GEOSPATIAL ASSESMENT OF GROUNDWATER POTENTIAL IN JOS SOUTH LOCAL GOVERNMENT AREA OF PLATEAU STATE, NIGERIA

BY

IKEGWUONU, Stanley Edozie
B.Sc (Unijos)
MSC/SCIEN/41125/2012-2013
0063

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

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

FEBRUARY, 2017

DECLARATION

I hereby declare that this thesis titled **"Geospatial Assessment of Groundwater Potential in Jos South Local Government Area, Plateau State, Nigeria"** was written by me and is a product of my research effort. It has not been presented in any previous application for any degree or diploma. All quotations are indicated and the sources of information are acknowledged by means of references.

IKEGWUONU, Stanley Edozie ....

(Signature) **(Date)**

CERTIFICATION

This thesis titled**,** titled **"Geospatial Assessment of Groundwater Potential in Jos South Local Government Area, Plateau State, Nigeria"** by **Stanley Edozie IKEGWUONU** meets the regulations that govern the award of Degree in Masters of Science (GIS and Remote Sensing) of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

Dr. B. AKPU

Major Supervisor ....

(Signature) (Date)

Dr. D.N JEB

Minor Supervisor ....

(Signature) (Date)

Dr. A.K. USMAN

Head of Department, Geography ....………… …………..

(Signature) (Date)

Prof. S.Z. ABUBAKAR

Dean, Postgraduate School …..……… ..…………

(Signature) (Date)

DEDICATION

This research work is dedicated to GOD Almighty, my wife Patience Ikegwuonu and to my dearest parents Mr and Mrs Ikegwuonu (Late).

ACKNOWLEDGEMENTS

I am most grateful to the King of Kings and the Lord of Lords, God Almighty, the most gracious and merciful, to Him I owe my eternal gratitude for my life. My sincere appreciation goes to my supervisors Dr. B. Akpu and Dr. D.N Jeb, for their immense and unreserved commitment and sacrifice to making sure that this work is accomplished. I am honestly grateful. I also appreciate my lecturers in the Department of Geography, Ahmadu Bello University Zaria for their support in the course of this study, I remain thankful to my course mates M.Sc (Remote Sensing and Geographic Information System, 2012-2013 Class). I say a big thank you.

I earnestly value the support of my family members towards the realization of this work. I also want to acknowledge in a very special way Mrs Ikegwuonu (Late) who taught me all I needed to know to be the person I am today and to my dearesr wife Mrs Patience Igwe for all her supports and encouragement.

My appreciation to Dr. H. Dibal, Mr. Ashika, Mrs Dorcas Ibinaye, Mrs. Ifeoma Ikegwuonu Obi for their encouragement and support. I also recognize the encouragement of my friend David Balogun, Ezekiel Wanikko amongst many, as well as all the PG Students of Geology Department. I appreciate you sincerely. I thank you all and may The Almighty God increase you beyond measure.

ABSTRACT

The drying up of the hand dug wells in Jos South L.G.A worsens the problem of water scarcity which is becoming progressively intense with growing population. This has been attributed to poor assessment of groundwater potential zones prior to water exploration in the area and there is no known study that investigated groundwater potential in the area. In this study, an attempt has been made to assess the possible groundwater potential zones in the Jos South Local Government Area, Plateau State using geospatial techniques. The data used include topographic map, satellite imageries and literatures while the thematic layers considered in this study include elevation, rainfall, drainage density, lineament density, geology, soil, slope steepness and landuse/landcover. All the thematic layers were then assigned weights according to their relative importance in groundwater occurrence and the corresponding normalized weights were obtained based on Saaty's Analytical Hierarchy Process (AHP). Eight thematic maps of factors contributing to groundwater recharge were generated and integrated in ArcGIS 10.1 environment using weighed sum overlay in spatial analyst tool. The resulted groundwater potential zoning map was validated based on existing geophysical investigation data of the study area, by determining the relationship between the results obtained using Remote Sensing and geographic information sysytem technology with that of electrical resistivity. Nine (9) electrical resistivity (one for each location) in Vom, Rayfield, Dutsen Kato, Barkin Columbai, Bukuru, Gyel, Kuru, Du and Shen were overlaid on the groundwater potential map generated from the integration of the various thematic maps. The coverage of the groundwater potential was estimated using the geometry calculator. Areas with larger value of aquifer thickness have high groundwater potential and areas with low aquifer thickness have low groundwater potential. Vom which has

aquifer thickness of 45m has the highest groundwater potential from electrical resistivity also has very high ground water from GIS method. On the other hand, Dutsen Kato and Du which both have aquifer thickness of 25m each were found to have low groundwater potential by resistivity method and very low from the GIS and remote sensing technique too. Thus, very good groundwater potential zones were identified in the Northern and Northeastern areas around Rayfield and Bukuru respectively, while the areas with low potential lie in the Western areas around Gyel. Very good groundwater potential zones in the study area occupies 14.1%, good potential occupies 22.4%, moderate occupies 15.0% while fair and low constitute of 23.9% and 24.6% respectively. Since the very good groundwater potential zones were identified in the Northern, North-eastern and Southern parts of the study area, it is important that the decision makers consider these areas when conducting groundwater exploration.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Water is an important constituent of all forms of life and is required in sufficient quantity and acceptable quality to meet the ever increasing demand for various domestic, agricultural and industrial processing operations. This requirement is hardly fulfilled because 97.5 % of the world global water is saline existing in the ocean, 69.5 % of the remaining 2.5 % world global water that is fresh is locked up in glaciers while 30.1 % and 0.4 % of it represent groundwater and surface/atmospheric water respectively (Oloruniwo and Olorunfemi, 1987). Water in rivers and lakes only account for less than 1% of the World's fresh water reserves (Jain, 1998). There has been an increase in the demand for freshwater due to rapid growth of population as well as the accelerated pace of industrialization in the last few decades. This demand has led to the use of groundwater not only for its wide spread occurrence and availability but also for its constituent good quality which makes it ideal for drinking (Yisa and Jimoh, 2010).

Groundwater is the largest available reservoir of fresh water, it comes from rain, snow sheet and hail that infiltrate the ground and become the groundwater responsible for the spring, wells and bore holes (Oseji, Atakpo, and Okolie, 2005).

Groundwater potential in an area is controlled by many factors such as geology, geomorphology, drainage, slope, depth of weathering, presence of fractures, surface water bodies, canals and irrigated fields amongst others (Jain, 1998).

Slope for example is one of the factors that control the rate of infiltration of rainwater into the subsurface and could therefore be used as an index of groundwater potential evaluation. In the gentle slope area the runoff is slow allowing more time for rainwater to percolate, whereas high slope area facilitates high runoff allowing less residence time for rainwater hence comparatively less infiltration (Jain, 1998). The groundwater occurrence in a geological formation and the scope for its exploitation primarily depends on the formation of porosity. Topographical depressions increase infiltration. An area of high drainage density also increases surface runoff compared to a low drainage density area. Surface water bodies like rivers, ponds, etc., can act as recharge zones (Murugesan, Thirunavukkarasu, Senapathi and Balasubramanian, 2012).

Groundwater refers to all waters stored beneath the surface of the Earth (the zone of saturation) in aquifers (Dasgupta and Sikdar, 1992). This aquifer is a unit of rock or an unconsolidated deposit that can yield a usable quantity of water (Onu, 2003). Aquifers are also known as underground reservoirs otherwise called underground flood and the water that reaches this chamber is usually much cleaner than the one at the earth surface (Gustafsson, 1994). Aquifers typically consist of gravel, sandstone, or fractured rock, like limestone. These materials are permeable because they have large connected spaces that allow water to flow through. Aquifer could be confined or unconfined (Gustafsson, 1994).

Confined aquifers are sandwiched between rock layers that are either effectively impermeable or have very low permeability. However, a combination of the two can occur and that aquifer is called Leaky or a semi-confined aquifer (Dasgupta and Sikdar, 1992). In order to use the water stored in an aquifer, it is necessary first to locate the aquifer, map its size, extent and depth, and then estimate recharge and discharge rates of water. The effects of additional extraction wells on the aquifer and its structural integrity must also be assessed (Benkabbour *et al.,* 2004).

Unconfined aquifers lie very near the water table, with little or no overlying rock or sediment and their water is usually at atmospheric pressure. Most local groundwater comes from unconfined aquifers made of loose slope materials, sands, gravels, and floodplain deposits left by stream and rivers (Benkabbour *et al.,* 2004).

Due to inherent qualities of ground water, it has become an immensely important and dependable source of water supplies in all climatic regions both in urban and rural areas of developed and developing countries (Ademilua, 1997).

The ever increasing demand for water especially for domestic purpose has led to widespread and very intensive search for water in all parts of Nigeria most especially in the crystalline complex where the occurrence and movement of groundwater in a crystalline bedrock setting depends on the degree of weathering and extent of fracturing of the rocks (Oloruniwo and Olorunfemi, 1987). The supply of fresh water to Nigerians has been inadequate and has subjected the inhabitants to resort to drinking water from wells (Sander, 2007). Nigerian government has invested a lot over the years in providing water for industrial, agricultural and domestic purposes. Despite all the government's effort, the Federal Ministry of Water Resources (2000) 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 which goes to show that a large part of the Nigerian population still do not have access to water of adequate quality and quantity (Sander, 2007).

Jos South Local Government Area is an extensively mined area, which was dominated by use of heavy earth moving equipments and draglines. As a result, the zone is characterized by deep excavation filled with contaminated water from tin mine ponds (Alkali and Yusuf, 2010).

These ponds formed during tin mining are the major source of water supply both for irrigation farming, fisheries, and of domestic purpose in some part of the area (Adiuku, 1999). During the rainy season the ponds carry huge amount of water and in the dry season it carries low quantity of water causing severe water scarcity in the area since most of the ponds and surface source have been heavily polluted and expensive to develop (Ogezi, 2007).

In order to meet the need for water, the Federal government in 1981 initiated the National borehole programme, marking a turning point in the groundwater resources development in Nigeria. In addition to this, the Plateau State government established some agencies to manage water projects on the Plateau these include; Plateau State Water Supply and Sanitation Agency (PRUWASSA), Plateau State Ministry of Water Resources and Energy (PMWRE), Plateau State water board, Plateau State Agricultural Development Program (PADP) all with the responsibility of providing safe drinking water, sanitation and to facilitate water supply in rural communities (Onugba and Eduvie, 2003). Despite their various efforts, an appreciable result is yet to be achieved in the area for adequate groundwater development (Onugba and Eduvie, 2003).

In Jos South Local Government Area of Plateau 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 the hand dug wells in the area worsens the problem which is becoming progressively intense with growing population. This has been attributed to poor assessment of groundwater potential zones prior to water exploration in the area. These communities therefore rely on self-water supply sources such as unreclamed lotto mine wells, river, canal, and mine ponds which play host to many diseases, such as malaria, typhoid fever, cholera, dysentery, cancer and as such, the people are vulnerable to these diseases.

Several conventional methods exist for the exploration and preparation of groundwater potential map of an area. These methods include; geological, geospatial, geophysical and hydrogeological. However, geospatial amongst these methods is considered to be more favorable as it is less expensive and applicable even in inaccessible areas. It is a rapid and cost effective tool in producing valuable data in geology and geomorphology (Sarma and Saraf, 2002).

Therefore there is need to assess the groundwater potential zones for effective yield during exploration in order to meet the water demand of the people. Hence this study focuses on the use of Remote Sensing and GIS in assessing groundwater potential zones in Jos South Local Government Area of Plateau State.

1.2 Statement of the Research Problem

Groundwater is gaining more attention due to drought problem, rural water supply, irrigation project and its low cost of development. The growing importance of groundwater is due to an increasing need for water which has led to unscientific exploitation of groundwater creating a water stress condition (Oteze, 2006). Despite the extensive research and technological advancement, the study of groundwater has remained more risky, as there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the geological and surface parameters (Oteze, 2006).

In Nigeria like in many other African countries, the provision of water for the teeming population is usually stated as one of the cardinal objectives of Government. In Plateau State specifically, many water provision initiatives have been undertaken over the years, though achievements have been recorded in certain areas, water provision in the state cannot be described as a complete success story (Mallo, 2007).

Severe water scarcity has been one problem citizens of Jos South Local Government Area had to contend with. Of the 3.6 million people in Plateau State, only those in Jos the state capital, could boast of access to potable water, though not all residents of the city have access to drinkable water (Onugba and Eduvie, 2003). Water projects constructed about 40 years ago when the state was created are no longer capable of providing enough water for the ever-growing population. This development has subjected the people of the state to rely on other sources of water such as; rain water, water from abandoned mining ponds which are seasonal and groundwater (PRUWASSA, 2012). Hand dug wells in the area yield little water which dries up eventually due poor construction and also lack of information on groundwater potential zone before groundwater exploration, likewise the poor yields from boreholes constructed by government agencies and other private organizations (Onugba and Eduvie, 2003).

Various researches and studies have been carried out on groundwater potential all with different views and opinion. For instance, Abiola, Enikanselu and Oladapo, (2009) used 51 Schlumberger Vertical Electrical Soundings (VES) to study the groundwater potential and aquifer protective capacity of overburden units in Ado-Ekiti, Ekiti State, southwestern Nigeria. According to them, the area is underlain by the Precambrian basement complex of southwestern Nigeria with the local geology predominantly been granite-gneiss and migmatite. Their interpretation revealed three distinct geoelectric layers overlying the resistive basement, the topsoil, the weathered layer and the partially weathered/fractured basement. The depth to the top of basement (overburden thickness) varied from 1.0 to 74.8m across the study area. Groundwater potential and overburden protective capacity maps were prepared. The VES assisted in the categorization of the area into high, medium and low groundwater potential zones. The clay content of the overburden was high, which informed the low groundwater potential rating but enhanced the overburden protective capacity. The characteristic longitudinal unit conductance (ranging from 0.004 to 2.11 mhos) of the area enabled the overburden protective capacity rating into good, moderate and weak. About 60% of the area fell within the good/moderate rating, suggesting a generally good overburden protective capacity around the area.

Abel and Moshood, (2011) mapped out the occurrence of groundwater in the Basement Complex terrain of Ekiti area, Southwestern Nigeria. They observed that, the aquifers were characteristically discontinuous (localized) warranting assessment of the groundwater potential of the area to serve as a guide for groundwater exploration. Thematic maps of geology, geomorphology, lineament, slope, drainage and drainage density were prepared and integrated using ArcGIS 9.1 software to produce the groundwater potential map of the area. They produced a groundwater potential map in which the study area was categorized into zones; very good, moderately good and poor. Furthermore, superimposition of the groundwater yield data from the study area on the groundwater potential map revealed that there were more number of high-yield wells in the favorable zones (very good to moderately good). Their study highlighted that the groundwater potential map would apart from its role as exploration guide be useful for the development of sustainable groundwater scheme in the area.

Waikar, Aditya and Nilawar, (2014) assessed the potential zone of groundwater recharge and its importance for the protection of water quality and the management of groundwater systems of Western India. They integrated RS and GIS techniques. In their findings the basements in the area have very little fractures which prevent water from getting to the aquifer. The parameters which they considered for identifying the groundwater potential zone such as geology, slope, drainage density, geomorphic units and lineament density were generated using the satellite data and survey of India (SOI) toposheets of scale 1:50,000 and further integrated with weighted overlay in ArcGIS. Suitable ranks were assigned for each category of these parameters. For the various geomorphic units, weight factors were decided based on their capability to store groundwater. The procedure was repeated for all the other layers and resultant layers were reclassified. They classified groundwater potential zones into five categories like very poor, poor, moderate, good and excellent. It is a known fact that there is scarcity of water in the study area (Onugba and Eduvie, 2003). Data on groundwater in the area is inadequate for the assessment of groundwater potential and there is no known study that investigated groundwater potential of the study area. This study will therefore, focus on the use of GIS and Remote sensing in assessing groundwater potential zones in the study area which could serve as a guide when conducting groundwater exploration.

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

1. What are features for determining the groundwater potential zone in Jos South?
2. What is the spatial distribution of groundwater potential zones in Jos South L.G.A?
3. Are there any relationships between the result obtained using geospatial technique with that of geophysical survey for determining groundwater potential zones in Jos South L.G.A/metropolis?

