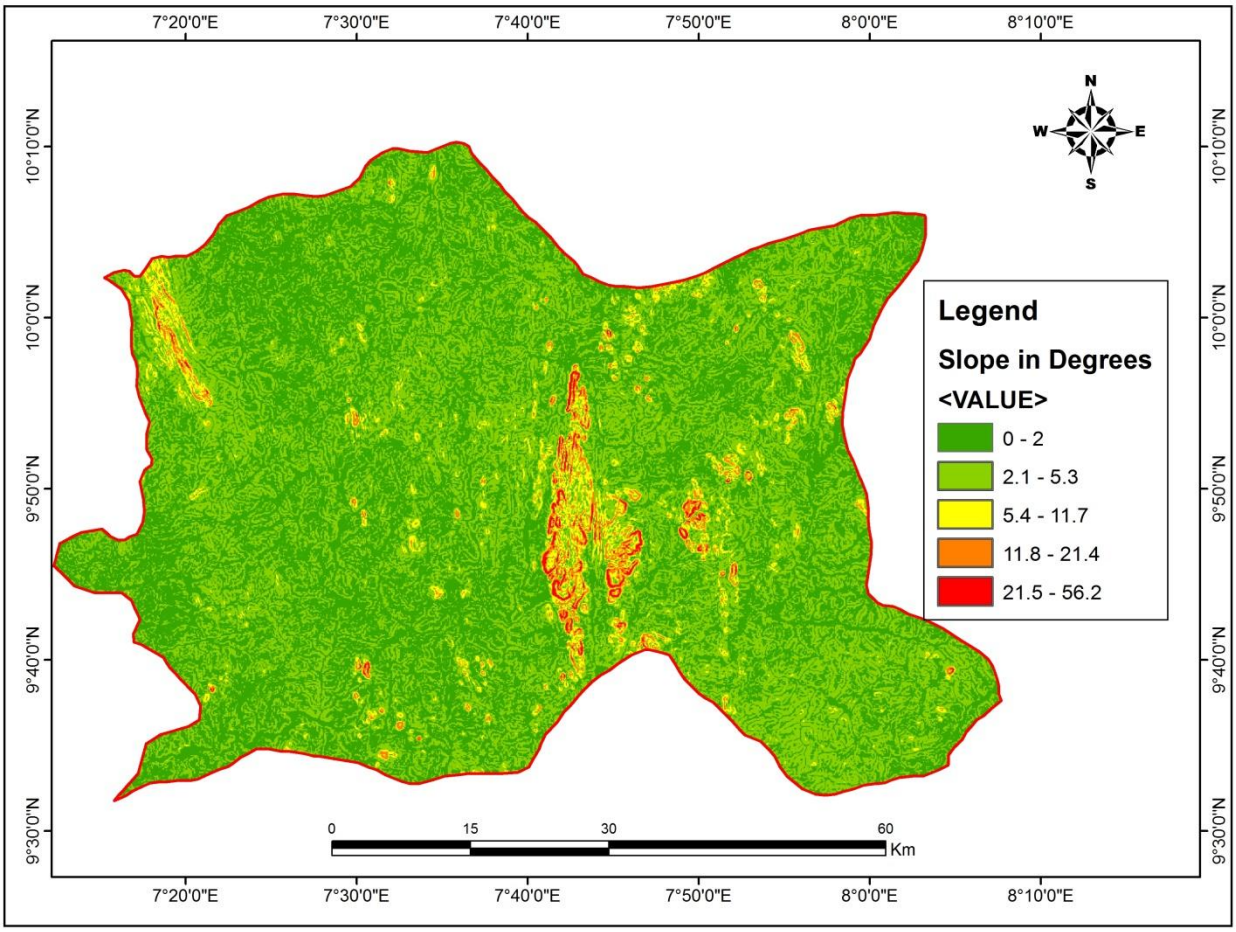

Figure 4.3: Slope Steepness of Kachia L.G.A.

Source: Author's Analysis, 2015

Table 4.3: Groundwater Potential for Slope Kachia L.G.A

Slope (%)	0-2	2.1-5.3	5.4-11.7	11.8-21.4	21.5-56.2	Weightage	Potential
0-2	1	2	5	7	9	0.47	Very Good
2.1-5.3	1/2	1	3	5	9	0.3	Good
5.4-11.7	1/5	1/3	1	3	7	0.14	Moderate
11.8-21.4	1/7	1/5	1/3	1	5	0.07	Fair
21.5-56.2	1/9	1/9	1/7	1/5	1	0.03	Low

Consistency Ratio=0.06

In Table 4.3 it is clear that areas that have the value of slope ranging from 0-2% have very good groundwater potential and those areas with high slope ranging from 21.5-56.2% have low water potential. Generally, flat and gently sloping areas promote infiltration and groundwater recharge, and steeply sloping grounds encourage run-off and little or no

infiltration. The areas that has a gentle slope supports low discharge of overland flow and high rate of infiltration. Therefore, groundwater potentiality is expected to be greater in the flat and gently sloping area (Solomon, 2003).

4.2.4 Drainage Network and Drainage Density

The drainage network of the area was derived fromSRTM data through on screen digitization as shown in Figure 4.4.The drainage density was calculated directly in Arcmap using spatial analyst extension. Five (5) drainage density categories were identified and mapped as shown inFigure.4.5 and the corresponding weightage value shown in Table 4.4 based on Tewodros (2005).

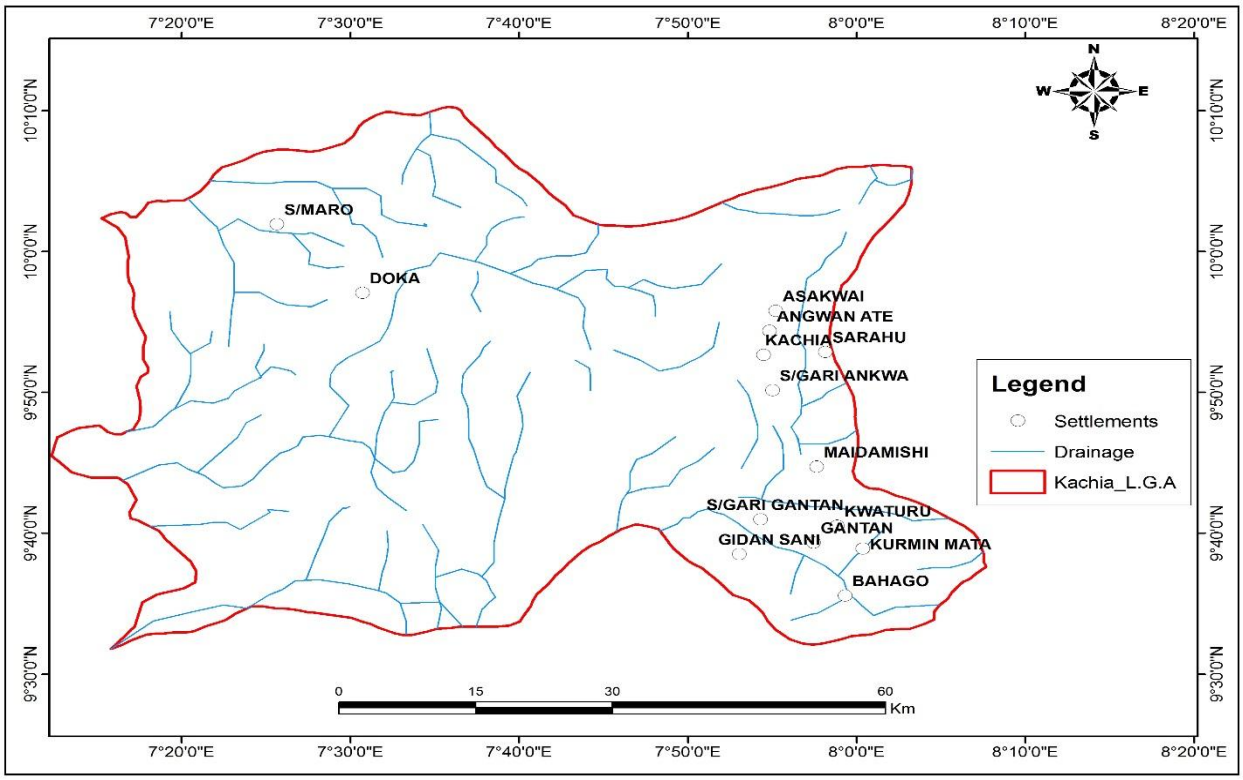

Figure 4.4: Drainage Network of Kachia L.G.A.

Source: Author's Analysis, 2015

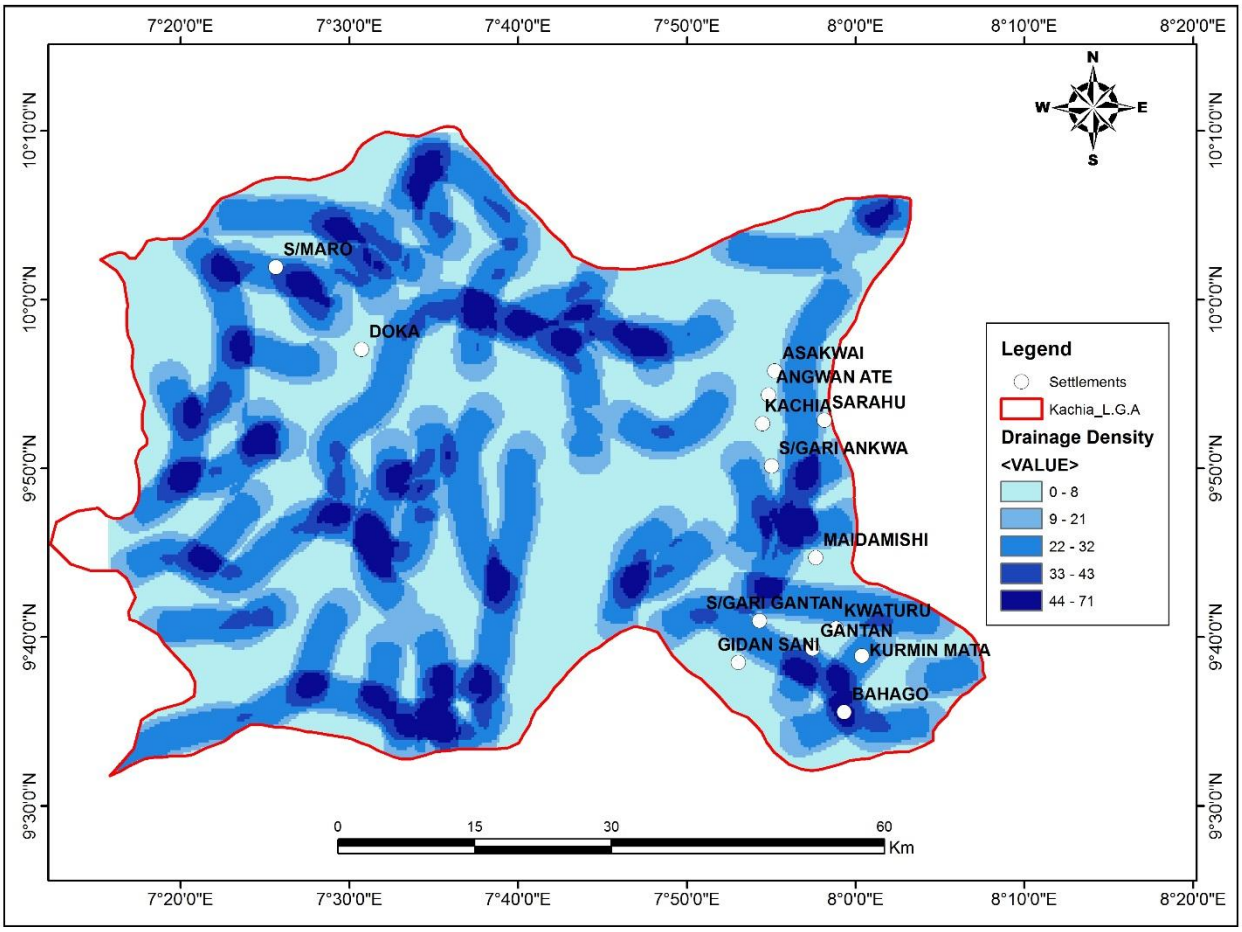

Figure 4.5: Drainage Density of Kachia L.G.A.

Source: Author's Analysis, 2015

Table 4.4: Groundwater Potential for Drainage Density (DD)

DD	0-8	21	22-32	33-43	44-71	Weightage	Potential
0-8	1/6	1/6	¼	1/2	1	0.05	Low
9-21	1/6	¼	½	1	2	0.07	Fair
22-32	1/5	1/3	1	2	4	0.12	Moderate
33-43	1/3	1	3	4	6	0.26	Good
44-71	1	3	5	6	6	0.49	Very Good

Consistency Ratio=0.06

The result in Table 4.4 reveals that areas with low drainage density has low groundwater potential and areas with low Drainage Density have very good water potential. According to Charon (1974), the drainage pattern is one of the most important indicators of hydrogeological features, because drainage pattern and density are controlled in a fundamental way by the underlying lithology. In addition, the stream pattern is a reflection of

the rate that precipitation infiltrates compared with the surface runoff. The infiltration/runoff relationship is controlled largely by permeability, which is in turn a function of the rock type and fracturing of the underlying rock or surface bedrock (Edet, Okereke, Teme, and Esu, 1998). When comparing two terrain types, the one that contains the greatest drainage density is usually less permeable (Edet *et al*., 1998). According to the authors, it is well known that the denser the drainage network, the less is the recharge rate and vice versa.

4.2.5 Lineament and Lineament Density

Lineaments map was extracted from satellite image using automated extraction techniques. The lineament were imported into the ArcGIS environment and the spatial analyst tool was used in generating the lineament density map for the study area. Figure 4.6 represents the lineament map and figure 4.7 represents the lineament density map. The result of the pair wise comparison from Solomon, (2003) criteria for groundwater potentiality is also in Table 4.5

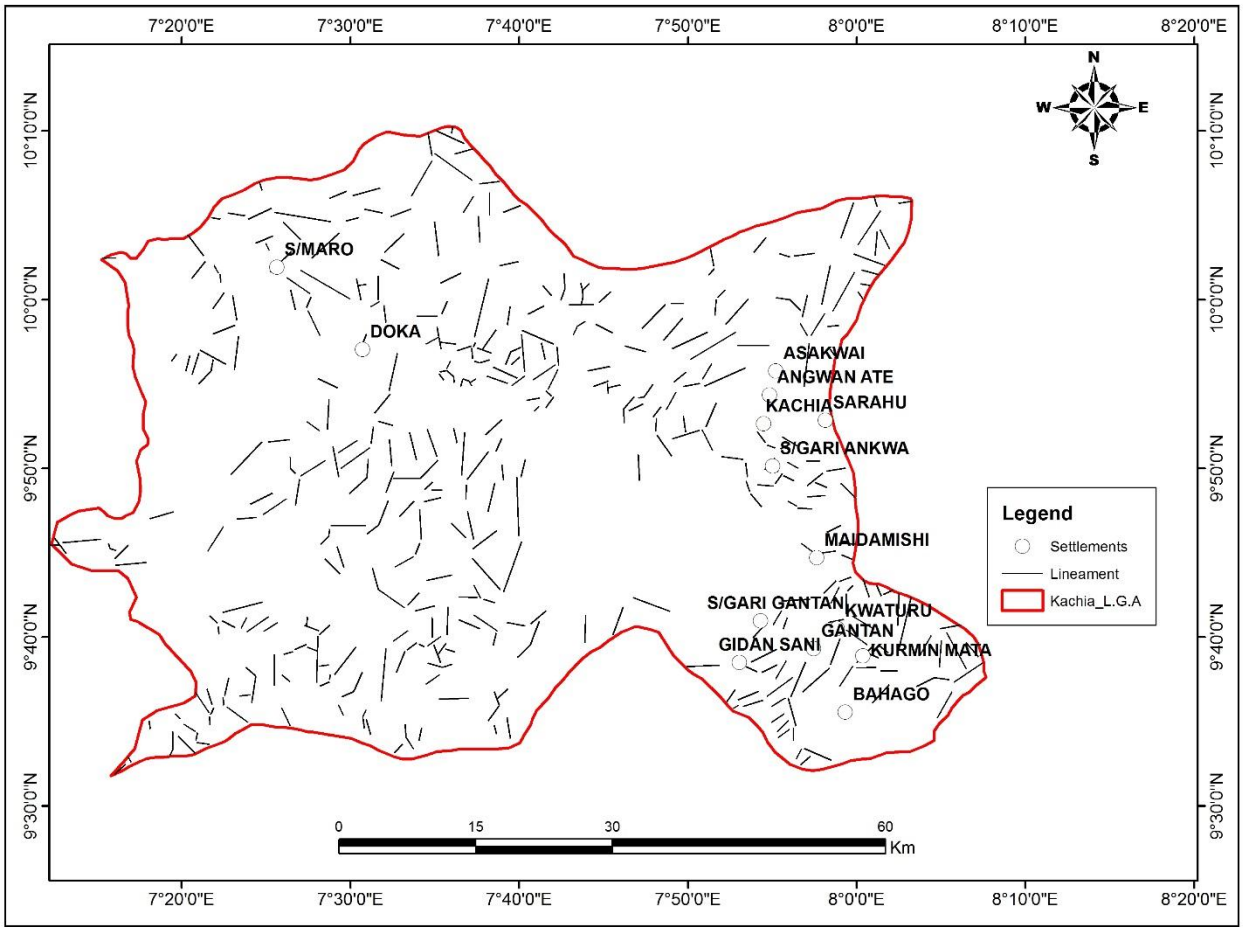

Figure 4.6: Lineament Map of Kachia L.G.A.