1.3 Aim and Objectives

The aim of the study is to assess the groundwater potential of Jos South Local Government Area Plateau State Nigeria using geospatial techniques. This can be achieved through the following set of objectives which are to:

i. establish/identify the features for determining groundwater potentials in Jos South
ii. establish the spatial distribution pattern of groundwater potential zones in Jos South

iii. determine the relationships between result obtained using geospatial technique with that of geophysical technique

1.4 Scope of the Study

The study area Jos South is the second largest Local Government Areas of Plateau State, it comprises of three districts; Du, Kuru and Vwang each districts has many villages such as Vom, Bukuru, Barkin Turu, Dagai, Wat, Daken, Dati, Shen, Du, Gero, Rayfield, Doi Du, Gyel etc. This study focuses on the assessment of groundwater potential zones using Remote Sensing and Geographic Information System. The factors to be considered in the study would include geology, lineament, land-use/land-cover, drainage, rainfall, soil, and slope.

1.5 Justification for the Study

It is very important to know the groundwater potential of an area before embarking on any further exploration, as these 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.

The scarcity of water in Jos South Local Government Area of Plateau State warrants for 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. There is the need for accurate estimate of the available subsurface resources for the importance of proper planning to ensure the continued availability of water.

This study will serve as a guide to the Government, and Non-Government Organizations and other stakeholders involved in water exploration. Also other water agencies in Plateau State can benefit from this research.

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 Introduction

This chapter reviewed relevant literature related to the topic of study. It touches the concept of groundwater, factors affecting groundwater storage, remote sensing and GIS, groundwater hydrology, and applications of geophysical method to groundwater exploration.

2.2 Conceptual Framework

2.2.1 Concept of Groundwater

Water is a chemical substance with a chemical formulae H_2O.Water covers 70.9% of the earth's surface and it is vital for all known forms of life. On earth, it is found mostly in oceans and other large water bodies, with 1.6% of water below ground in aquifers, 0.01% in the air as vapour, cloud and precipitation, 97% in ocean as surface water, 2.4% as glaciers and ice caps, 0.65% in rivers lakes and ponds as other surface water bodies. A very small amount of earth's water is contained within biological bodies and manufactured products (BBC report, 2007).

Macdonald (2005) pointed out that there are still at least 1.1 billion people across the world that does not have access to safe drinking water. Groundwater comprises water that exists beneath the land surface, held within openings or pores of soils and geological formations. According to most classical definitions, this term refers exclusively to water occurring at or beneath a surface, known as the water table. Below the water table is a region known as saturated zone where pores are completely filled with water Macdonald (2005). Trimmer (2000) defines groundwater as water that naturally occurs in porous rock materials underground. Groundwater potential means having a latent possibility or likelihood of occurrence of groundwater in an area. Areas or zones of abundant groundwater available for use are referred to as areas of good groundwater potential. Productive water bearing zones referred to as good groundwater potential aquifers. The search for groundwater has become quite intense in human history. This is due to the fact that government is unable to meet the ever increasing water demand; inhabitants have had to look for alternative sources such as surface streams, shallow wells and boreholes (Trimmer, 2000). Groundwater exploration is carried out in many ways ranging from traditional to modern methods. Everyday groundwater exploration is developing through new means and devices, Meijirik (2007) reports that exploration for groundwater using photo geology was a major field of interest in the past and still is in areas covered in adequately by geological maps. This is with regards to geological point of view. The classic work of Ray (1960) has assisted many beginners in the field of hydrogeology.

2.2.2 Factors Affecting Groundwater Storage

Groundwater storage depends on aquifer parameters, rate of water movement and recharge of the aquifers. Groundwater movement like surface water is affected by the nature of slope or elevation. Thomas (2003) states that groundwater moves from higher elevations to lower elevations and from location of higher pressure to location of lower pressure. Typically this movement is quite slow, on order of less than one foot per day to a few tens of feets per day. He also stated that the science of groundwater movement is described as groundwater hydraulics. In groundwater hydraulic, it is hydraulic head that determine groundwater movement. Groundwater movement is rapid in gravels and sands and slow in clay or in tiny rock features. The ability of a rock layer or geologic formation to move water is called hydraulic conductivity. Factors determining groundwater movement and storage in any form of aquifer are hydraulic properties or dimension of aquifers, type of aquifer confined or unconfined and climate that is in terms of rainfall recharge (David, John and Scott, 1997).

In another development Buddemeir and Schloss (2000) pointed out that groundwater development potential yield depend on aquifer characteristics such as hydraulic conductivity, aquifer thickness, storability, aerial extent, groundwater levels, available drawdown and recharge. This indicates that nature of soil, geology; climate and properties of aquifer are the major factors controlling movement and storage of groundwater in any part of the world. Groundwater recharge and storage in shallow unconfined aquifer is complex, and is dependent upon the occurrence, intensity and duration of precipitation, temperature, humidity, wind velocity as well as character and thickness of soil and rock above the water table and the surface topography, vegetation and land use (Arnold *et al.*,2000). Groundwater storage depends also on meteorological conditions, as well as soil type, soil-moisture status, vegetation cover and condition, slope, cultivation practices and most of all, on evapotranspiration, which is a function of the other factors (Cheng- HawLee, Wei-ping and Ru-huanglee, 2006).

2.2.3 Groundwater Potential Zones

Groundwater potential means having a latent possibility or likelihood of occurrence of groundwater in an area. Areas or zones of abundant groundwater available for use are referred to as areas of good groundwater potential. Productive water bearing zones referred to as good groundwater potential aquifers.

The search for groundwater has become quite intense in human history. This is due to the fact that government is unable to meet the ever increasing water demand; inhabitants have had to look for alternative sources such as surface streams, shallow wells and boreholes. This can be achieved through groundwater potential studies. For example Matthew (2006) pointed out that the groundwater potential of United States is divided into principal aquifers of over 300,000km^2, principal aquifers of over 20,000km^2, principal aquifers of less than 20,000km^2 and non-principal aquifers. Classification of areas into groundwater potential zones or classes is not a new issue in the field of hydrology.

Ali-elnaqa, Nezar, Khalil and Masdouq (2009) determined groundwater potential of Wadi Arabia and classified the area into 40% of higher potential, 40% moderate potential, 17% low potential and the rest were undecided. Groundwater potential is determined using remote sensing and GIS to evaluate the water resource potential.

Assessment of groundwater potential in Nigeria was conducted through delineation of aquifers by many researchers. Okoro *et al* (2010), evaluated groundwater potentials in parts of escarpment areas of south-eastern Nigeria through delineation of aquifers, the groundwater potential zones were classified as high, medium, low and poor potential zones.

2.2.4 Remote Sensing and Geographic Information System

The concept of remote sensing and GIS are used in groundwater exploration. Lillesan and Kiefer (2000) stated that remote sensing can be define as the science of obtaining information about an object, area or phenomenon through the analysis of data acquired by device that is not in contact with the object, area or phenomenon under investigation while GIS is a tool for analyzing remotely sensed data. The main reason for using remote sensing in groundwater exploration is cost effectiveness of well sites selection. Information on geology, geomorphology, land management and soil classes are mapped using remote sensing and GIS to identify potential groundwater zones (Taylor *et al.*, 1999).

Raghu and Venkata (2009) used integrated Remote sensing and GIS approach to identified groundwater potential zones of Vemulawada, Karimnagar District using high resolution Indian remote sensing satellite, IRC-IC false colour composite geocoded PAN + LISS-III merged satellite data, they found out that the basements in the area have very little fractures which prevented water from getting to the aquifer.

Candra *et al* (2010) also used RS and GIS in groundwater exploration, they used DEM, slope map, soil map, hydro geomorphology map and analyse them using ARC GIS 9.3 version spatial analyst. In their study, the groundwater potentiality of the area was assessed through integration of various layers including hydrogeomorphology, lineament, slope, aquifer thickness and clay thickness grid environment. The criteria for GIS analysis was defined on the basis of groundwater and appropriate weightage assigned to each information layer according to the contribution towards desired output. The groundwater potential map was generated and model was verified with field data to ascertain the validity of the model developed. The results showed that the groundwater potential zones demarcated through the model were in agreement with the bore well field data.

In recent years, intensive use of satellite remote sensing has made it easier to define the spatial distribution on different groundwater prospect water zones on the basis of geomorphology, hydrogeology and other associated features (Baber, 2001). Remote sensing and

GIS played significant role in groundwater exploration at both regional and local levels. Remote sensing data is capable of identifying potential areas of groundwater through delineation of geomorphic features like paleo channels, older flood plains, valley fills, alluvial plains, pediments, abandoned channels, Pedi plains and lineaments. High resolution satellite image is suitable for any groundwater exploration analysis due to its effectiveness and potentiality in completing the task. High-resolution satellite data has the potential to infer buried pediment plains and inter connected zones for the selection of groundwater exploration and artificial recharge sites (Mukherjee, 2008).

The use of satellite remote sensing for groundwater exploration is an established procedure which has a long pedigree. Remote sensing in conjunction with the contemporary studies is evolving increasingly as a powerful means to target potential groundwater resources. Remotely sensed data provides valuable information on the drainage pattern and drainage density, which have a bearing on the recharge conditions and permeability of rocks. Dykes which act as groundwater barrier can be easily identified on the imagery (Chandra *et al*, 2010). This is applicable to Basement Complex regions and other hard rock terrains if combined with ground truthting data.

2.2.5 Groundwater Hydrology

Hydrology is the study of water resources while groundwater hydrology is the study of groundwater resources. Groundwater is the water that fills pores and fractures in the ground, just as milk fills the voids within bits of granola in a breakfast bowl (Thomas, 2003). Groundwater supplies are obtained from aquifers, which are sub surface units of rocks and unconsolidated sediments which are capable of yielding water in usable quantities to wells, boreholes and springs. The hydrological characteristics of aquifers and chemical content of groundwater determine availability and suitability of groundwater resources for uses and development. Groundwater hydrology is beyond just study of groundwater resources but rather it is extended to include understanding what constitutes groundwater, how it develops or accumulates and how it moves. Groundwater hydrology helps many groups of people from farmers to rural homeowners to industrialist to well drillers learned about the development, occurrence and conservation of groundwater. Groundwater hydrology deal with all basic principles related to groundwater occurrence and development. Groundwater occupies the cracks and pore spaces between rocks and mineral grains below the land surface. Groundwater hydrology is the subdivision of the science of hydrology that deals with the occurrence, movement and quality of water beneath the earth's surface. It is interdisciplinary in scope in that it involves the application of physical, biological and mathematical sciences (Ralph, 1987).

Groundwater hydrology is a science whose successful application is of critical importance to the welfare of mankind and it is used in investigation and solving groundwater problems. The investigation involves groundwater occurrence and its position in the ground. Water in the saturated zone is the only underground water that is available to supply wells and springs and is the only water to which the name groundwater is correctly applied (Ralph, 1987).

In the saturated zone, especially all of the pores are filled with water (Buddemeier and Schloss, 2000). Groundwater is the part of precipitation that enters the ground and percolates down ward through unconsolidated materials and opening in bedrock until it reaches the water table. Water table is the topmost surface of groundwater. The zone between surface of the land and water table is called unsaturated zone and is the passage where the water move down and replenish the ground. Geologic formation that contain large amount of water is called aquifer, a formation that acts as water barrier between aquifers is called aquitered and a formidable flow barrier between aquifers is known as aquiclude (Thomas, 2003).

Aquifers are of two major types which are unconfined and confined. An unconfined aquifer is the one having no overlaying aquitard or aquiclude while confined aquifer the sandwiched between an aquitard above an aquiclude or aquitard such as the bed rock below it. All rocks or sediments contain openings, through which water flows. These openings are called voids, pores or interstices. Porosity of rock is its property of containing open spaces and can be expressed as the ratio of the total volume of its pore spaces to its total bulk rock volume. Thus porosity is expressed as percentage of total volume of rock which contains water. The size, shape and sorting of material determines the amount and interconnection of inter-granular pores and sand gravels deposits have high proportion of pore space and high permeability. Fine-grained or clay-rich deposits have a greater proportion of pores but a lower degree of permeability (Claudia,Diane and Grenville, 2006).

Study of these characteristics and properties of rocks, sediments, layers and their properties are very useful in groundwater hydrological investigations. Many studies were conducted on groundwater hydrology and of which aquifer properties, sediment materials and rock properties were considered. Among these studies one was conducted by Buddemeier and

Schloss (2000) in West Fork white river basin at Kansas. In their study potentiometric meter measurement of water level was undertaken using transect, well data and yield. The result of their study indicated that groundwater supply in the basin was obtained from unconsolidated and bedrock aquifer systems. In the study seven unconsolidated aquifer systems were identified, nine bed rock aquifer systems were identified and groundwater level elevations in the basin ranged from 1150feet m.s.l. Areas of recharge and discharge were identified and groundwater resource map was produced and the area was described to have regional aquifer system.

Marshal *et al.* (2008) undertook groundwater hydrology study of Deschutes basin in Oregon. In the study groundwater fluctuation was measured from wells, annual water level was measured, quantitative evaluation of groundwater and stream was undertaken, water balance was calculated from people's opinion and average annual rate of canal leakage was estimated. Result of their study indicated that precipitation was 3,500 ft^3/s, it was discovered that rain water enters into groundwater through inter basin flow, 800ft^3 flows into metolious river drainage showing that groundwater discharge was caused by geologic factors, in summer groundwater was approximately 4,000ft^3/s and estimated groundwater use in the area is 30ft^3/s.

In another development Kadam and Sankhua (2012) studied groundwater hydrology of Upper Karha watershed in India. In their study hydrogeomorphological mapping coupled with ground truth investigation was undertaken. Layers used in the study include hydrogeomorphology, landuse land cover, soil, slope and geology. Weighted overlay analysis in Arc-GIS environment was used to integrate the reclassified raster layers. Groundwater potential zones were identified to be excellent 0.40%, good 20.19%, moderate 64.11%, poor 14.93% and nil 0.36% of the study area.

2.2.6 Geophysical Measurement using (VES)

Geophysical measurements are also known for groundwater exploration using seismic methods, geophorning, schulumberger array and wenner array methods. Integrated geophysical tools, especially resistivity, electromagnetically more recently, nuclear magnetic resonance methods, are commonly used in groundwater exploration, mainly due to close relationship between electrical conductivity and some hydrological parameters (Sultan *et al*, 2009).

Resistivity methods are used in detecting groundwater presence and differentiating subsurface layers. Vertical Electrical Sounding (VES) is very useful in groundwater study especially when supported by other techniques of data collections. Emmanuel *et al* (2011) described VES method as a depth sounding method and have proved to be useful in groundwater studies and it is capable of investigating rock resistivity and properties which depends on lithology fluid contents.

Coker, Makinda and Olowefola (2008) conducted groundwater exploration in Oke-Bada Estate parts of Ibadan. In their study VES survey was carried out and borehole data was also used to validate the result. Four to Three layer configurations were identified. It is also seen that areas of low resistivity are areas of high porosity and high groundwater potential. Aquifer units thickness maps were produced using GIS analysis where poor, moderate, and good aquifers were identified.

Bello and Makinde (2009) undertake groundwater exploration study in Nupe Basin Kwara State using VES survey and bore holes data. Electrode spacing of AB/2 with bilogarithmic graph sheet was used. 3-5 layers were identified and the water was discovered in the weathered basement.

Julius (2009) used schlumberger array method with borehole data to study groundwater potential and recharge zones in parts of Delta state. In His study there was no use of G.I.S or remote sensing approach. Schulumberger array method was used together with depth to water level data obtained from handdug wells data, elevation and locations were taken using GPS. The result revealed that 4 to 5 layer configurations were identified and weathered basement was the promising area of groundwater potential.

Emmanuel *et al.* (2011) investigated groundwater condition of Moniya area in Ibadan where ABEM Terrametar SAS 300B was used; current electrode spacing (A/B) of 100m was used boreholes data was used. Result indicate that 3-4 layer configurations were identified. Weathered basement is the zone of high recharge, VES results are interpreted based on standards of resistivity values developed by Grant and West (1965) and based on Archie law as stated by Barnard (2003). (Table 2.1)

Table 2.1 Convectional Classification of Resistivity in relation to Groundwater occurrence

S/N	Resistivity (Ohm-m)	Depth (M)	Remark on Groundwater Occurrence
1.	Above 500 Ohm-m	<10 - 20	Low
2.	300 – 450	20- 30	Moderate
3.	30 – 400	30 to Above	High

Source: Grant and West (1965)

Groundwater exploration is often carried out using remote sensing and GIS techniques. Groundwater exploration on the other hand has many problems such as the paucity of existing data, the high cost of data gathering (subsurface and surface techniques) and relatively remote target aquifer. Remote sensing techniques and Geographic information system (GIS) techniques are considered the most appropriate new alternative tools for groundwater exploration (Moore, 1982).