Source: Author's Analysis, 2015

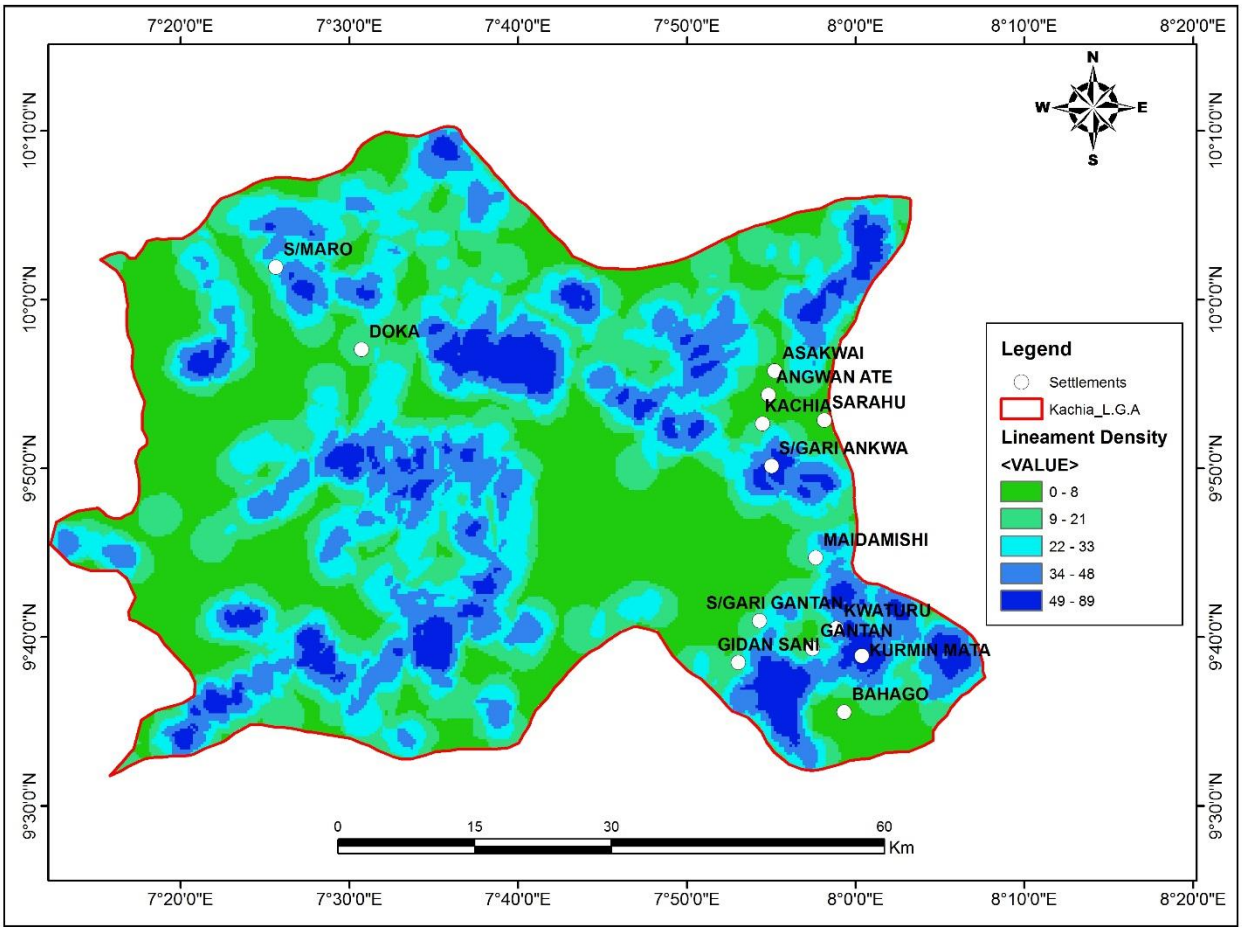

Figure 4.7: Lineament Density of Kachia L.G.A.

Source: Author's Analysis, 2015

Table 4.4: Groundwater Potential for Lineament Density (LD)

LD	0-8	9-21	22-33	34-48	49-89	Weightage	Potential
0-8	1/9	1/7	1/5	1/3	1	0.03	Low
9-21	1/7	1/5	1/3	1	3	0.06	Fair
22-33	1/5	1/3	1	3	5	0.13	Moderate
34-48	1/3	1	3	5	7	0.26	Good
49-89	1	3	5	7	9	0.51	Very Good

Consistency Ratio=0.08

Lineaments are underlain by zones of localized weathering and increased permeability and porosity. Previous studies have revealed a close relationship between lineaments and groundwater flowand yield (Magowe and Carr, 1999). The extension of large lineaments

representing a shear zone or a major fault and can extend from hilly terrain to alluvial terrain (Mondal, Pandey and Garg, 2007). It may form a productive groundwater reserve. Similarly intersection of lineaments can also be probable sites of groundwater accumulation. Therefore, areas with high lineament density may have important groundwater prospects even in hilly regions which otherwise have no groundwater prospects than area with low density.

4.2.6 Landuse/Landcover

One of the parameters that influence the occurrence of groundwater is the land cover and land use of the area. The landuse and land cover map was generated from the Landsat imagery by supervised classification and shown in Figure 4.8 and the weightages were assigned based of Pandian *et al.* (2013) and is shown in Table 4.5.

The result shows that the cultivated land occupies the highest 41.2% areal coverage in the study area with about (41.2%). This is followed by vegetation (23.5%), bare land cover (20.0%), built-up areas (13.7%) and waterbody occupies the least with a coverage of (1.6%).

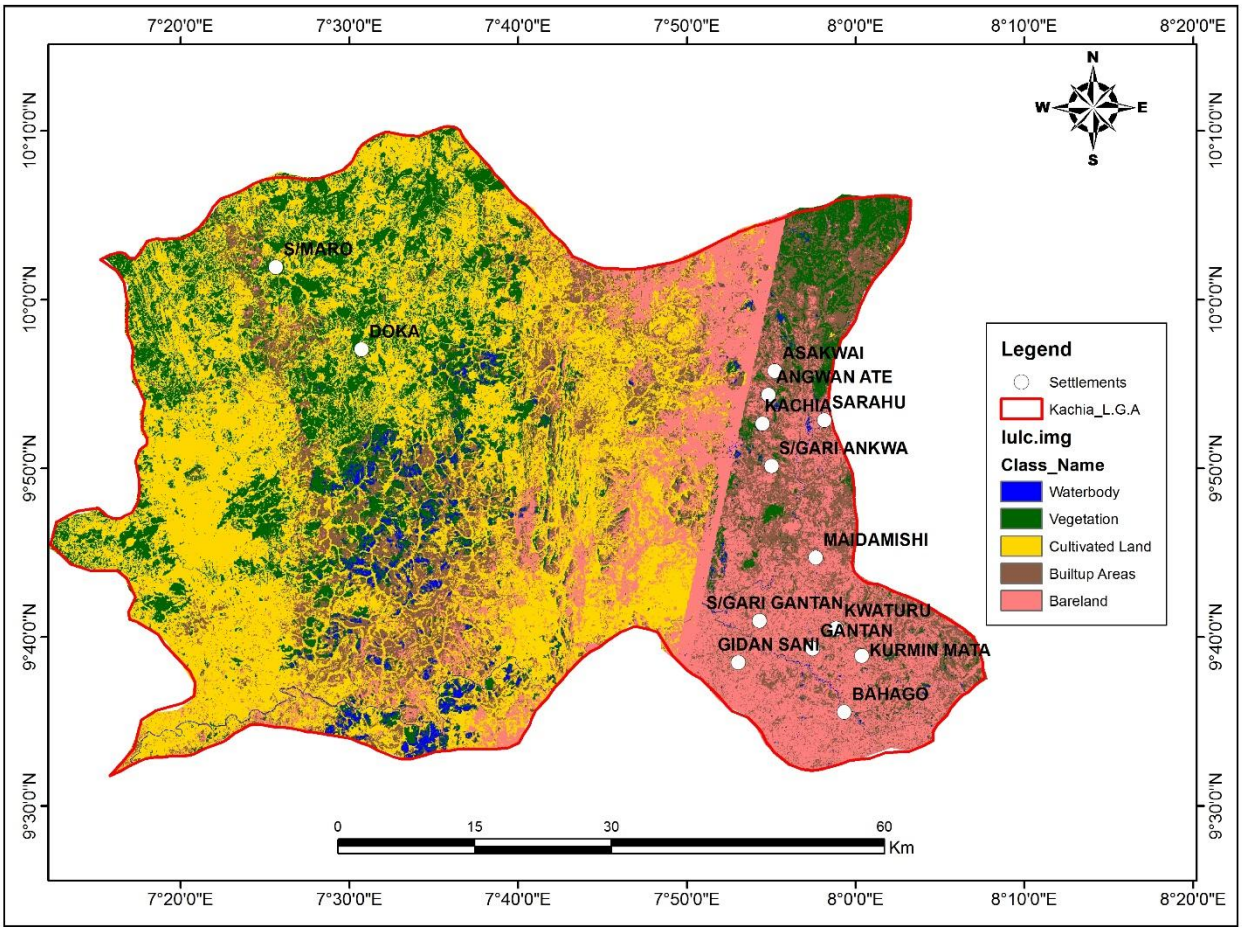

Figure 4.8: Landuse/Landcover of Kachia L.G.A.

Source: Author's Analysis, 2015

Table 4.5: Percentage Areal Coverage of LULC Kachia L.G.A.

LULC	Area in Sq. Km	%
Vegetation	1078.6	23.5
Cultivated Land	1895.7	41.2
Bare Land	921.8	20.0
Build-up Areas	631.2	13.7
Waterbody	71.9	1.6
Total	**4599.2**	**100**

Source: Author's Analysis, 2015

Table 4.6: Groundwater Potential for Landuse/Landuse

LULC	Waterbody	Vegetation	Bare Land	Cultivated Land	Build-up Areas	Weightage	Potential
Waterbody	1	5	7	6	9	0.56	Very Good
Vegetation	1/5	1	3	4	9	0.23	Good
Bare Land	1/7	1/3	1	2	7	0.11	Moderate
Cultivated Land	1/6	¼	1/2	1	4	0.07	Fair
Build-up Areas	1/9	1/9	1/7	1/4	1	0.03	Low

Consistency Ratio=0.12

The effect of land use / cover is manifested either by reducing runoff and facilitating, it or by trapping water on vegetation leaf. Water droplets trapped in this way go down to recharge groundwater. Land use/ land cover may also affect groundwater negatively through evapotranspiration, assuming interception to be constant. From Table 4.6, the result shows that area around the water body have very good ground water potential, followed by vegetated areas with good water potential. The bare land was weighed moderate while cultivated land and built-up land were noticed to fair and low ground water potential respectively.

4.2.7 Soil

Soil is influences groundwater recharge depending on the texture, grain size, and porosity. Soil can go a long way in influencing the infiltration of water. The soil map of the area was digitized from an existing soil map which is classified based on the Food and Agricultural Organization (FAO) standard. The soil of the study area includes the gleysols, luvisols and acrisols, and is shown in Figure 4.9 while Table 4.7 represents the weight and reclassification according to Pandian, and Kumanan, (2013) of groundwater potentiality in the study area.

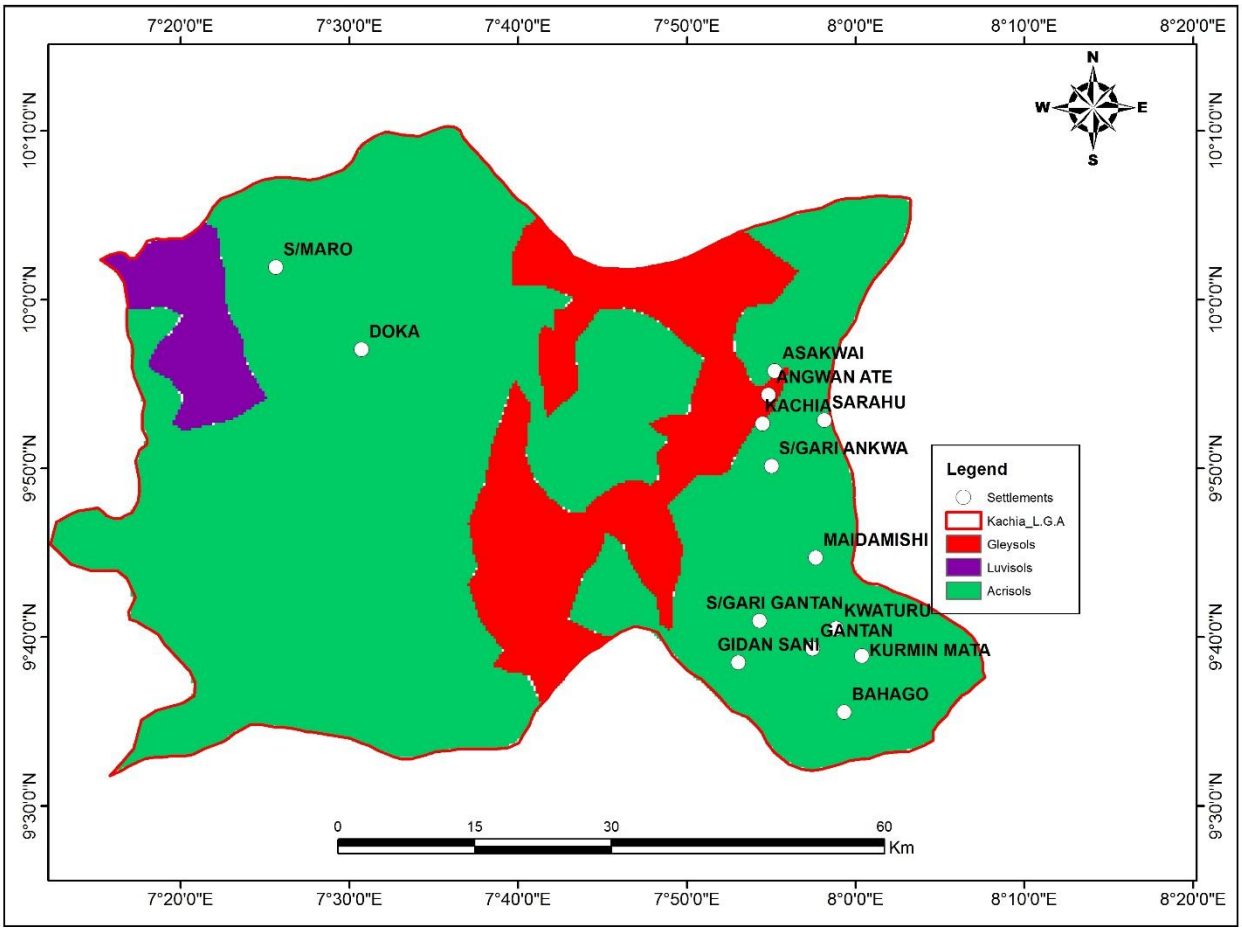

Figure 4.9: Soil Types of Kachia L.G.A.

Source: Author's Analysis, 2015

Table 4.7: Groundwater Potential for Soil

Soil	Gleysols	Luvisols	Acrisols	Weight	Potential
Gleysols	1	3	5	0.64	Good
Luvisols	1/3	1	3	0.26	Moderate
Acrisols	1/5	1/3	1	0.1	Low

Consistency Ratio=0.04

The soil forming factors, climate, parent rock, vegetation, fauna and physiography are responsible for the type of soil formed and plays an important role on groundwater recharge through infiltration and loss through run-off. The type of soil and permeability affects the water holding and infiltrating capacity of a given soil. The resultof the pair-wise comparisons

shows that gleysols have good infiltration rate and the luvisoil have moderate potentiality to groundwater. The acrisols has low groundwater potential.

4.2.8 Geology

It is well established that geology plays a vital role in the distribution and occurrence ofground water. The geological mapping was carried out by digitizing an existing geological map of the study area. Figure 4.10 shows the geology of the area and the classification and weight according Solomon (2003) is presented in Table 4.8

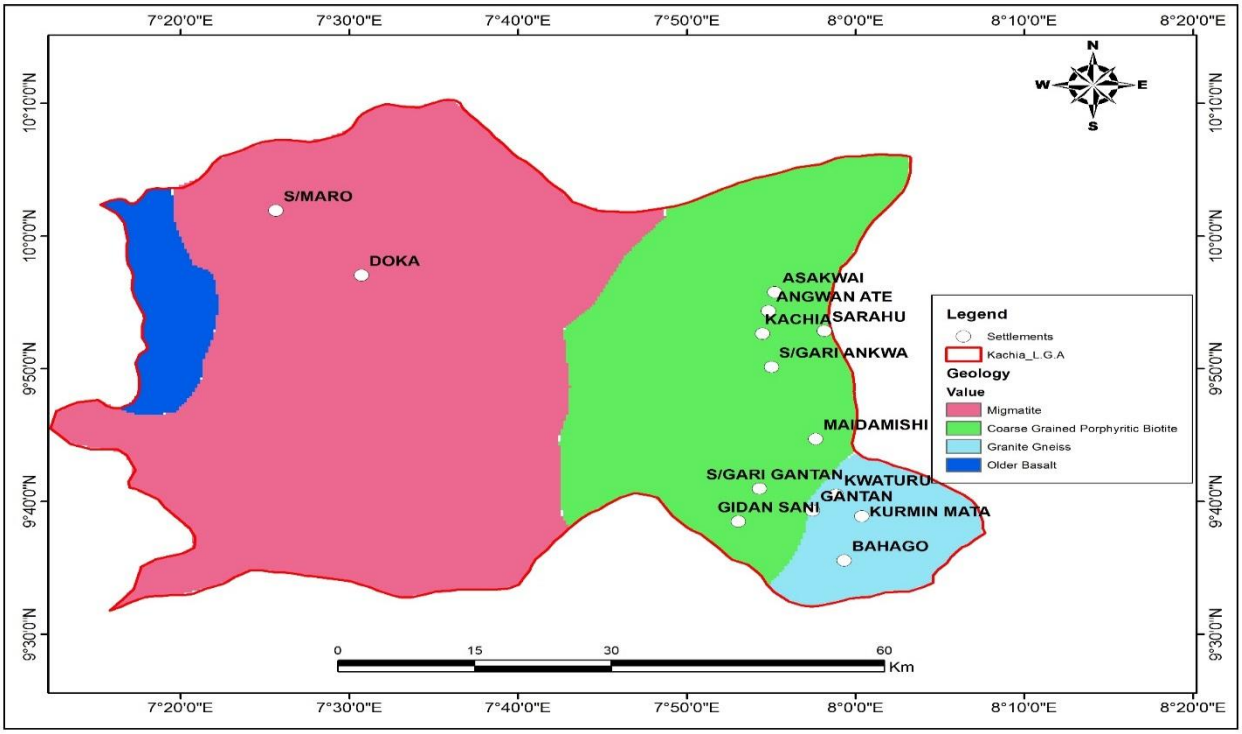

Figure 4.10: Geology of Kachia L.G.A.

Source: Author's Analysis, 2015

Table 4.8: Groundwater Potential for Geology

Geology	Coarse Grained Porphiritic Biotite	Granite Gneiss	Migmatite	Older Basalt	Weight	Potential
Coarse Grained Porphiritic Biotite	1	3	3	4	0.51	Good
Granite Gneiss	1/3	1	2	3	0.25	Moderate
Migmatite	1/3	1/2	1	2	0.16	Fair
Older Basalt	¼	1/3	1/2	1	0.09	Low

Consistency Ratio=0.04

It can be seen from Table 4.8 that the coarse grained porphyritic biotite have good groundwater potential, the gneiss have moderate water potential. The migmatite and the older basalt have fair and low groundwater potential respectively.