The main advantage of using remote sensing and GIS techniques for groundwater exploration are reduction of cost and time needed, the fast extraction of information on the occurrence of groundwater and the selection of promising areas for further groundwater exploration (Toleti *et al*, 2001).

2.3 Literature Review

The availability of water, both in quantity and quality is the prime factor in deciding the growth of towns and cities and so on. In the age of technological revolution, many investigations have been made to study the availability of water and also its quality.

2.3.1 Groundwater Studies using Remote Sensing and GIS Techniques

Many researchers have come out with procedures and techniques of generating the groundwater potential zone maps by identifying remote sensing based on spatial layers of groundwater controlling parameters using GIS.

KhairulAnam *et al* (2000) identified groundwater potential zones in Langat basin India using integrated method. They integrated and analysed Land Sat TM and borehole data based on annual rainfall, lithology, lineament density, topography, elevation, slope steepness, drainage density and soil types. The result indicated that the study area was classified into Very poor, Poor, Good, Very Good and Excellent in terms of groundwater potential.

Amaresh, Singh and Prakash (2009) Used remotely sensed data, depth to water level pre and post monsoon, geo-electrical sounding data and drilling data of Nagar block of Mirzapur district of Utter Pradesh. In this case polygons were created from thematic maps and suitable weights were assigned to each category of class using GIS. The study area was categorised into excellent, very good, good, moderate and poor groundwater potential zones.

Mohammad, Mehdi and Timothy (2009) in Isfahak district, Eastern Iran. In this study Land Sat ETM+ was used. Thematic layers such as geomorphology, lineament, active faults, slope, land use land cover and drainage density were assigned weights according to their relative importance in groundwater occurrence using Saaty‟ s analytical hierarchy process. Four categories of groundwater classes were identified as very good, good, moderate and poor.

Shahid *et al* (2009) used GIS and Remote Sensing in the assessment of groundwater potential of Midnapur District in India. Data obtained from VES surveys were interpolated for the estimation of the subsurface parameters. The parameters were contoured using krigging method and thematic maps were prepared. The result showed that 18% of the study area wss of higher prospect, 39% of moderate prospect and 43% poor prospect.

Tesfaye (2010) studied groundwater potential of Bilate river cathment of Ethiopia through integration of lithology, geomorphology, landform, drainage density, lineament density, soil and slope using Saaty‟ s analytical hierarchy process approach. Land sat ETM+ of the study area was used. The area was divided into very low, low moderate and high in terms of groundwater potential.

Abel and Monshood (2011) in Ekiti SW Nigeria also use integrated approach to study groundwater potential through weighted overlay analysis where land Sat and thematic maps were integrated and the result indicated that the study area was categorised into very good, good, moderate and poor in terms of groundwater potential and among the factors lineament was found to be the most influential.

Anudu *et al* (2011) conducted research on groundwater potential in Wamba Nassarawa State Nigeria. The thematic maps they used were slope map, Drainage density, contour map and lineament density. The result indicated that lineament and drainage were the most important factors of groundwater identification in the area.

2.3.3 Geophysical Method

Amaresh, Singh and Prakash (2009) Used remotely sensed data, depth to water level pre and post monsoon, geo-electrical sounding data and drilling data of Nagar block of Mirzapur district of Utter Pradesh. In this case polygons were created from thematic maps and suitable weights were assigned to each category of class using GIS. The study area was categorised into excellent, very good, good, moderate and poor groundwater potential zones.

Abiola, Enikanselu and Oladapo, (2009) used 51 Schlumberger Vertical Electrical Soundings (VES) to study the groundwater potential and aquifer protective capacity of overburden units in Ado-Ekiti, Ekiti State, southwestern Nigeria. According to them, the area was underlain by the Precambrian basement complex of southwestern Nigeria with local geology predominantly granite-gneiss and migmatite. Their interpretation revealed three distinct geoelectric layers overlying the resistive basement, the topsoil, the weathered layer and the partially weathered/fractured basement. The depth to the top of basement (overburden thickness) varied from 1.0 to 74.8m across the study area. Groundwater potential and overburden protective capacity maps were prepared. The VES assisted in the categorization of the area into high, medium and low groundwater potential zones. The clay content of the overburden was high, which informed the low groundwater potential rating but enhanced the overburden protective capacity. The characteristic longitudinal unit conductance (ranging from 0.004 to 2.11 mhos) of the area enabled the overburden protective capacity rating into good, moderate and weak. About 60% of the area were within the good/moderate rating, suggesting a generally good overburden protective capacity around the area.

Kavidha and Elangovan (2013) conducted an integrated study of groundwater in Erode District India. The study involved the use of Wenner array method of VES survey and weighted overlay analysis of GIS and remote sensing. The result indicated that 4-5 layers were identified. Ground water potential zones identified include very good, moderately-good, good and poor and the zones were as follows very good 1%, moderately good 20%, moderate 69% and poor 10%.

2.4 Summary of Literature Review

This chapter has discussed about the review of literatures in the field of groundwater studies using remote sensing and GIS, and geophysical method. From the review of the various literatures it is evident that lot of research has been carried out in the above fields. Their analysis could be used for the study area to assess the groundwater as it requires exploring the groundwater potential for easy assessment and to overcome over exploitation in the study area.

CHAPTER THREE

STUDY AREA AND METHODOLOGY

3.1 Introduction

This chapter is concern with the description of the study area and also the methods applied to achieve the objective of the research work.

3.2 The Study Area

3.2.1 Location and Size

The study area is located from Latitudes 9^o35□ - 9^o 55□ North of the Equator and Longitudes 8^o37□ - 8^o57□ □East of the Greenwich Meridian. Jos South L.G.A includes parts of Bukuru town and extends to some parts of Rayfield (Shen opposite Buken Academy to Sparkling Junction) and other surrounding environs, all in the Jos-Bukuru Younger Granite Complex (Falconer, 1911), (See Figure 3.2).

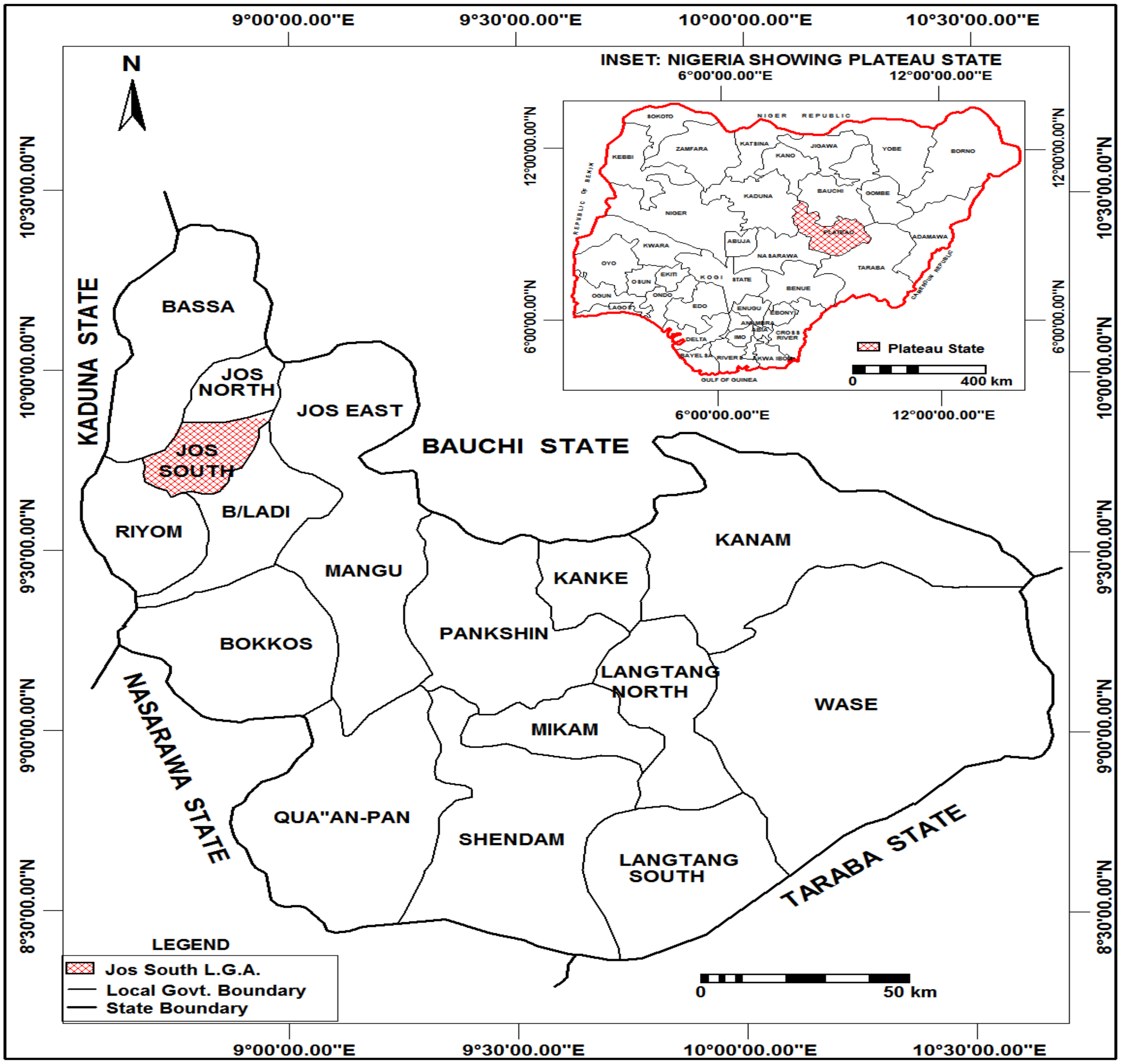

Figure 3.1: Jos South Local Govt. Area in Plateau State

Source: Adopted from Administrative map of Plateau State (2012)

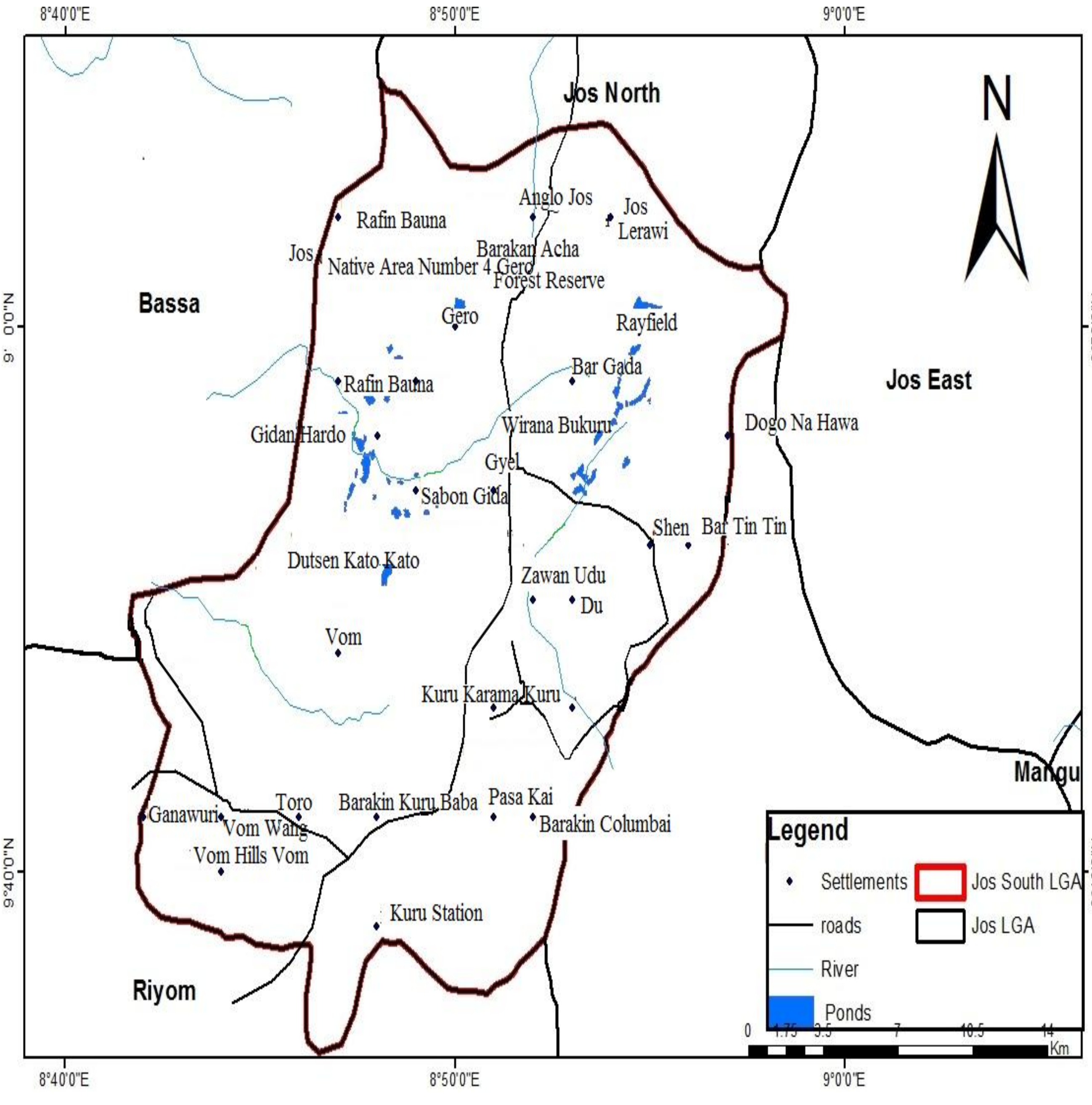

Figure 3.2: Jos South L.G.A (Study area)

Source: Adopted from Administrative map of Plateau State (2012)

3.2.2 Climate

Jos South falls within the Jos Plateau climatic condition of the middle belt of Nigeria. The significant repercussion of the high elevation of the Jos Plateau controls its climate which differs from the surrounding plains. The climate of Jos Plateau is typical of the tropical zone type. The moisture laden South-West trade winds and the North-East trade winds known as the harmattan, both dominate the climate of West Africa. The year is therefore divided into two seasons; the rainy and dry seasons respectively corresponding to the periods when each of these wind influence most of the West Africa.

The rainy season in Jos commences in April and lasts until October which is typical of the tropics where the rains are brought by the south-western trade winds, around this time there is sufficient water in the mine ponds, wells and other sources of water but from late October dry season sets in with prevailing water scarcity all through the season as most of the ponds, wells, tend to dry up.

Jos South has a near temperature climate with an average temperature of between 18^0C and 22^0C. Jos enjoys a more temperature climate than much of the rest of Nigeria. Night-time temperature drops as low as 11^0C (52 ^{0}F), resulting in chilly nights. Hail sometimes falls during the rainy season, owing to the cool high altitude weather. Harmattan winds cause the coldest weather between December and February. The warmest temperatures usually occur in the dry season months of March and April. The cooler temperatures have meant that, from colonial times until the present day, Jos is a favorite holiday location for both tourists and expatriates based in Nigeria (Falconer, 1911). The mean annual rainfall in Jos South varies from 131.75cm (52in) in the southern part to 146cm (57in) on the Plateau (Blench *et al.,* 2003).

3.2.3 Vegetation

Vegetation refers to the general distribution, density and type of plant cover present in an area. The natural vegetation of the study area is typical of the Jos Plateau, which belongs to the Northren Guinea savannah, but most of the plants have been removed by deforestation attributed to earlier tin mining in the area. At present agriculture has began in some part of the study area, the vegetation of the area is mostly covered with grasses, shrubs, and little woodland which is heavily used for fuel, building construction and other purposes (Lar, 2007).

3.2.4 Drainage

The drainage system also known as river systems are the patterns formed by the streams, rivers and lakes. The main factor influencing the development of drainage is the type and attitude of the rock on which drainage develops. Several smaller streams called tributaries run from higher elevated areas and supply water to the main stream. In Jos south the drainage system comprises of a network of streams which radiate outward from the central circular or oral highland and flow down the flanks in all directions. This is called radical drainage pattern. At the eastern part of the area, the streams tend to rode into a branching network system resembling a tree dentritic drainage pattern. The two drainage patterns flow from their point sources to major rivers and ponds present within the area (Lambert, David, 1998).

3.2.5 Relief

The unique physical features of the study area are its high relief, especially in the north. It is the general undulations dominating a region. On the Jos Plateau, the highest peak or point is located around the shere hills, where it rises up to 1,777 meters, but the most gently undulating top lies between 915 meters and 1,300 meters with an average of about 1,250 meters (Lar, 2007).