4.3 Identification of the Ground Water Prospect Zones from the Thematic Maps

In an attempt to calculate the groundwater prospects zones in Kachia L.G.A., all the thematic maps of the factors influencing the groundwater recharge in the area were weighed and integrated in the order suggested by Saraf and Choudary(1998). Table 4.9 represents the weight of the groundwater controlling factors and Figure 4.11 represents the groundwater prospect zones within the study area.

Table 4.9: Weights of the entire Groundwater Factor Map in the Study Area

	Rainfall	Lineament	Geology	Slope	Elevation	Soil	Drainage	LULC	Weight	Weight *100
Rainfall	1	3	3	4	5	6	7	9	0.34	34
Lineament	1/3	1	2	3	5	6	7	9	0.24	24
Geology	1/3	1/2	1	2	2	3	4	7	0.14	14
Slope	1/4	1/3	½	1	2	3	4	5	0.1	10
Elevation	1/5	1/5	½	1/2	1	3	4	5	0.08	8
Soil	1/6	1/6	1/3	1/3	1/3	1	3	5	0.05	5
Drainage	1/7	1/7	¼	1/4	1/4	1/3	1	3	0.03	3
LULC	1/9	1/9	1/7	1/5	1/5	1/5	1/3	1	0.02	2

Consistency Ratio=0.05
Source: Author's Analysis, 2015

From Table 4.9 it can be seen that rainfall was weighed the highest with (34%) followed by lineament (24%), geology is weighed (14%). The least groundwater contributor in the study area is the landuse/landcover.

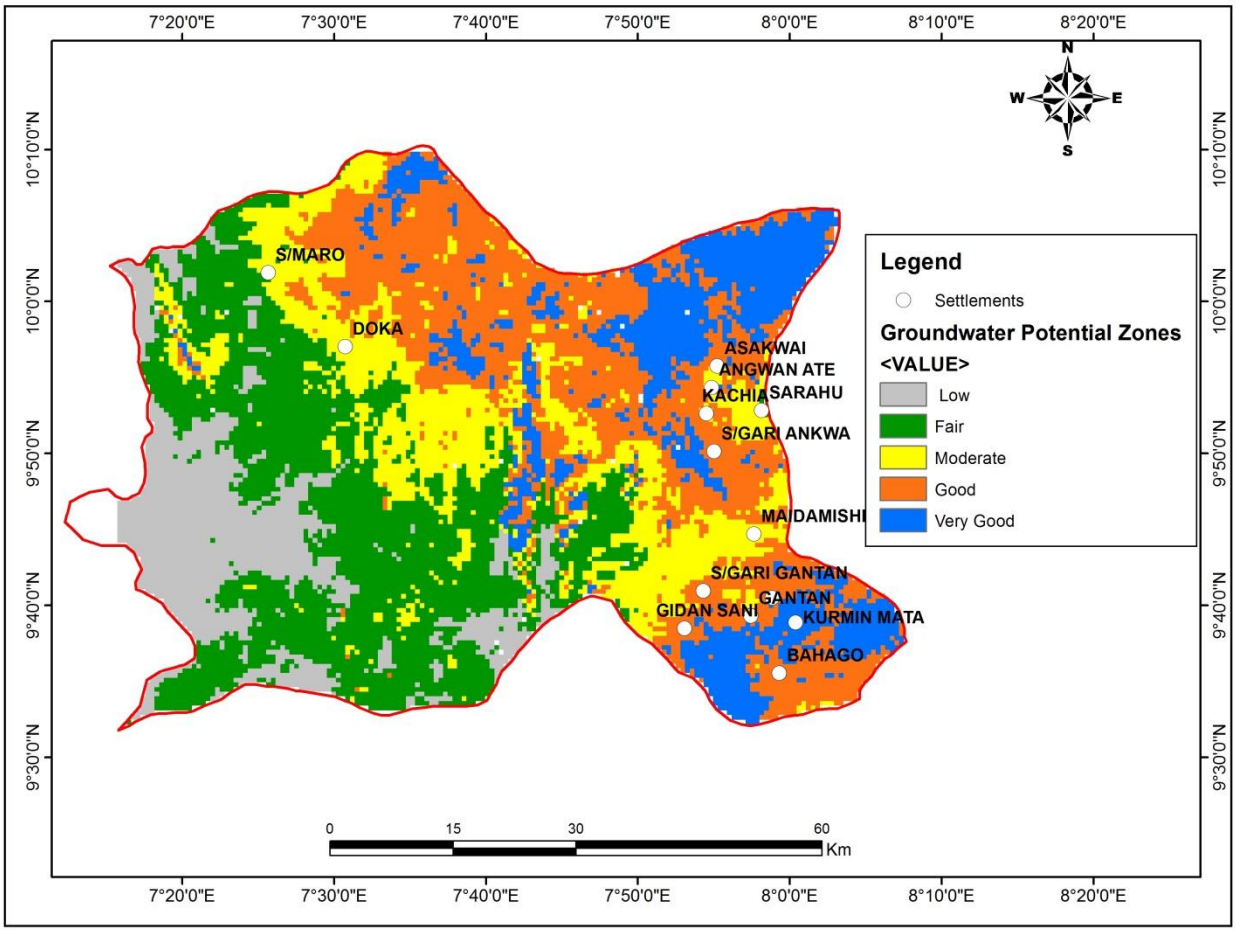

Figure 4.11: Groundwater Potential Zones of Kachia L.G.A.

Source: Author's Analysis, 2015

The delineation of groundwater potential zones by reclassifying into different potential zones; Very Good, Good, Moderate, Fair and Low (Figure 4.11) was made by utilizing the raster calculator in ArcGIS spatial analyst tool. The map produced has shown that the groundwater potential of the study area is related mainly to rainfall, lineaments, geology slope, elevation, soil, drainage and landuse/landcover. It can also be seen from the map that the areas with very good groundwater potential are within the eastern part of the map while the areas by low potential are towards the western area. It can be observed from the thematic maps generated that the areas with very good groundwater potential in the eastern area were characterized by high lineament density and are of flats areas or gentle slope. This is not contrary to the study of Khalekand Ahmed (2008)that identified lineament and slope as the major factors that contribute to groundwater research in their study area.

4.4 Estimation of the Areal Coverage of the Underground Water Potential Zones

The areal coverage occupied by the groundwater potential zones was estimated in ArcGIS by converting the potential to shapefiles and using the calculate geometry tool in the attributes table to calculate the each of the potential zones. Table 4.9 represents the estimated area coverage of the groundwater potential zones in square kilometer and in percentage.

Table 4.9: Areal Coverage of Groundwater Potential Zones

Groundwater Potential Zones	Area in Sq. Km	Percentage %
Very Good	648.6	14.1
Good	1029.9	22.4
Moderate	691.8	15.0
Fair	1097.0	23.9
Low	1131.8	24.6
Total	**4599.2**	**100.0**

Source: Author's Analysis, 2015.

Table 4.9 shows that the very good groundwater potential occupies 648.8 sq. km (14.1%), the good potential zones constitute about 1029.9 sq. km (22.4%) of the study area; the moderate potential areas constitute 691.8 sq. km (15.0%). The fair and low occupies the highest coverage constituting about 1097.0 sq. km (23.9%) and 1131.8 sq. km (24.6%) respectively. It can be seen from the result that Kurmin Mata falls in the area with a very good groundwater potential and this shows that exploration with cost less in this area. The result also reveals that Gantan, Sabon-Gari Gantan, Kwaturu and Asakwai have good water potentiality, while sarahu have a fair ground water potential.

4.5 Validating the Groundwater Potential Zones Using Resistivity Survey of Geophysical Investigation

The validity of the result of Remote Sensing and GIS technique was tested against the resistivity survey investigation. Fourteen (14) geophysical surveyed points were overlaid on

the groundwater potential map generated from the integration of thee various thematic maps.Figure 4.12 shows the overlay of the VES points on the groundwater potential zones and Table 4.10 shows the comparison of groundwater potential from the geophysical technique and the remote sensing and GIS technique.

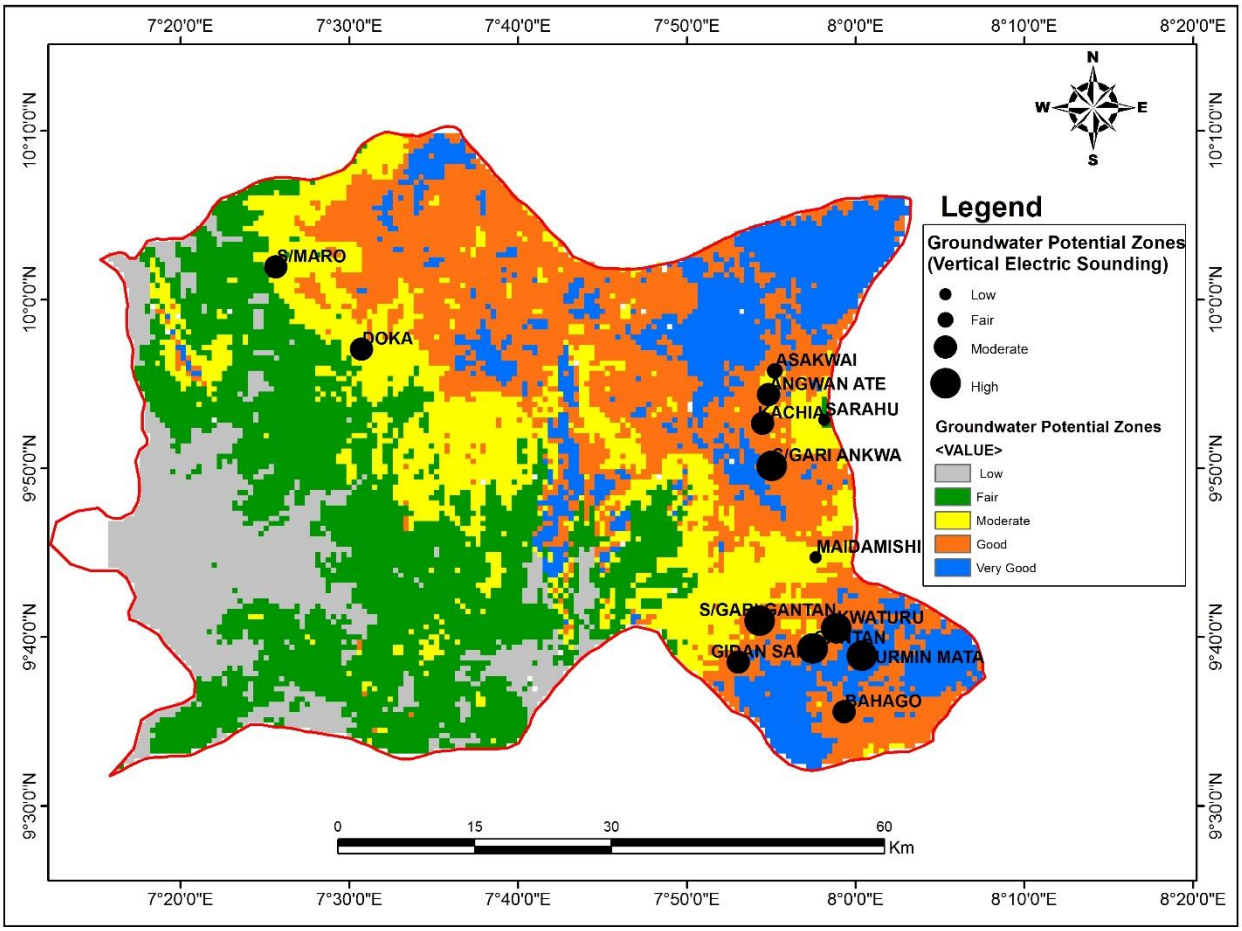

Figure 4.12: Overlay of VES on Groundwater Potential Zones of Kachia L.G.A.

Source: Author's Analysis, 2015

Table 4.10: Groundwater Potentiality from Geophysical Survey and Remote Sensing and GIS

SN	Location	Latitude	Longitude	Aquifer Resistivity	Aquifer Thickness	Depth	Potential (Resistivity)	Potential (RS and GIS)
1	Kurmin Mata	9.64333	7.98729	186.65	23.626	30.346	High	Good
2	Maidamishi	9.68448	7.97518	298.71	17.701	19.936	Low	Moderate
3	Bahago	9.63315	7.98274	59.46	17.766	28.787	Moderate	Good
4	Angwan Ate	9.90367	7.95699	204.14	Infinity	Infinity	Moderate	Moderate
5	Gidan Sani	9.647764	7.94155	15.46	17.722	17.452	Moderate	Good
6	Kachia	9.871417	7.95725	54.44	12.459	23.101	Moderate	Moderate
7	Sarahu	9.857017	7.999	616.96	1.809	11.715	Low	Fair
8	Gantan	9.645933	7.951567	77.23	8.769	19.839	High	Good
9	Kwaturu	9.66685	7.95	292.91	38.846	19.108	High	Good
10	S/Gari Gantan	9.657933	7.932533	517.53	Infinity	Infinity	High	Good
11	S/Gari Ankwa	9.84045	7.9635	90.45	28.48	43.968	High	Good
12	Asakwai	9.937883	7.95	148.41	5.913	8.468	Fair	Moderate
13	Doka	9.935433	7.425383	708.59	19.996	21.993	Moderate	Moderate
14	S/Maro	10.02002	7.3931	183.32	17.654	22.16	Moderate	Moderate

Source: Field Survey, (2015).

The result of the overlay of the geophysical survey on the groundwater potential zones obtained from the GIS technique shows that Kurmin Mata which has very good groundwater potential, Maidamishi which has moderate potential, Kachia which is moderate by the geophysical method appears to be moderate by the GIS technique. The result of the groundwater potentiality of geophysical surveys of Gantan, Kwaturu,S/Gari Gantanand S/Gari Ankwa corresponds to the groundwater potential zones which indicate moderate potential.This result indicates that areas with good groundwater potentialfrom the GIS technique corresponds to areas with high aquifer thickness and depth recommended for groundwater exploration from the geo-physical survey. This result is not contrary to the study of Hadithi *et al* (2003) that observed the higher the aquifer thickness the better the groundwater potential and the lower the thickness the lower the groundwater potential in the Ratmau-Pathri Roa watershed, Haridwar district, India.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter highlights the summary of findings, conclusion and the recommendation made in order to investigate the groundwater potential in Kachia Local Government Area, Kaduna State.

5.2 Summary of Findings

This study aimed to investigate the groundwater potential zones in Kachia L.G.A. The study was carried out to examine the characteristics of groundwater potential zonesin the study area using Analytical Hierarchy Process (AHP). Eight thematic maps of factors contributing to groundwater recharge was generated and integrated in ArcGIS environment using weighted sum overlay in spatial analyst tool. The coverage of the groundwater potential was estimated using the geometry calculator. Finally, the potential groundwater zones were validated using geophysical surveyed points of some settlement in Kachia L.G.A.

The results show that:

a) Topography, rainfall, drainage density, lineament density, geology, soil, slope steepness and landuse/landcover contribute significantly to groundwater prospects in the study area.

b) Weightages of the factors influence groundwater prospects show that rainfall and lineament density were weighed the highest with 34% and 24% respectively.

c) The very good groundwater potential zones were identified in the eastern areas while the areas with low potential lie in the western areas.

d) The result of the study shows that very good groundwater potential zones occupies a coverage of about 14.1%, good potential constitute 22.4%, moderate occupies 15.0% while fair and low constitute of 23.9% and 24.6% of the study area respectively.

e) Kurmin Mata was identified to the high ground water potential within the study area.

f) The result of the study shows that the higher the aquifer thickness and depth the better the groundwater potential for both resistivity method and GIS & remote sensing

5.3 Conclusion

The ground water potential zones have been derived for the entire Kachia Local Government Area of Kaduna State Nigeria, and it has been divided into mainly five categories namely very good, good, moderate, fair and low potential. It is observed from the study that the very good ground water potential zones are located in the eastern part of the study area. However, the study shows that there is a relationship between the vertical electrical sounding (VES) and remote sensing result as the overlay shows that areas with high value of VES aligns with very good areas on the water potential zone map.

This study has shown that there is large spatial variability of ground water potentiality within the study area. The variability closely followed variability in the rainfall,geology, topography, slope, drainage density, lineament density and land use/cover of the study area. The most promising potential zone in the area is related to low slope and high lineament density. Mostof the zones with fair to low groundwater potential lie far from lineaments.This study generally shows that ground water potentiality increases with an increase in the thickness of aquifer and depth for both GIS and Remote sensing techniques and alsowith electric resistivity method.

5.4 Recommendations

The use of remote Sensing techniques is a very cost effective approach in prospecting and in preliminary survey because the cost of drilling in random way is very expensive. However, the study recommends the following:

a) Groundwater potential zones mapping should be carried out for the entire country to serve as a guide for water resource agencies.

b) Study of this nature can be useful for the optimum utilization of water resources in the study area

c) Surface water development is thus recommended in the difficult, low to very low zone yield areas, againstthe prevailing groundwater development.

d) The groundwater potential map and thematic maps produced are sources of vital information and data base which can be updated from time to time by adding new information for development.

REFERENCES

Abubakar Y.I and Auwal L.Y. (2012), Geoelectrical Investigation of Groundwater Potential of Dawakin Tofa Local Government Area of Kano State Nigeria.*American International journalof Contemporary Research*, 2(9), 188-197.

Adanu E.A. (1989). *Hydrogeology of the Base Complex Terrain in the Zaria-Kaduna Area*. Berlin: Technischen Universitat,75

Adeoti, L., and Ishola, K. S. (2008).Geophysical and Hydrogeological Assessment of Proposed refinery site in the lower plains of Niger Delta, Nigeria.*Journal of Science, Technology and Environment*, 8(1/2), 31-38.

Adepelumi, A. A., Yi, M. J., Kim, J. H., Ako, B. D., and Son, J. S. (2006).Integration of surface Geophysical methods for Fracture Detection in Crystalline Bedrocks of Southwestern Nigeria.*Hydrogeology Journal*, 14, 1284-1306.

Adiat, K. A. N., Nawawi, M. N. M., and Abdullah, K. (2012).Assessing the Accuracy Of GIS-Based Elementary Multi-Criteria Decision Analysis as Spatial Prediction Tool: a case of predicting potential zones of sustainable groundwater resources.*Journal of Hydrology*, Vol. 440-441, pp. 75-89.

Akintola, W.D. (2006). Kaduna State Government: Draft Report on IBP Rural Water Supply Study.

Ako, B.D., and V.C. Osondu, (2006), Electrical resistivity of the Kerri-kerri Formation, Darazo, *Nigeria: Journal of African Earth Sciences*, v. 5/5, p. 527-534.

Amadi, A.N. and Olasehinde, P.I. (2010).Application of Remote Sensing Techniques in Hydrogeological Mapping of Parts of Bosso Area, Minna, North-Central Nigeria.*International Journal for.Physical. Science*, 5(9), 1465–1474.