This is expected since the study area belongs to the younger granite province, which intruded the older rocks and shows high weathering. Thus hillocks of both igneous and volcanic rock are prominent and their surroundings are low-lying plains. The landscape is characterized by flat, or broadly undulating with flat-topped hills, above which raise the picturesque alkali tounger granite bodies (Lar, 2007). The average elevation of the study area is 1265m and the approximate highest elevation is about 1325m (Falconer, 1911).

3.2.6 Geology

The geology of the Jos Plateau is made-up of the Precambrian Basement migmatite-gneiss-quartzite complex which underlies about half of the entire State and some places has been intruded by Precambrian to the late Paleozoic Pan-African granite (Older Granite), diorite, charnockite etc. Intrusive into these Basement Complex rocks are the Jurassic anorogenic alkali Younger Granites. In association with the Younger Granites are volcanic rocks such as basalts and rhyolites that overly or cross-cut this formation as well as the Basement rocks. These volcanic rocks are believed to have been formed during the early Cenozoic (Tertiary) “Older Basalts” and Quaternary “Newer Basalts” (Macleod *et al*., 1971). The geology of the study area falls within the Jos-Bukuru Complex which is predominantly of biotite- granite type as exhaustively studied by Falconer (1921).

3.2.7 Soil

The major soil units of Jos South belong to the broad category of tropical ferruginous soils, which are much thinner on the high plateau but attain greater depths in the southern part of the state. There are also sizeable pockets of loamy soil of volcanic origin in the high Plateau. These soil groups respond quite well to fertilizers. Soil erosion is a major environmental problem on Jos Plateau. Tin mining, in its heyday, rendered some localities around Jos, Bukuru, Mangu and BarakinLadi more susceptible to soil erosion. Today, however, the soil erosion menace is being accentuated largely by over grazing which has resulted in gully along the numerous cattle paths which criss-cross the Plateau surface. The soil erosion problem in the study area is attributed to the mining activities which has disrupted the soil profile reducing its porosity and permeability making the soil to hold back groundwater (Lar, 2007).

3.2.8 Population and Economic Activities

The history of the establishment and growth of Jos South area is most closely related to the history of British and the tinmining industry on the Jos Plateau. Jos south Local Government Area has an area of 510km^2 and a population of 306,716 at the 2006 cencus. The high concentration of people in this region can be attributed to the attraction of mining, industrial and commercial activities. Though mining has adversely affected the morphology of Jos south metropolis not only has much arable land been lost to mining in this area, the numerous mine pits and heaps of overburden which were not effectively recovered or removed have greatly reduced its natural profile thereby altering the parameters influencing groundwater prospecting in the area. Though the ponds serve as a temporary source of water supply but also habor several bacterial that could have adverse health effects (Lar, 2007).

3.3 Methodology

3.3.1 Reconnaissance Survey

Preliminary survey was carried out in order to familiarize the researcher with the study area during which permission was obtained for access to the study area from the head of the wards under the area covered by the study.

3.3.2 Types and Sources of Data

The data used for this study include topographic map, satellite imageries and literatures. The data and their sources are given in Table 3.1.

Table 3.1: Types and Sources of Data

S/NO	TYPES OF DATA	SOURCE	SCALE/RESOLUTION
1	SRTM-90 2015	National Institute of Remote Sensing, Bukuru, Jos Nigeria	Spatial Resolution of 90m
2	LANDSAT 7 (2015)	National Institute of Remote Sensing, Bukuru, Jos Nigeria	Spatial Resolution of 30m
3	Topographic Map	Ministry for land survey Plateau State	Scale: 1:100,000
4	Geologic Map	Department of Geology, University of Jos	Scale 1:50000
5	Soil Map	Department of Geology, University of Jos	Scale 1:50000
6	Rainfall data (2004-2014)	Nigeria Metrological Agency (NIMET)	Scale 1:50000
7	Resistivity data	Ministry for Water Resources Plateau State	-

Source: Author's compilation, 2016.

3.3.3 Materials and Software Used

A. Hardware

- Laptop for GIS operations
- Global Positioning System (portable GPS) for field verification of features on the imageries.

B. Software

These softwares would be used for underground water potential zones in the study area:

i. ArcGIS 10.1 for digitizing and Groundwater analysis.
ii. ERDAS IMAGINE for image processing and classification.
iii. PCI Geomatica v10.0 for lineament extraction.
iv. Microsoft Excel graphical representation of charts.

3.3.4 Data Processing

3.3.4.1 Image Processing and Classification

LANDSAT 7 was in three different bands and the bands were layer stacked using ERDAS imagine 9.2 software; subset of the area was obtained using the ERDAS imagine software subset tool. Supervised classification was performed using maximum likelihood classifier since it is a land-use/land cover classification which was used to produce the output layer. This method of classification involves the procedure of identifying pixels possessing the same spectral features. The pixels were grouped and organized into land cover classes. The classes were built-up, vegetation, bare land, agricultural area, and water bodies as suggested by U.S.G.S classification (Anderson's Classification, 1971).

3.3.4.2 Classification Scheme

Based on the prior knowledge of the area and reconnaissance survey, a classification scheme after Anderson, Hardey, Roach and Witmer, (1976) was adopted for this study. In this study however, the classification scheme waas modified to present Built-up land, vegetation land, agriculture land, water and barren ground as shown in Table 3.2:

Table 3.2: Land use classification scheme

CODE	**LANDUSE/LAND COVER CLASSES**	**DESCRIPTION**
1	Build-up land	Land use for settlement and building of urban infrastructures such as schools, roads, etc.
2	Vegetated land	Land covered with natural vegetation such as grasses, shrubs, grass like-plants and natural forest.
3	Agricultural land	Land used as cropland, agricultural farmland etc.
4	Water body	Rivers, streams, ponds and dams.
5	Barren Ground	Land devoid of vegetation cover and exposed soils.

Source: Modified from Anderson, Hardey, Roach and Witmer (1976).

3.3.4.3 Processing of thematic maps

a) Annual rainfall map

An annual rainfall of the study area at 2014 was prepared by the Inverse Distance Weighing (IDW) interpolation method using the rainfall measured data from NIMET meteorology stations bordering Jos South Local Government Area. This was done by entering the coordinates and the mean annual rainfall from the stations into excel and saved as .csv (comma delimited) file format. The coordinates were imported into ArcGIS and the IDW interpolation of the spatial analyst toolbox was used to produce the annual rainfall.

b) 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 in producing the slope map for the study area. The Shuttle Radar Topographic Mission (SRTM) data with spatial resolution of 90m was used as the source of digital elevation model for the study. The DEM was imported into the ArcGIS version 10.1 environment. The DEM was interpolated using the krigging algorithm and slope function in the ArcToolbox of the GIS spatial analyst was used to produce the slope map of the study area at 20m interval of contour interval.

c) 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 compared with the surface runoff (Chowdhury, Jha, and Machiwal, 2003). The drainage map was digitized from the DEM and the line density function under the density tool in the spatial analyst was used to produce the drainage density map.

d) Land use/Land cover map

One of the parameter that influence the sub surface groundwater occurrence is the present condition of landcover and landuse of the area. The effect of landcover/landuse is manifested either by reducing runoff to facilitate recharge or trap water on their leaf and water droplets go down to recharge groundwater or negatively they facilitate loss by evapotranspiration (especially in arid and semi-arid areas). The land use/land cover was generated from the Landsat 8 imagery of 2015 by training the classes in Erdas Imagiine version 9.2. Maximum likelihood supervised classification was carried out to classify the land cover into built-up, vegetation, bare land, agricultural area, water bodies.

e) Geology map

The nature of the geology of an area also affects the ground water potentiality of an area. The geological map for the study area was digitized from an existing geology map and classified into alluvium, basalt, older basalt, granite and migmatite. The geology classes were then converted into image raster format.

f) Lineament map

Lineaments give a clue to movement and storage of groundwater and important guide for groundwater exploration (Subba *et al.*, 2001). Recently, many groundwater exploration projects made in many different countries have obtained higher success rate when sites for drilling are guided by lineament mapping (Teeuw, 1995). The lineament map was derived from Landsat imagery through image enhancement and digitizing with detailed image interpretation. The lineament density was derived from the drainage map from the line density in ArcGIS spatial analyst tool.

3.3.6 Techniques for Data Analysis

OBEJECTIVE 1: Assess the Features for Determining Groundwater Potential Zones in Jos South

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 to each other by pair-wise and eight important 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 3.3: 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).

The demarcation of groundwater potential zones for the study area was made by grouping the interpreted layers through weighed multi influencing factor and finally assigned different potential zones as categorized above.

OBJECTIVE 2: Examine the Spatial Distribution Pattern of Groundwater Potential Zones in Jos South

Integration of the thematic maps was carried out in ArcGIS 10.1 using the weighted overlay in spatial analysis tool. GIS-based multi-criteria evaluation based on Saaty’s Analytical Hierarchy Process (AHP) was used to compute the rates for the classes and weights and ranks for thermatic layers (Arivalagan *et al*. 2015). The groundwater potential zone was determined by integrating the various thermatic maps of the features that contribute to groundwater potential using the following equation given by Magaji 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.

Groundwater prospect map of the area was developed using weighted linear combination of the thematic layers and reclassified into five zones ranging from very high to very low classes.

OBJECTIVE 3: Determine the relationships for result obtained using geospatial technique with that of geophysical technique

Geophysical investigations make 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 is often related to strength and conductivity of the formation. The result obtained during a geophysical investigation for groundwater potential zone in the study area by the (ministry of water resourses and rural development Plateau State) were overlaid on groundwater potential map generated from the integration of various thematic maps so as to know if there is any relationship between the investigation for groundwater potential using geospatial technique and geophysical technique.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.2 Introduction

This Chapter is concerned with the assessment of surface features for estimating groundwater potential in Jos South L.G.A; determining the spatial distribution pattern of groundwater potential area, and finally determine relationships between result obtained using geospatial technique with that of geophysical technique

4.2 Features for Determining Groundwater Potential Zones in Jos South L.G.A

The groundwater potentiality of Jos-South was carried out by analyzing the surface features. The weightages of surface features contributing to groundwater prospects in the study area were evaluated by pair-wise comparison using Analytical Hierarchy Process (AHP). The thematic maps of the surface features contributing to groundwater were produced in ArcGIS 10.1 environment and the results are presented in Figures 4.1 to 4.10 while the weightages of the factors are represented in Tables 4.1 to 4.7

4.2.1 Elevation

The 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 weights of elevation and potentiality for groundwater prospects in the area of study.

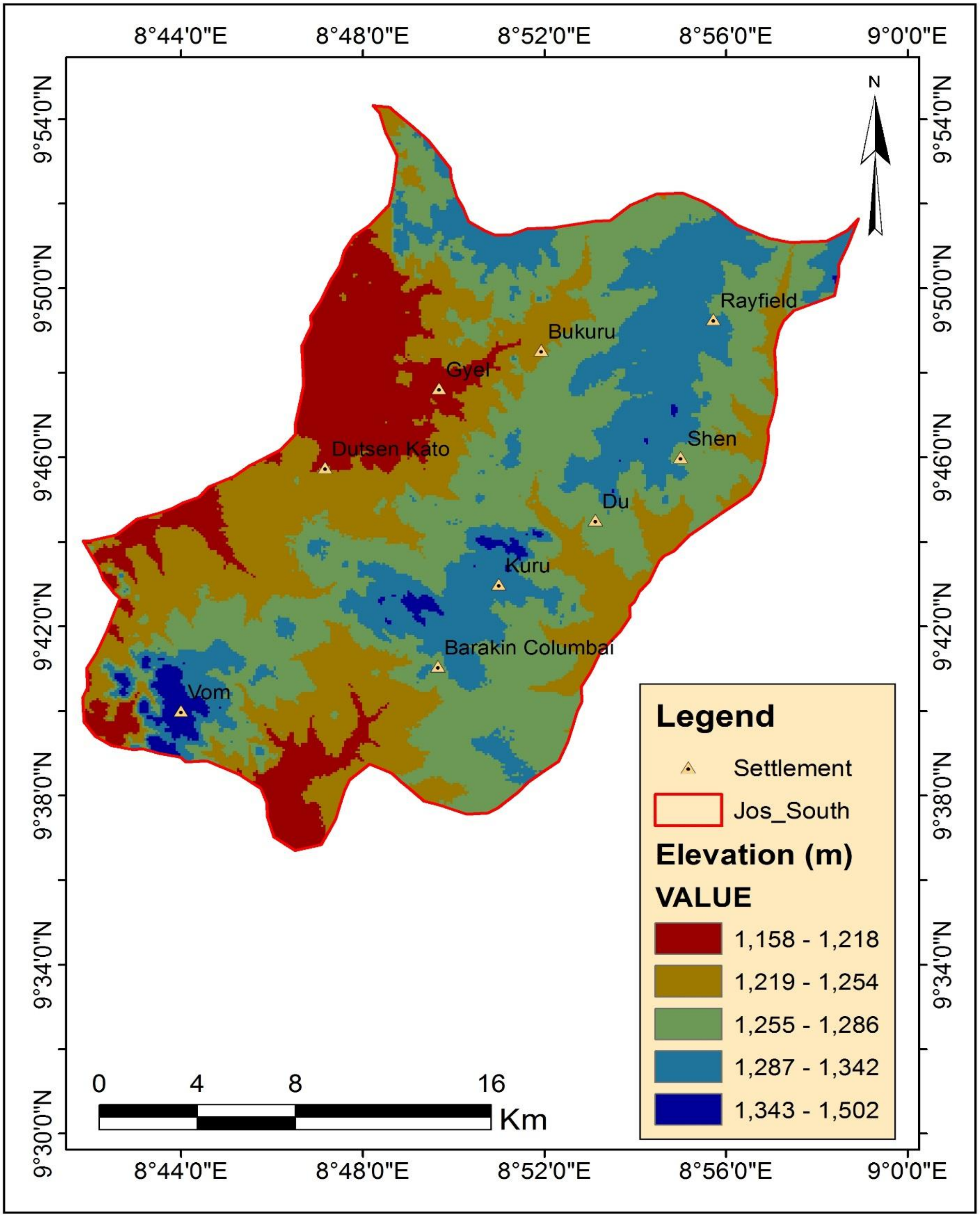

Figure 4.1: Elevation Digital Model of Jos-South L.G.A.

Source: Author's Analysis, (2016)

Table 4.1: Groundwater Potential for Topography in Jos-South L.G.A.

Elevation	1158-1218	1219-1254	1255-1286	1287-1342	1342-1502	Weightage	Potential
1158-1218	1	3	4	5	7	0.49	Very High
1219-1254	1/3	1	1	3	5	0.20	High
1255-1286	1/4	1	1	3	5	0.19	Moderate
1287-1342	1/5	1/3	1/3	1	3	0.08	Low
1342-1502	1/7	1/5	1/5	1/3	1	0.04	Very Low

Consistency Ratio=0.04

The result shows that areas with low elevation (1158m-1218m) values have very good groundwater potential and places on high elevation have low water potential. This is because places on low elevation will give more chance for groundwater accumulation (Solomon, 2003). Topographic data is a vital element in determining the water table elevations (Sener, Davraz and 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 940-974 mm 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 1,112 – 1,180mm. A pair wise comparison and reclassification was carried for the mean annual precipitation of the study area using AHP and the result is presented in Table 4.2.

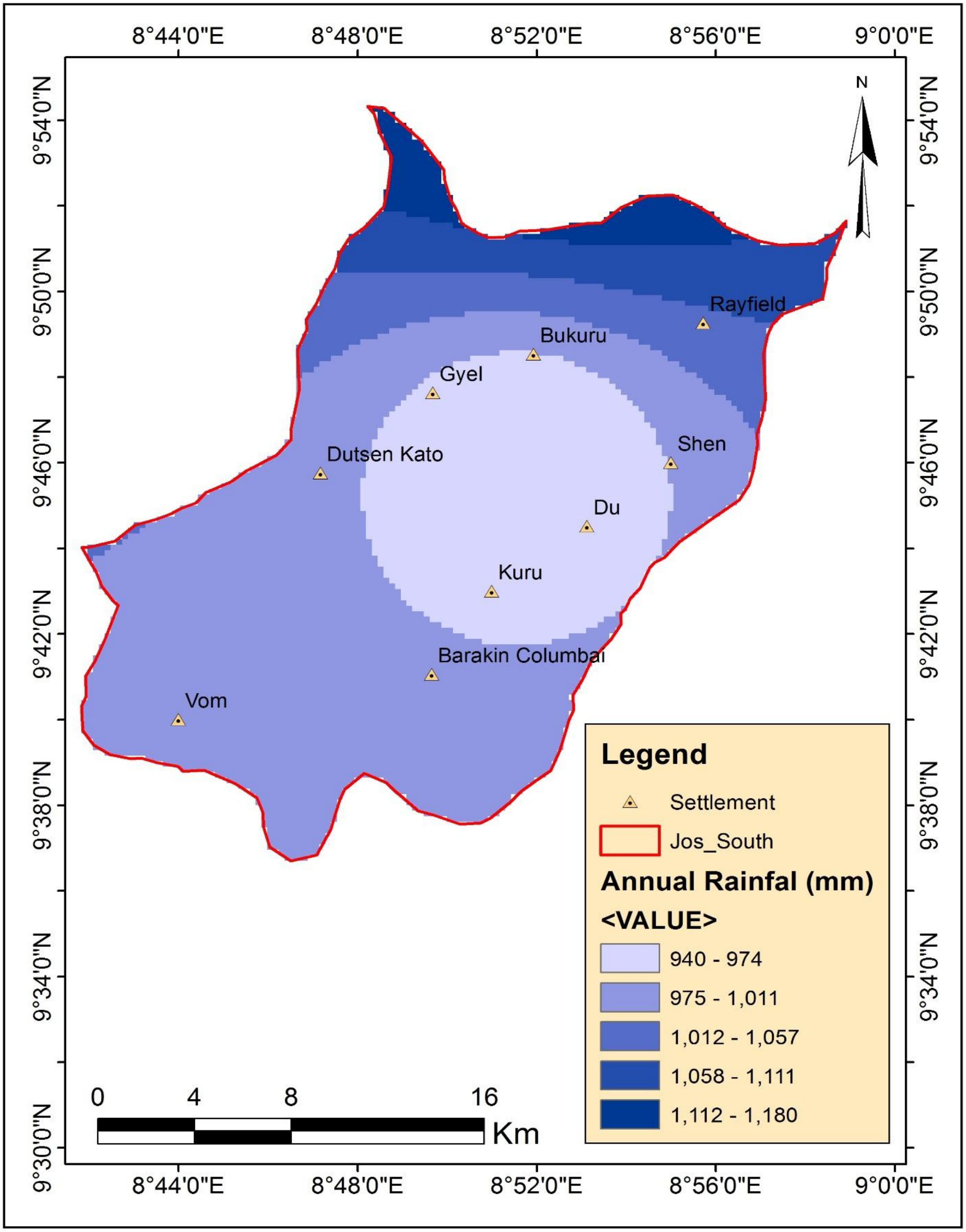

Figure 4.2: Average Annual Rainfall of Jos-South L.G.A.

Source: Author’s Analysis, (2016)

Table 4.2: Groundwater Potential for Rainfall in Jos-South L.G.A.

Rainfall	940-974	975-1011	1012-1057	1058-1111	1112-1180	Weightage	Potential
940-974	**1**	2	2	2	2	0.11	Very Low
975-1011	1/2	**1**	2	2	2	0.14	Low
1012-1057	1/2	1/2	**1**	2	2	0.19	Moderate
1058-1111	1/2	1/2	1/2	**1**	2	0.24	High
1112-1180	1/2	1/2	1/2	1/2	**1**	0.32	Very High

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 the groundwater. Table 4.2 shows that the high rainfall amounts imply the possibility of high groundwater recharge and vice versa. The area characterized by high rainfall amount shows high groundwater potential zones

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 and is represented in Table 4.3.

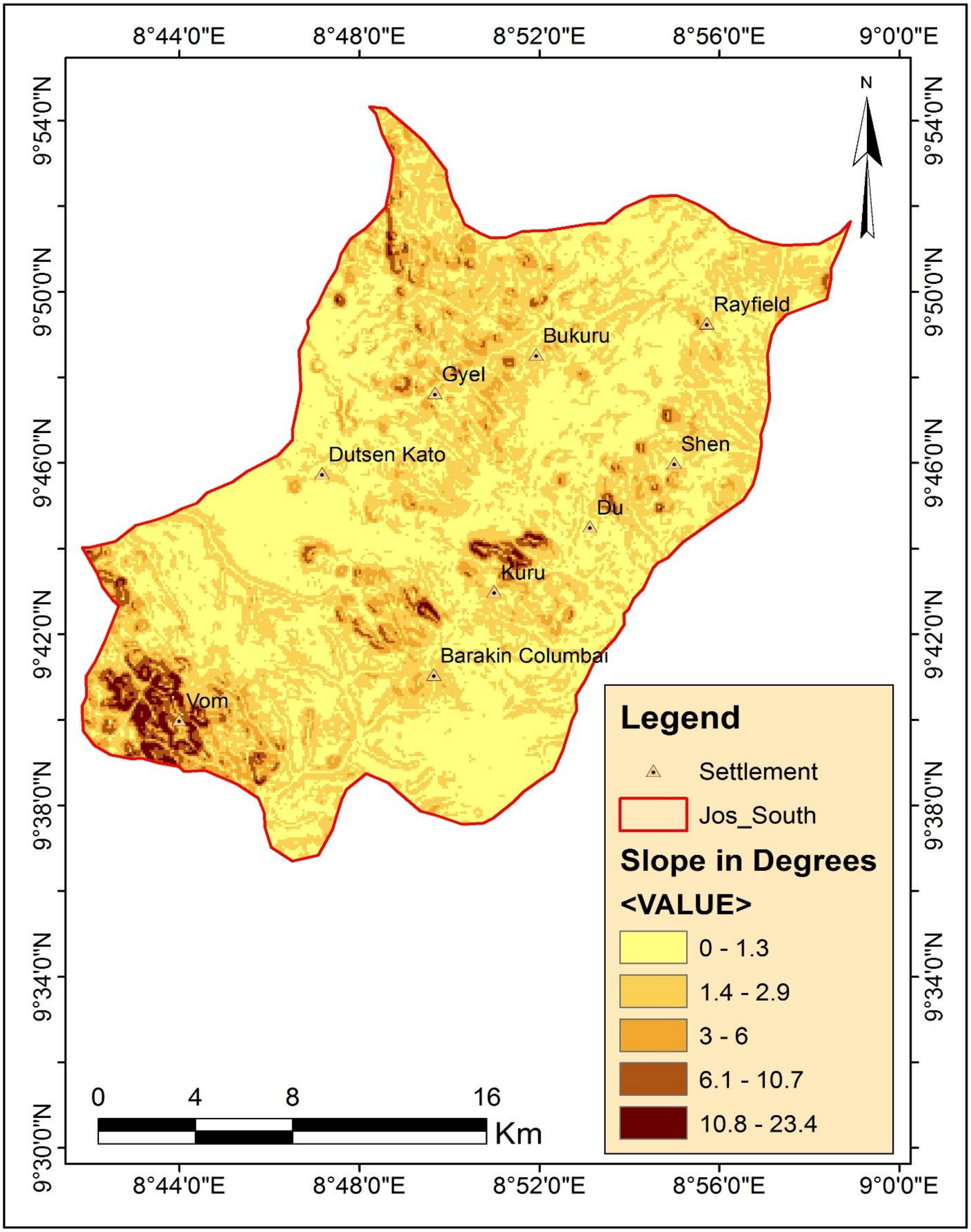

Figure 4.3: Slope Steepness of Jos-South L.G.A.

Source: Author's Analysis, (2016)

Table 4.3: Groundwater Potential for Slope Jos-South L.G.A

Slope (%)	0-1.3	1.4-2.9	3-6	6.1-10.7	10.8-23.4	Weightage	Potential
0-1.3	1	2	5	7	9	0.47	Very High
1.4-2.9	1/2	1	3	5	9	0.30	High
3-6	1/5	1/3	1	3	7	0.14	Moderate
6.1-10.7	1/7	1/5	1/3	1	5	0.07	Low
10.8-23.4	1/9	1/9	1/7	1/5	1	0.03	Very Low

Consistency Ratio=0.06

In Table 4.3 it is clear that areas that have the value of slope ranging from 0-1.3% have very good groundwater potential and those areas with high slope ranging from 10.8-23.4% have low water potential. 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. Also figure 4.3 shows that Vom is highly sloppy while Bukuru, Barkin Columbai and Dutsen Kato are on low elevation

4.2.4 Drainage Network and Drainage Density

The drainage density was calculated directly in Arcmap using spatial analyst extension. In the study area, mainly five (5) drainage density classes were identified and mapped. The drainage network is presented in Figure 4.4 and the Figure 4.5 represents the drainage density of the study area, also the weightages is shown in Table 4.4.

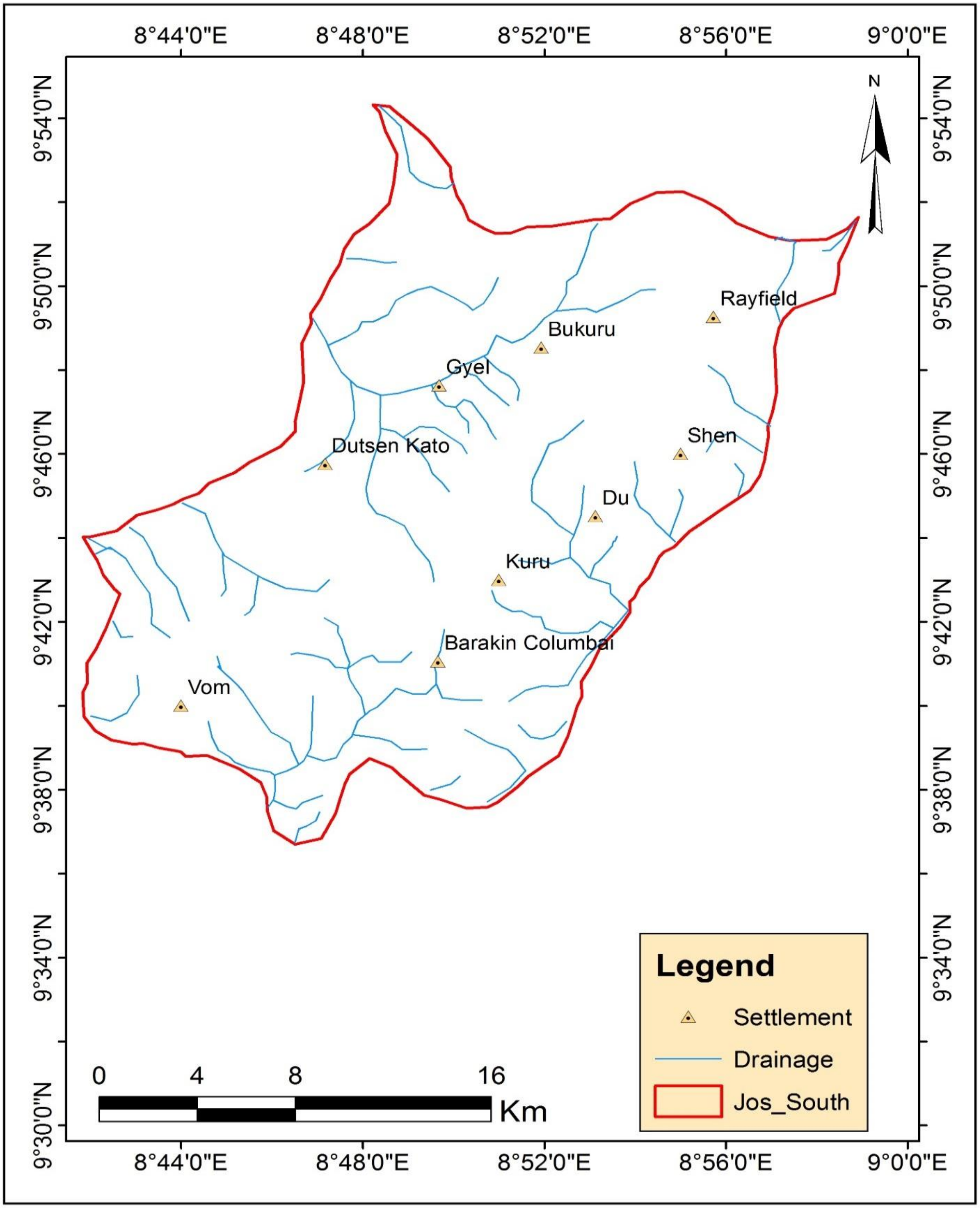

Figure 4.4: Drainage Network of Jos-South L.G.A.

Source: Author's Analysis, (2016)

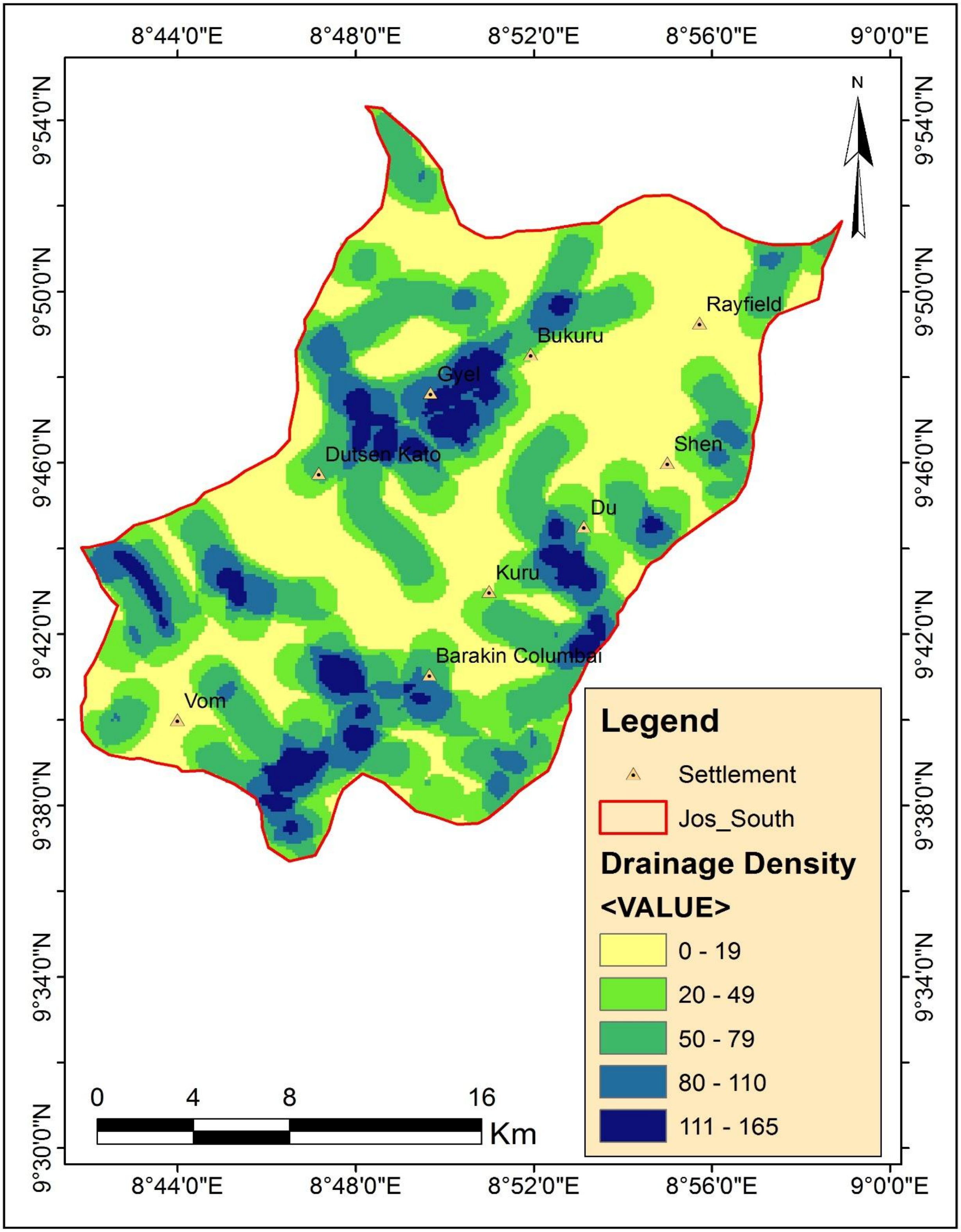

Figure 4.5: Drainage Density of Jos-South L.G.A.