Anudu G.K, Onuba L.N and Ufondu L.S. (2011).Groundwater Exploration in the Crystalline Basement Terrain around Onipe and Adjoining Areas, South-western Nigeria.Volume 1, Number.*Indonesian Society of Sanitary and Environmental Engineers*, Jakarta Open Accessed http://www.trisanita.org/jates

Ariyo, S. O., and Adeyemi, G. O. (2009). Role of electrical resistivity method for groundwater exploration in hard rock areas: a case study from Fidiwo/Ajebo areas of southwestern Nigeria. *Pacific Journal of Science and Technology*, 10(1), 483-486.

Ayers, R.S., and D.W. Westcot.(1985). Water Quality for Agriculture, FAO Irrigation and Drainage Paper 29 rev 1. FAO, UN, Rome 174pp.

Babu, M. J.R. (2011).Assessment of Groundwater Pollution in Parts of Guntur District Using Remote Sensing & GIS. 1024 International *Journal of Earth Sciences and Engineering* ISSN 0974-5904, 04, 1024-1030.

Barker, R. D., (1981), Investigation of groundwater salinity by geophysical methods, in Ward, S. H., Ed., Geotechnical and environmental geophysics, 02: Society Of Exploration Geophysicists, 201-211.

Bobba, A.G, Bukata, R.P. and Jerome, J.H. (1992).Digitally processed satellite data as a tool in detecting potentialgroundwater flow systems.*Journal of Hydrology*, 131(1-4), 25–62.

Brunner, P., Khan, S., Kinzelbach, W. (2004)Comparing different arid basins with secondary salinization: towards a uniØed deØnition of sustainability, *Journal of Experimental Botany*, Vol 54,(58-59)

Burrough, P.A. (1986). *Principles of Geographical Information Systems for Land Resources Assessment.*Oxford:OxfordUniversity Press, 193 pp

Clarke K. and Jones M. (1985) Getting Started with Geographic Information Systems. 3rd edition, Prentice Hall, NJ

Charon, J.E. 1974. Hydrogeological applications of ERTS satellite imagery. In: Proc UN/FAO regional seminar on remote sensing of earth resources andenvironment, Cairo. *Commonwealth Science Council,*439-456.

Cherkauer, D.S. (2004). Quantifying ground water recharge at multiple scales using PRMS and GIS.*Groundwater*, 42(1),97–110

Chowdhary, V.M., Roan, N.H. and Sarma, P.B.S, (2003). GIS Based Decision Support System For Groundwater Assessment In Large Irrigation Project Areas. *Agricultural Water Management* 62:229-252.

Chowdhury, A., Jha, M.K. and Machiwal, D. (2003) Application of Remote Sensing and GIS in groundwater studies: An Overview. Proceedings of the International Conference on Water & Environment (WE-2003). Ground Water Pollution, 15–18 December, 2003, M.P., India pp. 39–50

Dan Hassan M.A. and Olurunfemi, M.O.(1999).Hydrogeophysical investigation of a Basement Terrain in the North Central part of Kaduna State Nigeria.*journal of mining and Geology* 35 (2) pp 189-206

Dawodu, M.O. and Ipaiyeda, A. (2007). Evaluation of groundwater and Stream Quality Characteristics In The Vicinity Of A Batter Factory in Ibadan, Nigeria, *Res. J. Applied Sci*., 2, 1071-1076.

Groundwater Research Department (GWRD) report, (1994)

Driscoll, W. (1986).GroundwaterandWells:A comprehensive study of groundwater and the technologies used to locate, extract, treat,and protect this resource.Second Edition.

DuPreez, J.W. and Barbar, W. (1965).The distribution and chemical quality of ground water in northern Nigeria.*G.S.N. Bulletin*, 36, 12-20

Dubey, O.P.and Sharma, D.C. (2002).Integrated remote sensing and factor analytic GIS model for evaluating groundwaterpollution potential.www.GISdevelopment.net (accessed on July 24, 2003)

Edet, A.E,Okereke, C.S.,Teme, S.C. and Esu, E.O. (1998). Application of remote sensing data to groundwater exploration:a case study of the cross-river state, Southeastern Nigeria. *Hydrogeology Journal*, 6,394–404

Ehirim, C.N and Nwankwo, C.N. (2010).*Archives of Applied Science Research*, 2(2), 396-403.

Elango, L. and Arrikkat, S. (1998). Groundwater recharge studies in Ongur subbasin, south India using geographicalinformation system. *Proceedings of the 3rd International Conference on Hydroinformatics*, 24–26 August1998, Copenhagen, Denmark Vol. 1, pp. 505–510

Emenike, E.A. (2001). Geophysical exploration for ground water in asedimentary environment.*Global J. Pure Appl. Sci.*, 7(1): 97-1 02.

Engman, E.T. and Gurney, R.J. (1991).*Remote Sensing in Hydrology*.London:Chapman and Hall, pp 225.

Farnsworth, R.K., Barret, E.C. and Dhanju, M.S. (1984).*Application of Remote Sensing to Hydrology including Ground Water*. IHP-II Project A. 1.5, UNESCO

Fasunwon, O., Olowofola J., Akinyemi O., Fasunwon B. and Akintokun O. (2008).Contaminants Evaluation as Water Quality Indicator in Ago-Iwoye, South-western, Nigeria, African *Physical Review*, 2, p. 12.

Fayer, M.J., Gee, G.W. Rockhold, M.L. Freshley, M.D. and Walters T.B.(1996). "Estimating Recharge Rates for a Groundwater Model Using a GIS."*J. of Environ. Qual.* 25:510–518.

Federal Ministry of Water Resources (2000)Water Supply & Sanitation Interim Strategy Note November 2000

Foster, S. (1998) Groundwater: Assessing Vulnerability and Promoting Protection ofa Threatened Resource. Proceedings of the 8th Stockholm Water Symposium, 10–13 August, Sweden, pp. 79–90

Goyal, S., Bharadwaj, R.S. and Jugran, D.K. (1999).Multi-criteria analysis using GIS for ground water resource evaluationin Rawasen and Pilli watersheds, U.P., India. www.GISdevelopment.net (accessed on Dec. 7, 2014)

Griner, A.J. (1993).Development of awater-supply protection model in a GIS.Water Resources Bulletin,AWRA29(6), 965–971.

Gustafsson, P. (1993). High Resolution Satellite Data and GIS as a Tool for Assessment of Groundwater Potential of Semi-Arid Area. In: IXth Thematic Conference on Geologic Remote Sensing. 8-11.February, 1993 at Pasadena, California, USA.

Hadithi, M.A., Shukla, D.C. and Israil, M. (2003).Evaluation of groundwater resources potential in Ratmau-PathriRao watershed Haridwar district, Uttaranchal, India using geo-electrical, remote sensing and GIS techniques.Proceedings of the International Conference on Water and Environment (WE-2003), *Bhopal,India, Ground Water Pollution* pp. 123–125

Heath, R.C. (1983). *Basic Ground-Water Hydrology.United States Geological Survey*, paper 2220. Virginia:Reston.

Kamaraju MVV, Bhattacharya A, Reddy GS, Rao GC, Murthy GS, Rao TCM (1995) Groundwater potential evaluation of West Godavari District, Andhra Pradesh State, India - A GIS approach. Ground Water 34(2):318-325.

Khalek, A.A. and Ahmed, O. (2008).Integration of Remote Sensing, Geophysics and GIS to Evaluate Groundwater Potentiality – A Case Study In Sohag Region, Egypt.The 3rd International Conference on Water Resources and Arid Environments, 1st Arab Water Forum.

Krishnamurthy, J. and Srinivas G. (1995). Role of Geological and Geomorphological factors in groundwater exploration: a study using IRS LISS data. *International Journal of Remote Sensing*,16(14), 2595–2618.

Krishnamurthy, J., Mani, A., Jayaraman, V. and Manivel, M. (2000). Groundwater Resources Development in Hard Rock Terrain – An Approach using Remote Sensing and GIS techniques. *Journal of Applied Geology*,2(3/4), 204–215

Macleod, W.N. (1971). The Geology of the Jos Plateau with 1:100, 000 sheets 147, 148, 168, 169, 189 and Geological survey of Nigeria Bulletin 32.

Magowe, M. and Carr, J.R.(1999).Relationship between Lineament and Groundwater in Western Botswana.*Groundwater 37* no. 2, 282-286

Mbonu, M.C. (1988). Contribution of Knowledge Relative to the hydrogeology of the basement rock of north-central Nigeria. A paper presented at the universite pierre et marie gurie, Paris VI, Paris-France.

Mbonu, M.C., Travi, Y. and Guiraud, R. (1988).Ground water quality in the complex basement region of North-Central Nigeria.A Precursory Survey of Nitrate Concentration. A paper presented at NAH Conference.

McCurry, P. (1976). The geology of the Precambrian to lower palaezoic rocks of northern Nigeria-A review in: Kogbe C.A. (Ed) *Geology of Nigeria*- Elizabth Pub. Co., Ibadan, Nigeria pp 15-38.

Mogaji, K.A., Aboyeji O.S. and Omosuyi G.O. (2011).Mapping of lineaments for groundwater targeting in the basement complex region of Ondo State, Nigeria, using Remote Sensing and Geographic Information System (GIS) techniques. *International Journal of Water Resources and Environmental Engineering* Vol. 3(7), pp. 150-160, August 2011. Available online at http://www.academicjournals.org/ijwree.