Source: Author's Analysis, (2016)

Table 4.4: Groundwater Potential for Drainage Density (DD)

DD	0-19	20-49	50-79	80-110	110-165	Weightage	Potential
0-19	1	6	4	6	6	0.49	Very High
20-49	1/6	1	2	1	2	0.26	High
50-79	1/5	1/3	1	2	4	0.12	Moderate
80-110	1/3	1/6	1/2	1	6	0.07	Low
110-165	1	1/2	1/4	1/6	1	0.05	Very Low

Consistency Ratio=0.06

Very high drainage density is found in the western, eastern and southern part of the study area whereas high drainage density is found scattered in all parts of the area. Moderate and low drainage density concentrates in the northern and central part of the project area. Table 4.4 shows that higher drainage density relates to low groundwater potential and vice versa.

According to Tewodros (2005) drainage density with respect to groundwater potential is determined by analyzing the drainage density calculated using the stream length within grid area. Higher the drainage density the lesser the infiltration capacity that is low void ratio of the terrain which in turn the lesser the groundwater potentiality. This is because much of water coming as rainfall goes as run off. In general drainage density is an important parameter that control groundwater occurrence and distribution.

4.2.5 Lineament and Lineament Density

Mapping of lineaments in this study was done by visual interpretation of various digitally enhanced single band and multi band images that involves standard band combinations, principal component analysis and directional filtering, since 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. Lineament features were interpreted from satellite imagery. In the imagery they were identified on the basis of break of slope, truncation of terraces knick points, abrupt change in stream course, lithology, vegetation, texture, drainage density etc. Figure 4.6 represents the lineament map and Figure 4.7 represents the lineament density map. Table 4.5 shows the weightages of the lineament density

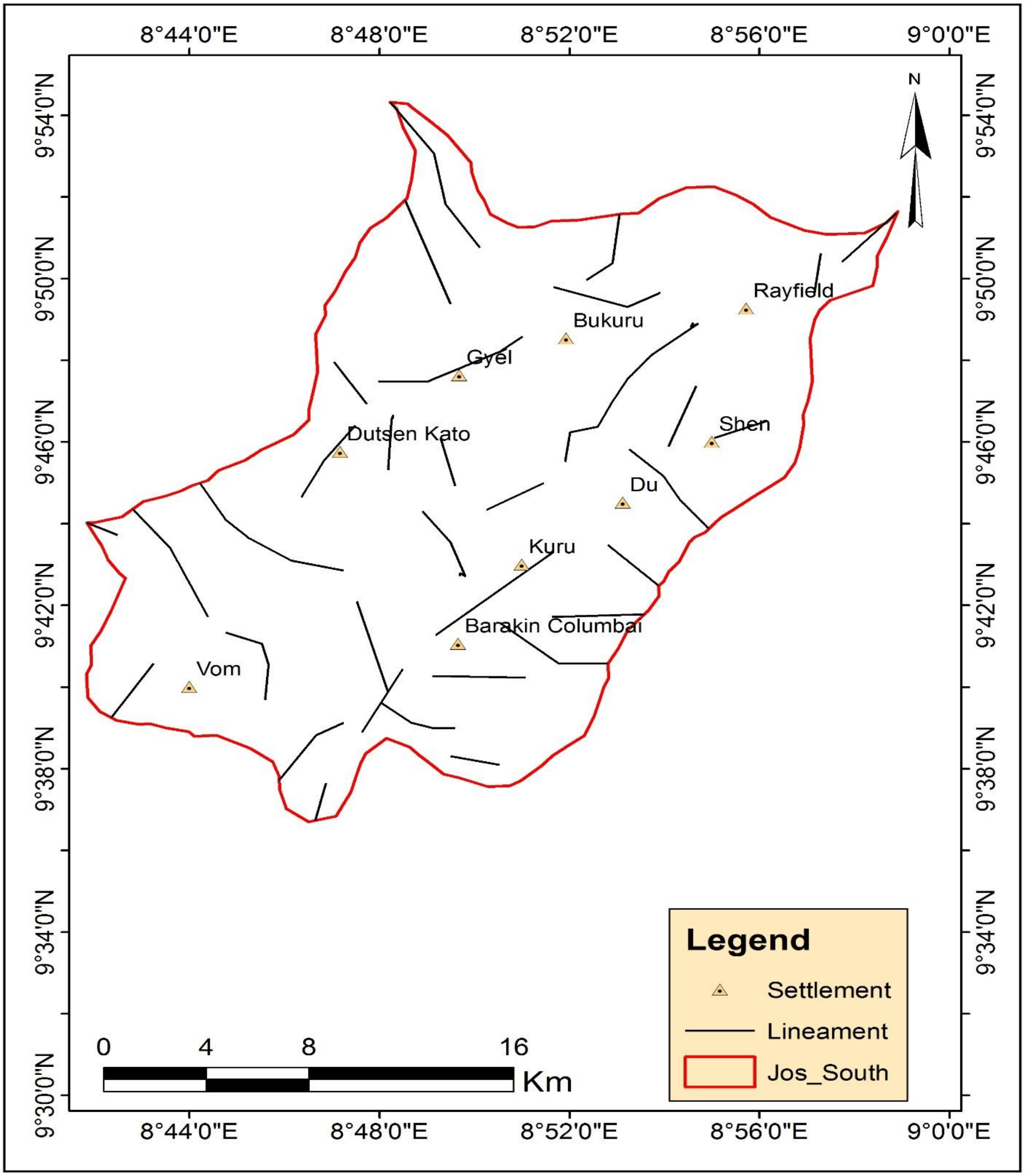

Figure 4.6: Lineament of Jos-South L.G.A.

Source: Author’s Analysis, (2016)

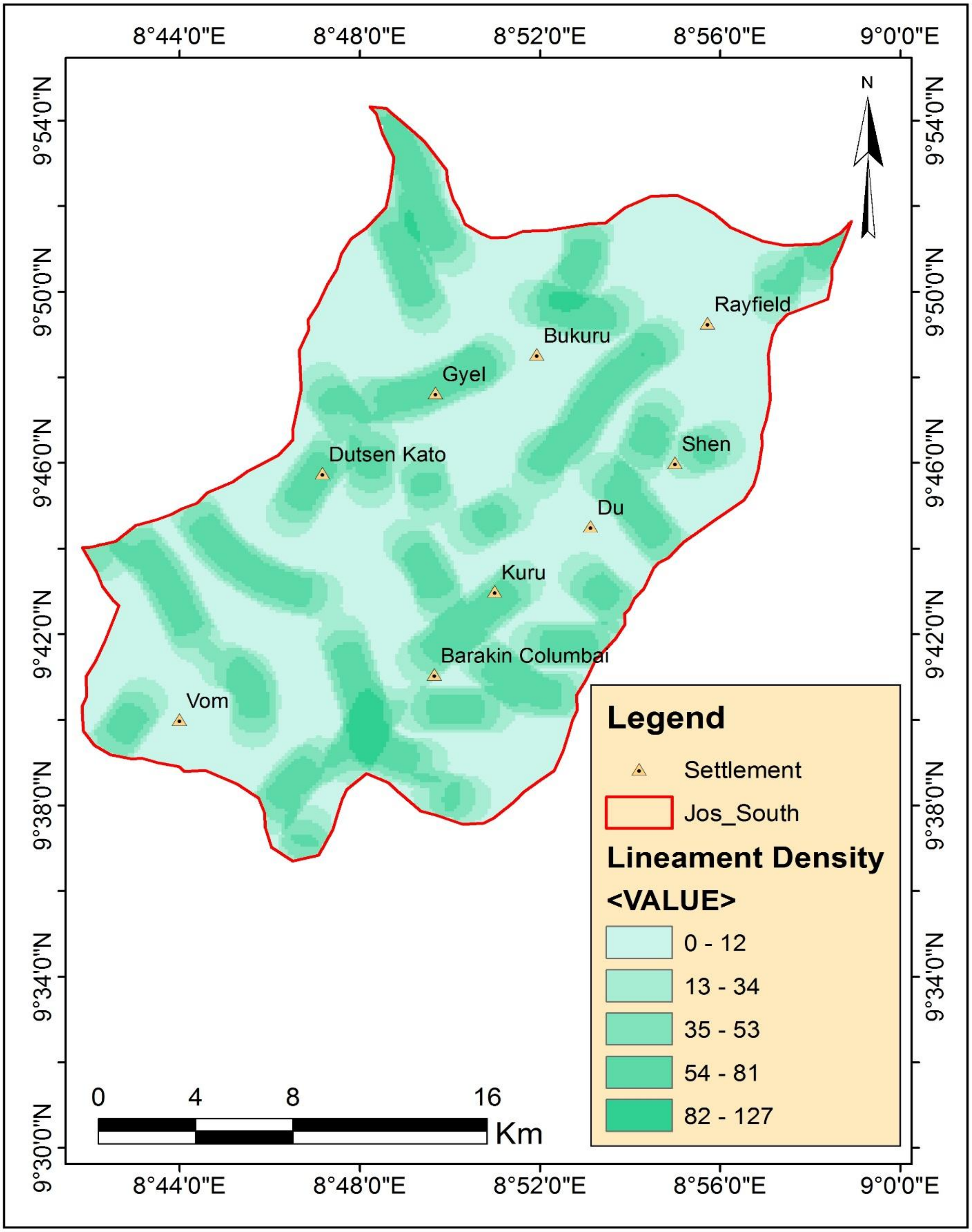

Figure 4.7: Lineament Density of Jos-South L.G.A.

Source: Author’s Analysis, (2016)

Table 4.5: Groundwater Potential for Lineament Density (LD)

LD	0-12	13-34	35-53	54-81	82-127	Weightage	Potential
0-12	1/9	1/7	1/5	1/3	1	0.03	Very Low
13-34	1/7	1/5	1/3	1	3	0.06	Low
35-53	1/5	1/3	1	3	5	0.13	Moderate
54-81	1/3	1	3	5	7	0.26	High
82-127	1	3	5	7	9	0.51	Very High

Consistency Ratio=0.08

The pair-wise comparison was done based on the fact that areas closer to lineaments are the highest zone of increased porosity and permeability which in turn have greater chance of accumulating groundwater. Figure 4.6 shows that lineament feature are distributed in all parts of the study area and Table 4.5 reveals that lineament density ranging between 82 and 127 have very high groundwater potential while the range between 0 and 12 have very low potential.

From the ground water point of view lineament features includes valleys controlled by folding, faulting and jointing, hill ranges and ridge lines, abrupt truncation of rocks, straight segments of streams and right angled offsetting of stream courses as these linear features are commonly associated with dislocation and deformation they provide the pathways for groundwater movements (Small, 1970). Lineaments are important in rocks where secondary permeability and porosity dominate the intergranular characteristics combine in secondary openings influencing weathering, soil water and ground water movements. The fracture zones forms an interlaced network of high transmission and acts as ground water conduits in massive rocks in inter fractured areas. The lineament intersection area are considered to be good ground water potential zones. The areas with higher lineament density and topographically low elevated grounds are considered to be the best aquifer zones.

4.2.6 Landuse/Landcover

One of the parameters that influence the occurrence of groundwater is the landcover and landuse of the area. The landuse and landcover map was generated from the Landsat imagery by supervised classification and shown in Figure 4.8 and the weightages is shown in Table 4.6.

Table 4.6: Percentage Areal Coverage of LULC Jos-South L.G.A. in 2015

LULC	Area in Sq. Km	%
Vegetation	101.68	20.6
Farmland	257.45	52.1
Bare Land	25.56	5.2
Build-up Areas	105.72	21.4
Water body	3.54	0.7
Total	**493.95**	**100**

Source: Author's Analysis, 2016

The result shows that Jos-South occupies an area of 493.95 sq. km of which farmland occupies the highest with 257.45 sq. km (52.1%). This is followed by built-up areas with 105.72 sq. km (21.4%), vegetation cover 101.86 sq. km (20.6%), bare land and water body occupies the least with the coverage of 25.56sq. km (5.2%) and 3.54sq. km (0.7%) respectively.

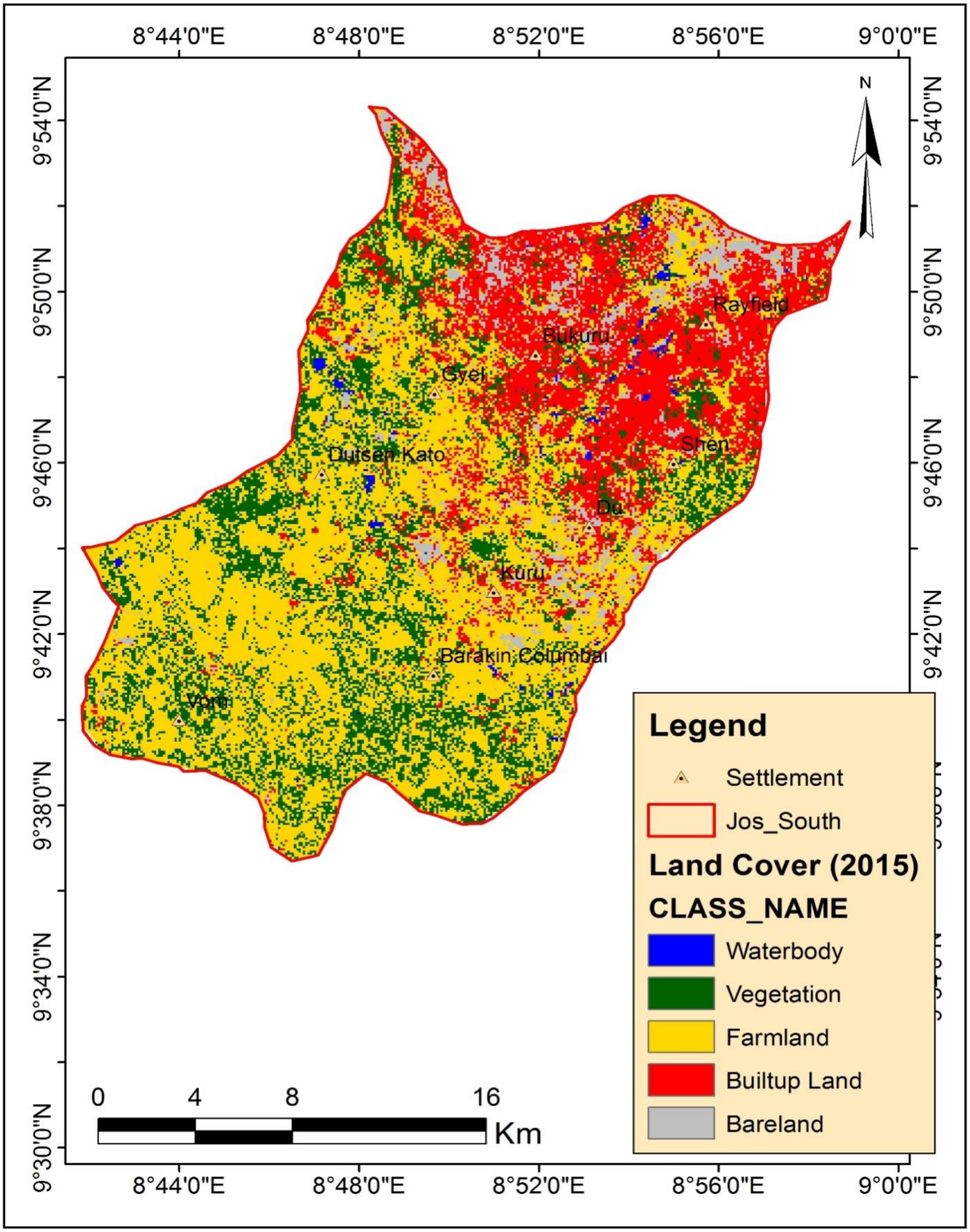

Figure 4.8: Landuse/Landcover of Jos-South L.G.A.

Source: Author's Analysis, (2016)

Table 4.7: Groundwater Potential for Landuse/Landcover

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

Consistency Ratio=0.12

From Table 4.7, 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 had low and very low ground water potential respectively.

The LULC of an area provides important indications of the extent of groundwater requirement and utilization. The effect of land use/cover is demonstrated either by reducing runoff and facilitating, or by trapping water on their leaf. 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. From the point of view of land use, farmland with vegetation is an excellent site for groundwater exploration (Todd and Mays, 2005). The area with water bodies is good for groundwater recharge while built-up land is poor for it. Chowdary *et al.* (2009) stated that sixty percent of the area covered by forest, farmland land and water bodies are favorable for groundwater potential.

4.2.7 Soil

The soil influences groundwater recharge depending on the texure, grain size, and porosity. Soil can go a long way in influencing the infiltration of water. The soil map of the area was generated and classified according to Food and Agricultural Organization (FAO) standard in 2003. The soil of the study area includes the leptosols, cambisols and acrisols, as shown in Figure 4.9 while Table 4.8 represents the weight of groundwater potentiality in the study area.