Mondal, M.S., Pandey, A.C. and Garg R.D. (2007) Groundwater prospects evaluation based on hydrogeomorphological mapping using high resolution satellite images: a case study in Uttarakhand. Journal of the Indian Society of Remote Sensing 36:69-76.

Musa, K.A., Juhari Mat, A., and Abdullah, I. (2000).Groundwater prediction potential zone in Langat basin using the integration of remote sensing and GIS.The 21 st Asian Conf. on Remote Sensing, Taipei (Taiwan).

Nefedov, K.E.and Popova, T.A. (1972).*Deciphering of groundwater from aerial photographs.* Amerind, New Delhi.

Niwas, S., de Lima, O. A. L., (2002). Aquifer parameter estimation from surface resistivity data. GROUND WATER Vol. 41 - No.1, 94–99, techical Note.

Oguntoyinbo, J. (1983). *Geography of Nigerian* Development.Heinemann.

Okezie, C.N. (1970). Interim Report of the Geology of the Basement Complex of 1:100,000 street 167 (Kafanchan) S.W. Unpublished PhD. GNS report No. 1127.

Okolie, E.E, Osemeikhian, J.E.A. and Asokhia, M.B. (2005). Estimate of Groundwater in parts of Niger Delta Area of Nigeria using Geoelectric Method, *Journal Applied Science. Environment*.Management. 9(1), 31-37.

Olaniyan, I.O., Agunwamba, J.C. and Ademiluyi, J.O. (2010).Lithologic Characteristics of parts of the crystalline basement complex of northern Nigeria in relation to groundwater exploitation. *ARPN Journal of Engineering and Applied Sciences* 5(7):56-60, Asian Research Publication Network (ARPN) www.arpnjournals.com.

Oluronfemi M.O. and Fasuyi S.A. (1993). "Aquifer types and Geoelectrical/ hydrogeologic Characteristics of Central Basement Terrain of Nigeria "*Journal of African Earth Science* (16): 309-317.

Olorunfemi M.O. and Okhue E.J. (1992). Hyrogeologic and Geologic significance of a Geoelectric Survey at Ile–Ife, Nig. *J. Min. Geol*. 28:242-350.

Afolayan J. F. and Afolabi, O. (2004)."Geoelectric/Electromagnetic VLF Survey for groundwater in a Basement Terrain: A case Study," Ife journal of Science 6 (1): 74-78.

Olayinka A.I., Olorunfemi M.O. (1992). Determination of Geoelectric Characteristics in Okene Area and Implications for Borehole Siting. *J.Min. Geol.* 28(2):403-411.

Oluyide, P.O. (1988). *Structural trends in the Nigerian basement complex. In: Precambrian of geology of Nigeria*. A publication of the *GSN* pp 93-97

Oluyide, P.O. (1995). Mineral Occurrences in Kaduna State and their Geological Environments.Proceedings of a workshop held by Nigeria mining of Geoscience Society, Kaduna chapter in collaboration with the Kaduna State Government.

Oyedele AA. Adelusi AO, Ayuk MA, (2009). Hydrogeophysical Analysis of Owode Area around Oba-Ile near Akure, SW Nigeria.*Afr. J. Develop. Stud.* 4(1 &2):11 -14.

Palacky, G.J., Ritsema I. L and De Jong (1981).Electromagnetic Prospecting for groundwater in PrecambrianTerrains in the Republic of Upper Volta.GeophysicalProspecting. Vol. 29, pp. 932-955.

Pandian, M. and Kumanan, C. J. (2013).Geomatics Approach to Demarcate Groundwater Potential Zones Using Remote Sensing and GIS techniques in part of Trichy and Karur district, Tamilnadu, India.Archives of Applied Science Research.Retrieved from http://scholarsresearchlibrary.com/archive.html.

Ramalingam, M. and Santhakumar, A.R. (2002) Case study on artificial recharge using remote sensing and GIS.www.GISdevelopment.net (accessed on June 25, 2013)

Rampal, K.K. and Rao, K.V.G. (1989). Groundwater targeting using digitally enhanced imagery. www.GISdevelopment.net(accessed on July 24, 2013).

Saaty, T.L. and Vargas, L.G. (1991).*Prediction, Projection and Forecasting.*Dordrecht:Kluwer Academic Publishers, 251 pp.

Salama, R.B., Ye, L. and Broun, J.L. (1996).Comparative study of methods of preparing hydraulic-head surfaces andthe introduction of automated hydrogeological-GIS techniques. *Journal of Hydrology*,185(1–4), 115–136.

Salama, R.B., Tapley, I., Ishii, T. and Hawkes G. (1994) Identification of areas of recharge and discharge usingLandsat-TM satellite imagery and aerial photography mapping techniques.*Journal of Hydrology*, 162(1–2), 119–141.

Sander, P., Chesley, M.M. and Minor, T.B. (1996). Groundwater assessment using remote sensing and GIS in a Rural Groundwater Project in Ghana: lessons learned. *Hydrogeology Journal*, 4(3), 40–49.

Sander, P. (2007). Lineaments in Groundwater Exploration: A Review of Applications and Limitations. *HydrogeologyJournal*, 15, 71-74.

Saraf, A.K. and Choudhury, A. (2002). Study of Land Use-Ground–Water Relationship Using an Integrated Remote Sensing and GIS approach. http://www.gisdevelopment.net.

Seaton, W.J., and Burbey, T.J., 2000, Aquifer characterization in the Blue Ridge physiographic province using resistivity profiling and borehole geophysics: geologic analysis. *Jour.Of Environmental and Engineering Geophysics*, v. 5.issue 3, p. 45-58.

Sener, A., Davraz, A. and Ozcelik, M. 2005. An integration of GIS and remote sensing in groundwater investigations: a case study in Burdur, Turkey. *Hydrogeol. J.*, 13:826-834.

Shahid, S. and Nath, S.K. (2002).GIS integration of remote sensing and electrical sounding data for hydrogeologicalexploration.*Journal of Spatial Hydrology*, 2(1), 1–10.

Sikdar, P.K., Chakraborty, S., Adhya, E. and Paul, P.K. (2004). Land use/land cover changes and groundwater potentialzoning in and around Raniganj coal mining area, Bardhaman District, West Bengal: A GIS and remotesensing approach. *Journal of Spatial Hydrology*, 4(2),1–24

Singh, A.K. and Prakash, S.R. (2002).An integrated approach of remote sensing, geophysics and GIS toevaluation of groundwater potentiality of Ojhala sub-watershed, Mirjapur district, U.P., India.www.GISdevelopment.net (accessed on June 25, 2013).

Singh, A.K., Raviprakash, S., Mishra, D. and Singh, S. (2002). Groundwater potential modeling in Chandrapraha

Solomon, S. (2003). Remote Sensing and GIS: Applications forGroundwater Potential.*Environmental and Natural Resources Information Systems*

Stone, D.B, Moomaw, C.L. and Davis, A. (2001).Estimating recharge distribution by incorporating runoff frommountainous areas in an alluvial basin in the Great Basin region of the southwestern United States.*Ground Water* 39(6), 807–818.

Subba Rao, N. 1992. Factors affecting optimum development of groundwaters in crystalline terrain of the eastern Ghats, Visakhapatnam area, Andhra Pradesh, India. *J. Geol. Soc. India*, 40 (5): 462–467.

Subba, R.N., Chakradhar, G.K.J. and Srinivas, V. (2001).Identification of Groundwater Potential Zones Using Remote Sensing Techniques in and Around Guntur Town.*Andhra Pradesh, India,* 29(1&2), 69–78.

Teeuw, R.M. (1995). Groundwater Exploration Using Remote Sensing and a Low-Cost Geographical Information System.*Hydrogeology Journal,* 3(3), 21–30.

Tewodros, R.G. (2005). *Application of remote sensing and GIS for geological investigation of ground water potential zones identification in south eastern Ethiopia, plateau, Bale mountains and surrounding areas*. A thesis submitted to the school of graduate studied, Addis Ababa University.

Telford, W.M., Geldert, C.P., Sheriff, R.S. and Keys, O.A. (1976).*Applied geophysics,* Cambridge University Press. Cambridge.

Todd, D.K. and Mays, L.W. (2005).*Groundwater Hydrology*. 3rd edition, NJ:John Wiley & Sons, pp. 636.

Todd, D.K. (1980). *Groundwater Hydrology*. 2nd edition, NY:John Wiley & Sons, pp. 111–163.

Travaglia, C. and Ammar, O. 1998.Groundwater exploration by satellite remote sensing in the Syrain Arab Republic.Technical Report. FAO.TCP/SYR/6611, 33p

Tyagi, P.D., Buddhi, R., Chaudhary, K.C. and Sawhney, R.L. (2002). Degradation of Ground Water Quality In Industrial Area in India, *Ind. J. Environ. Protect*, 20, 174-181.

Vasanthakumaran, T., Shyamala, R. and Sridhar, K. (2002). Role of Remote Sensing and GIS in Identifying ArtificialRecharge zones of upper Kolavarnar river basin, Tamil Nadu. www.GISdevelopment.net (accessed on June25, 2003)

Wright, C. P. (1992). The Hydrogeology of Crystalline Basement Aquifers in Africa. In: C. P. Wright and W. C. Burgess (eds). Hydrogeology of Crystalline Basement Aquifer in Africa. Geological Society of London Special Publication No. 66 Pp. 1 – 27.

WATSAN (2006). Rural Water Supply and Sanitation Agency (WATSAN) Report.

Yisa, J. and Jimoh, T. (2010), Analytical Studies on Water Quality Index of River Landzu. American *Journal of Applied Sciences*, 7(4), 453-458.