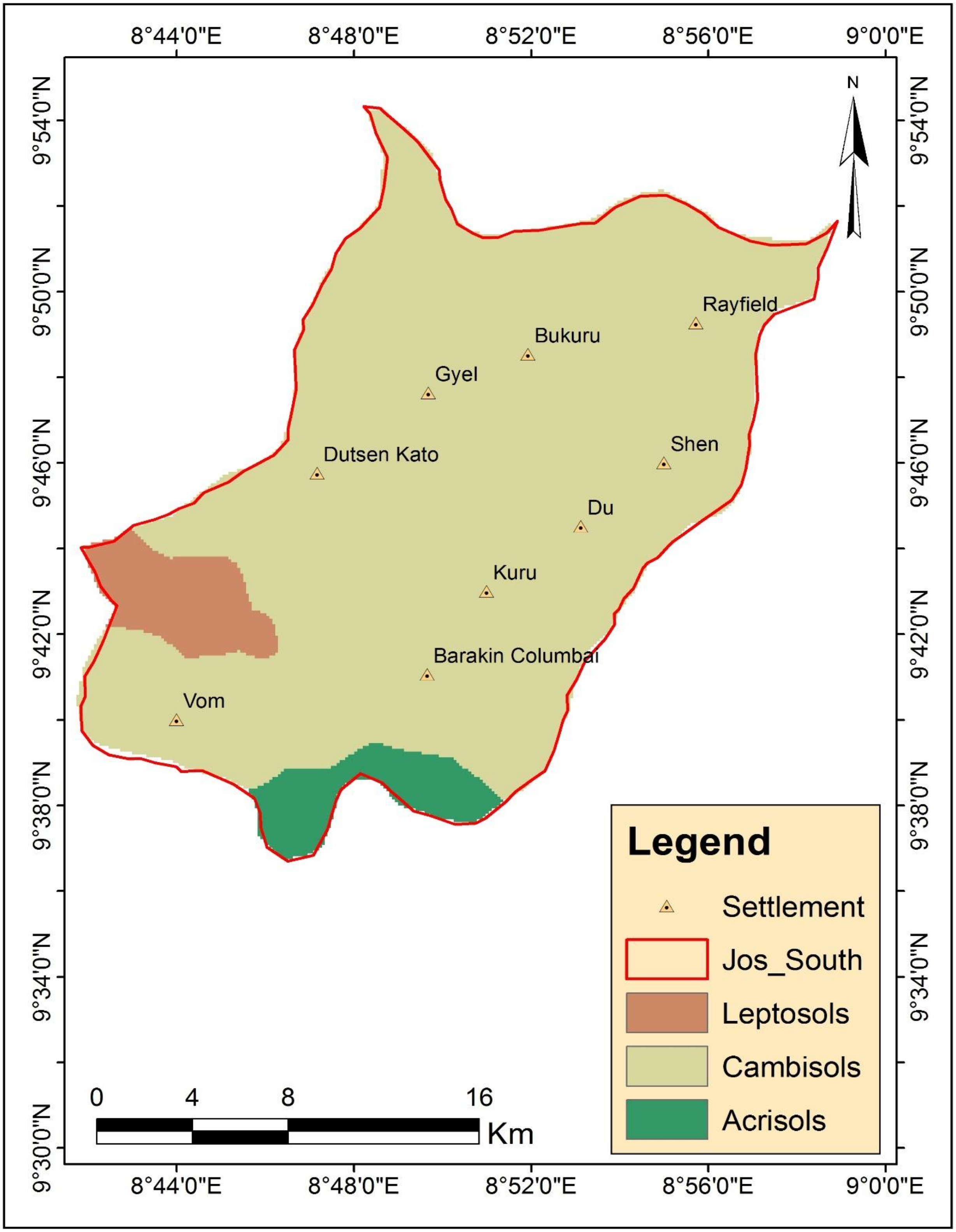

Figure 4.9: Soil Types of Jos-South L.G.A.

Source: Author's Analysis, (2016)

Table 4.8: Groundwater Potential for Soil

Soil	Cambisols	Acrisols	Leptosols	Weightage	Potential
Cambisols	1	3	5	0.64	High
Acrisols	1/3	1	3	0.26	Moderate
Leptosols	1/5	1/3	1	0.1	Low

Consistency Ratio=0.04

The result of the pair-wise comparisons shows that cambisols have high infiltration rate and the acrisols have moderate potentiality to groundwater. The leptosols have low groundwater potential. According to Tewodros (2005) 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.

According to Tewodros (2005) most Cambisols are medium-textured and have a good structural stability, a high porosity, and good water holding capacity and good internal drainage. Most Cambisols also contain at least some weatherable minerals in the silt and sand fractions. Based on these characteristics, Cambisols have good infiltration capacity to recharge groundwater. On the other hand, leptosols are found in all climatic zones, particularly in strongly eroding areas and are and implicit low water holding capacity.

4.2.8 Geology

Geology of an area plays a vital role in the distribution and occurrence of ground 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 weight is presented in Table 4.9

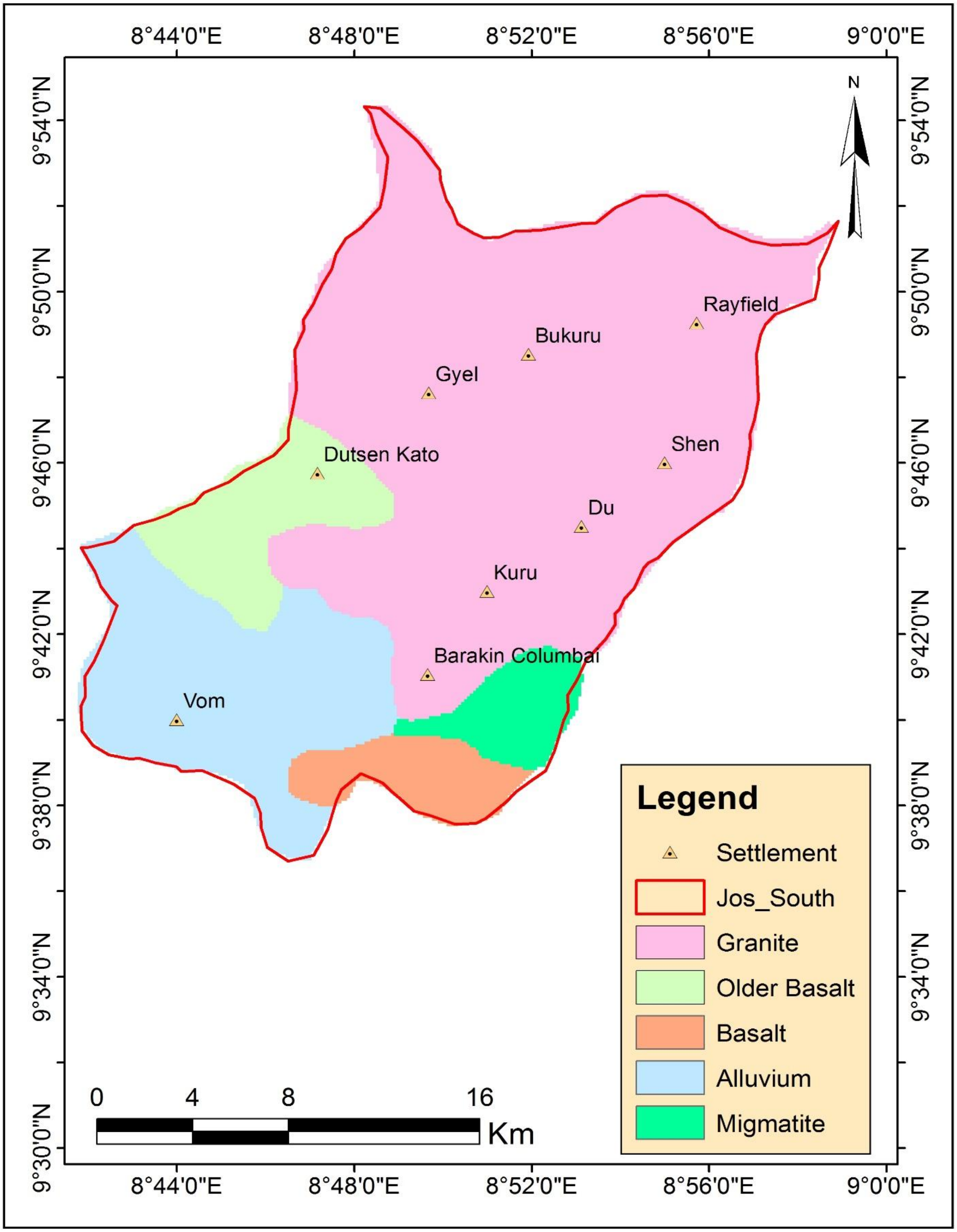

Figure 4.10: Geology of Jos-South L.G.A.

Source: Author's Analysis, (2016)

Table 4.9: Groundwater Potential for Geology

LULC	Alluvium	Basalt	Older Basalt	Granite	Migmatite	Weightage	Potential
Alluvium	1	2	3	5	7	0.41	Very High
Basalt	1/2	1	3	5	7	0.31	High
Older Basalt	1/3	1/3	1	3	5	0.16	Moderate
Granite	1/5	1/5	1/3	1	4	0.07	Low
Migmatite	1/7	1/7	1/5	1/4	1	0.04	Very Low

Consistency Ratio=0.04

Five (5) major rock exposures were identified in the study area. They are the alluvium, basalt, older basalt, granite and migmatite. It can be seen from Table 4.10 that the alluvium have very good groundwater potential, the basalt have good groundwater potential while the older basalt have a moderate potential. The granite and migmatite have low and very low groundwater potential respectively.

4.3 Distribution Pattern of Groundwater Potential Zones in Jos South L.G.A.

The groundwater potential zones in Jos South L.G.A. were determined from the integration of all the thematic maps of the contributing surface features of groundwater recharge. The weight of the surface features was carried out using Analytical Hierarchy process according to Saraf and Choudary (1998). Table 4.9 represents the weight of the surface features of ground water-recharge

Table 4.10: Weightages of the Surface features of Groundwater Potential

	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	1/2	1	2	3	4	5	0.10	10
Elevation	1/5	1/5	1/2	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	1/4	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, 2016

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 with (2%). Groundwater prospect zones within the study area presented in Figure 4.11

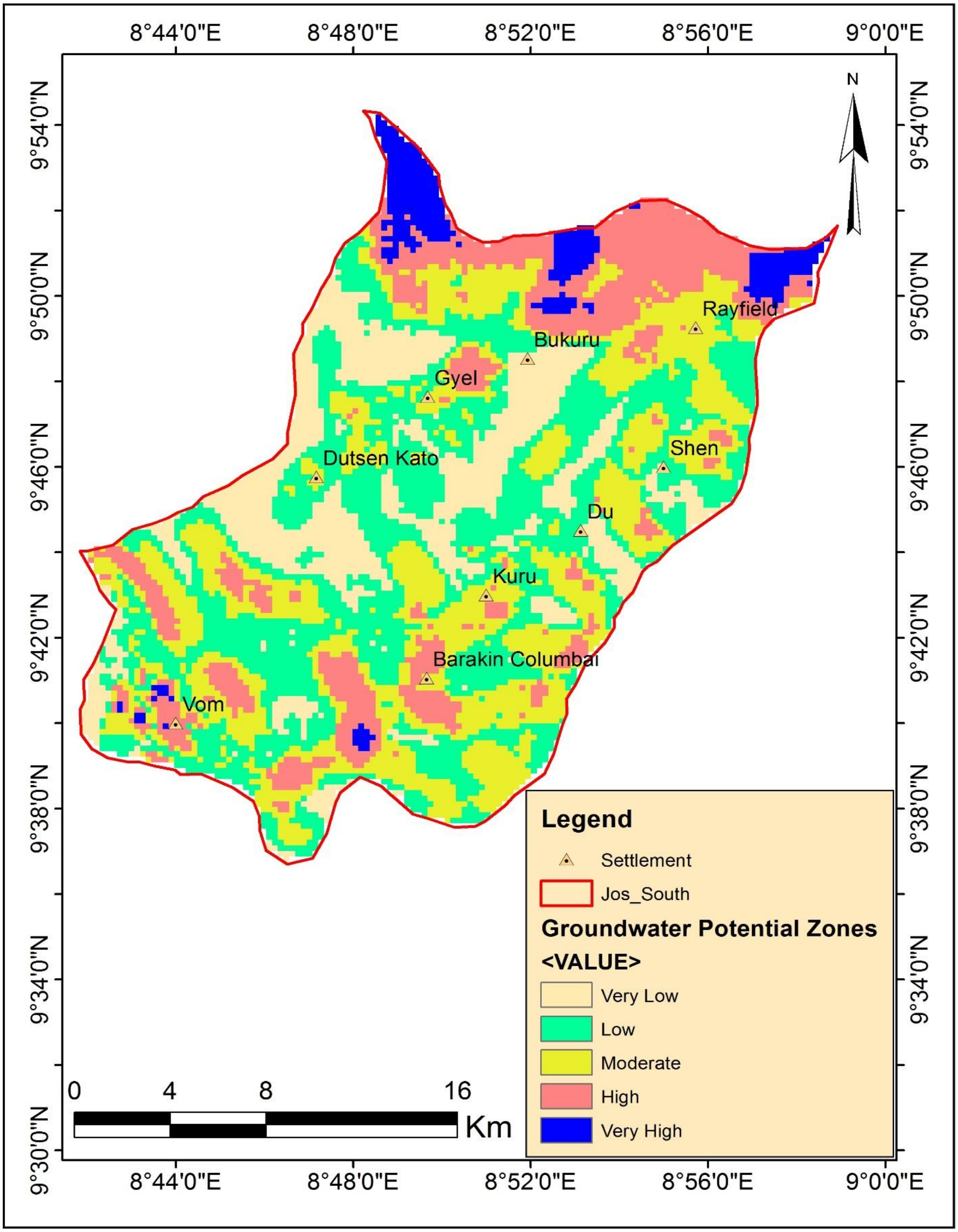

Figure 4.11: Groundwater Potential Zones of Jos-South L.G.A.

Source: Author’s Analysis, (2016)

Figure 4.11 shows the five (5) different potentiality of ground water within area of study and they are classified into very low, low, moderate, high and very high. The result shows that the northern area with very high groundwater potential is characterized by high rainfall, low slope and dominated with cambisols which have a relative high water holding capacity. The central areas with very low ground water potential is characterized by low rainfall, moderate slope, low lineament density, high drainage density and dominated by granite which has low ground water potential. It can be observed from the result that high rainfall and high slope are the major factors contributing to ground water potential in the study area as places with high rainfall and low slope were found to be the areas with very high groundwater potentiality.

It can also be observed from Figure 4.11 that the pattern of distribution of the very high groundwater potential is located mainly within the northern areas and few pockets in the Southern part. The moderate and low groundwater potential are scattered all over the study area while the very low is found in central areas.

4.4 Relationships between result Obtained Using Geospatial Technique with that of Geophysical Technique

The relationship between the result of Remote Sensing and GIS technology was determined with that of electrical resistivity. Nine (9) electrical resistivity (one for each location) in Vom, Rayfield, Dutsen Kato, Barkin Columbai, Bukuru, Gyel, Kuru, Du and Shen were overlaid on the groundwater potential map generated from the integration of the various thematic maps. Figure 4.12 shows the overlay of the VES points on the groundwater potential zones and Table 4.11

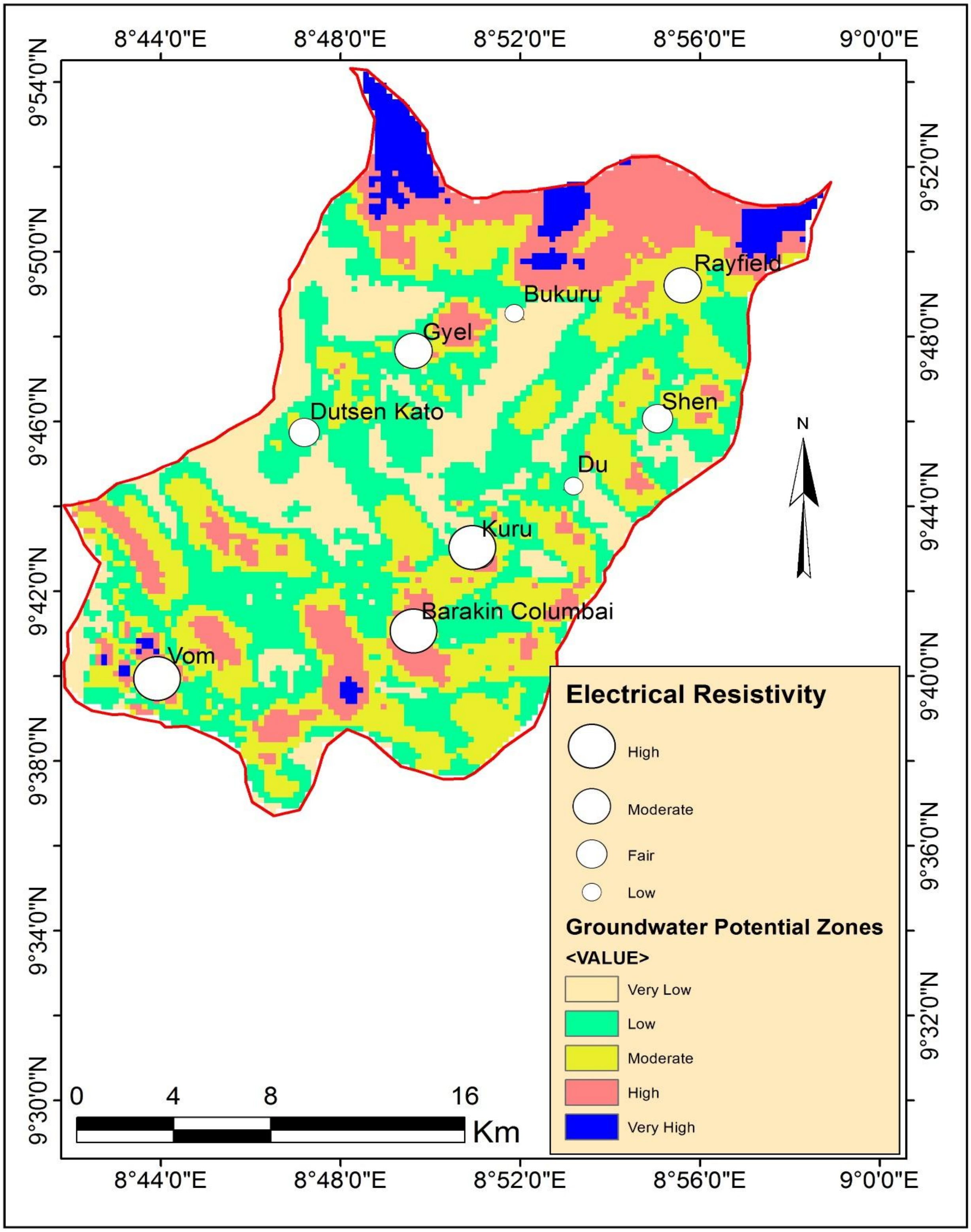

Figure 4.12: Overlay of VES on Groundwater Potential Zones of Kachia L.G.A.

Source: Author’s Analysis, 2015

Table 4.11: Groundwater Potentiality of Electrical Resistivity against Remote Sensing and GIS.

			Electrical Resistivity		GIS
LAT	**LONG**	**Location**	**Aquifer Thickness (m)**	**Groundwater Potential**	**Groundwater Potential**
9.666667	8.733333	Vom	45	High	Very High
9.766667	8.916667	Shen	35	Moderate	Fair
9.833333	8.900000	Rayfield	35	Moderate	Moderate
9.716667	8.850000	Kuru	40	High	Moderate
9.783333	8.850000	Gyel	30	Fair	Low
9.750000	8.783333	Dutsen Kato	25	Low	Very Low
9.750000	8.883333	Du	25	Low	Very Low
9.80000	8.866667	Bukuru	40	High	High
9.684505	8.828122	Barakin Columbai	40	High	High

Source: Field Survey, (2016)

It is observed from result obtained from electrical resistivity shown in Table 4.11 that areas with larger value of aquifer thickness have high groundwater potential and areas with low aquifer thickness have low groundwater potential. It can also be seen that Vom which has aquifer thickness of 45m has high groundwater potential from electrical resistivity also have very high ground water from GIS method. On the other hand, Dutsen Kato and Du which both have aquifer thickness 25m each was found to have low groundwater potential by resistivity method and very low from the GIS and remote sensing technique. The result obtained from this study is not different from the observation of Oyedele, (2012) that concluded that areas characterized by aquifer thickness greater than 30m generally indicates good Groundwater Potential.

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 Jos-South Local Government Area, Plateau State.

5.2 Summary of Findings

This study was aimed to investigate the groundwater potential zones in Jos-South L.G.A. The study was carried out to examine the characteristics of groundwater potential zones in 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 groundwater potential zone was validated by determining the relationship between the results obtained using geospatial technique with that of geophysical survey using some point settlement in Jos-South L.G.A.

The result of the findings shows 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 that influence groundwater prospects in the study area shows that rainfall and lineament density were weighed the highest with 34% and 24% respectively, meaning that lineament density is the major contributor for ground water

prospecting in the study area. Drainage density and landuse/landcover were weighed the least with 2% and 3% respectively.

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

d) Very good groundwater potential zones constitutes 14.1%, good potential constitute 22.4%, moderate occupies 15.0% while fair and low constitute of 23.9% and 24.6% respectively.

5.3 Conclusion

In this study, an integrated approach using GIS and remote sensing was adopted to find the potential sites for groundwater exploration in the alluvial aquifer. A weighted overlay model was implemented using eight different effective weighted parameters including; annual rainfall, geology, lineament density, soil, elevation, slope, land cover and drainage density. The groundwater potential map was obtained by algebraic summation of these effective parameters being multiplied by their effective weights. 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.

The final map of groundwater potential zones produced shows that the pattern of distribution for areas classified as very high potential zones are located within the Northern areas around Bukuru and Northeastern areas around Rayfield while areas with the high potential lie in the North central and Southern part around Gyel and Barakin Colombai respectively. The moderate and low groundwater potential areas are scattered all over the study area while very low groundwater potential areas are found in central areas around Dutsen Kato.

5.4 Recommendation

Proper groundwater management must be done for meeting the ever growing demand for water in the study area.

a) Since the very good groundwater potential zones were identified in the northern and southern parts of the study area, it is important that the decision makers consider these areas when caring out ground water exploration.

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

c) The scarcity of water in Jos South Local Government Area of Plateau State warrants for a detailed investigation of the ground water potential characteristics of the area so that an exploration guide as well as sustainable groundwater management strategy can be developed.

d) Remote sensing data and GIS are powerful tools to improve our understanding of groundwater systems. They provide continuous detailed terrain information and allow the mapping of features significant to groundwater development therefore it is important to incorporate them in the data collection stage of groundwater exploration works.

e) There is the need for accurate estimate of the available subsurface resources for the importance of proper planning to ensure the continued availability of water.

f) Results obtained from the present study work are very good. Therefore, more study should be done such as groundwater recharge, groundwater pollution in order to protect the groundwater potential zone.

REFERENCES

Abel, O. T., and Monshood, N. T. (2011) Integrated remote sensing and GIS approach to groundwater potential assessment in the basement terrain of Ekiti area south western Nigeria. *Material and Geo environmental Journal*, 58 (3) 303-328

Abiola, O., Enikanselu P. A. and Oladapo M. I., (2009). Groundwater Potential and Aquifer Protective Capacity of overburden Units in Ado-Ekiti, southwestern Nigeria. *International Journal of Physical Sciences* Vol. 4 (3), pp. 120-132, March, 2009. Available online at http://www.academicjournals.org/IJPS ISSN 1992 - 1950

Abubakar, Y. I. and Auwal, L.Y. (2012) Geoelectrical Investigation of Groundwater otential of Dawakin Tofa Local Government Area of Kano state Nigeria. *American International Journal of Contemporary research*, 2 (9) sept.2012

Ademilua, O.L., (1997). A Geoelectric and Geologic Evaluation of Groundwater Potential of Ekiti and Ondo States, Southwestern Nigeria. Unpublished M.Sc. Thesis, Department of Geology, Obafemi Awolowo University, Ile Ife, Nigeria, Pp1-67

Adams, W.M (1992) *Green Development Environment and Sustainability in the third World. London Routledge.*

Adanu E.A. (1989). Hydrogeology of the Base Complex Terrain in the Zaria-Kaduna Area; pp 75 published by Technischen Universitat, Berlin.

ADB (2001) *water for all:* The water policy of the Asia development Bank.

Ademilua, O.L., (1997). A Geoelectric and Geologic Evaluation of Groundwater Potential of Ekiti and Ondo States, Southwestern Nigeria. Unpublished M.Sc Thesis, Department of Geology, Obafemi Awolowo University, Ile Ife, Nigeria, Pp1-67

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*, Vol. 8 No. 1/2, pp. 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*, Vol. 14, Pp. 1284-1306. *Journal of Contemporary Research* Vol. 2 No. 9; pp. 188-197.

Ader, H.J., Mellerbergh, G.J. and Hand, D.J.(2008) *Advising on research Methods:* A consultant .Huizen.Therlands:Johannas.Van Kessel Publishing.Wikepedia, the free encyclopedia.

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.

Adiuku Brown M.E., (1999). The Danger Posed by the Abandoned Mine Ponds and Lotto Mines on the Jos Plateau. *A journal of Environmental Science 3(2). Pp 258-265.*

Aditi D.R and Tushaar S. (2002) The Scio Ecology of Groundwater in India. *Water policy Briefing IWMI–Tata water policy program.* Issue 4 www iwmi.org/org/iwmi-tata.

Ahmed, K. (2003) *Kano Environment:* A publication of **Kano** Forum

Ajayi J.O Sonuga F.A Aliboh O.P Oloke D.A(2003) Sustainable Potable Water supply to Nigeria though Conjunctive Development of surface and Groundwater research. *International Journal of geosciece* 2 (23) 23-45 USGS

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

Alabi A.A., Bello R, Ogungbe A.S., Oyerinde HO (2010). Determination of Groundwater Potential in Lagos State University, Ojo; using Geo-electric Methods (Vertical Electrical Sounding and Horizontal Profiling), Rep. Opin., 2(5): 68-75.

Ali EL – Naqa, Nezar H, Khalil I. and Masdouq E. (2009) Integrate Approach for Groundwater Exploration in Wadi Arabia using Remote Sensing and GIS*: Jordan journal of civil Engineering,* 3 (3) ,2009.

Alile MO, Jegede SI, Ehigiator OM (2008). Underground Water Exploration Using Electrical Resistivity Method in Edo State, Nigeria, *Asian Journal of Earth Sci*ence, 1(1): 38-42.

Alkali, S.C., Gadzama, E.M. and Yusuf, S.N. (2011) Study of Boreholes Data from Eastern part of Mandara Hill Area in Gwoza of Northern Nigeria. *Scholars Research Library Achieves of applied Science Research,* 2 (3) 34-44

Alkali, S.C., Yusuf, K., (2010), The Danger Posed by Abandoned Mine Ponds on the Plateau. *A Journal of Environmental Science 3(2), Pp 258-265.*

Almasri M.N., Kaluarachchi J.J. (2004) Implications of on-ground Nitrogen Loading and Soil Transformations on Groundwater Quality Management. Journal of the American Water Resources Association 40(1):165–186

Amadi, A.N, Nwawulu, C. D., Unuevho, C. I.,Okoye, N. O., Okunlola, I. A., Egharevba, N. A., Ako, T. A and Alkali Y. B. (2011). Evaluation of the Groundwater Potential in Pompo Village, Gidan Kwano, Minna Using Vertical Electrical Resistivity Sounding. *British Journal of Applied Science & Technology*, 1(3): 53-66

Amaresh, K.R., Singh, T and Prakash, R. S. (2009) *Integration of Thematic Maps through GIS for identification of Groundwater potential zones in Mirzapur district India*: Remote Sensing Applications Centre U.P., Sector –G, Jankipuram, Luknow publication, India.

Anderson J.R., (1971). Landuse Classification Schemes Used in Selected Recent Geographic Applications of Remote Sensing. *Photogrammetric Engineering and Remote Sensing (PE&RS), Vol. 37, no. 4, Pp. 379-387.*

Anomohanran O. (2011). Underground Water Exploration of Oleh, Nigeria Using the Electrical Resistivity Method. Scientific Research and Essays Vol. 6(20), pp. 4295-4300. Available online at http://www.academicjournals.org/SRE accessed on 12/09/2014

Anthony, Y.and Doreen M.Y. (1977) *Slope Development*. Macmillan Education Ltd, London

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

Anudu, G.K., Essien, B.I., Onuba, N.L. and Ikpokonte, A.E. (2011) Lineament Analysis and Interpretation for Assessment of Groundwater Potential of Wamba and adjoining areas In Nassarawa State North Central Nigeria. *Journal of Applied Technology in Environmental Sanitation*, 1(2) 185-189.

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*, Vol. 10 No. 1, pp. 483-486

Arlegui, L.E. and Soriano M.A. (1998). Characterizing Lineaments from Satellite Images and Field Studies in The Central Ebro Basin (NE Spain). *Int. J. Rem. Sens*., 19: 3169-3185.

Arlosorof, S., Gerhard, T., David, W., Andrew, K.L. Otto, L. and Robered, R. (1987) *Community Water Supply. The hand pumps option; the* World Bank Washington DC 1987.

Arnold, J.G., Muttiah, R.S., Srinivasan, R. and Allen, P.M. (2000) Regional Estimation of Base Flow and Groundwater Recharge in the Upper Mississippi River Basin. *Journal of hydrology*, 22(7) 21-40

Aronoff S (1989) Geographic Information Systems: A Management Perspective. WDL Publications, Ottawa

Arun, K.S., Kundu, B. S. and Kundu, B. (2009) *Integrated Remote Sensing and GIS in Groundwater Recharge Investigation and Selection of Artificial Recharge sites in a hard rock terrain:* A publication of Indian Institute of Technology Roorkee India

Asadi, S.S, Vasantha B.V.T. Rao, Raju M.V. and Anand S. (2011). Creation of Information System for Identification of Ground Water Pollution Prevention Zones Using Remote Sensing and GIS: A Model Study. *International Journal of Emerging Technology and Advanced Engineering* Website: www.ijetae.com (ISSN 2250-2459, Volume 1, Accessd on December 2012.

Arivalagan J., Sleight V.A., Throne M.A., Peck L.S., Berland S., Marie A., Clarke= M.S., (2015) Characterisation of the Mantle Transcriptome and Biomineralisation Genes in the Blunt-gaper Clam, Mya Truncata, Mar Genom 27: 47-55. Doi:10.1016/j.margen.2016.01.003

Ayoade J.O (1975) Water Resources and Their Development in Nigeria. *Hydrological Science bulletin*. Xx1412/1975.

Ayush (2010) *Health and Family* 11th five year plan: Planning Commission of India Retrieve 19 – 09- 2010.

Baber, M.D. (2001) Hydro geomorphologic Studies by Remote Sensing Application in Akoli Watershed (Jintur) Parbhani, dist, Maherastra, India. *Spatial information Technology, Remote Sensing and GIS- ICORG*, 2 (2) 137 – 14

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, Volume 04, pp 1024-1030.

Baker CP, Bradley MD, Bobiak SMK (1993) Well Head Protection Area Delineation: Linking Flow Model with GIS. *Journal of Water Resources Planning and Management*, ASCE 119(2):275–287

Barber C, Otto CJ, Bates LE, Taylor KJ (1996) Evaluation of the Relationship Between Land-use Changes and Groundwater Quality in a Water-supply Catchment using GIS Technology: the GWELUP Well field, Western

Basagaoglu H, Celenk E, Marino MA, Usul N (1997) Selection of Waste Disposal Sites Using GIS. *Journal ofthe American Water Resources Association* 33(2):455–464

Batayneh, A.T., Elawadi E.A., Al-Arifi N.S. (2010). Use of Geo-Electrical Technique for Detecting Subsurface Fresh and Saline Water: A Case Study of The Eastern Gulf of Aqaba Coastal Aquifer, *Jordan Journal for Coastal Resource.,* 26(6): 1079-1084.

Batayneh, A.T. (2009). A Hydro-Geophysical Model of Relationship Between Geo-electric and Hydraulic Parameters, *Central Jordan, J. Water Res. Prot*., 1(6): 400-407.

Batelaan O, Smedt FD (2001). WetSpass: a Flexible, GIS Based, Distributed Recharge Methodology for Regional Groundwater Modeling. Proceedings of a Symposium Held During the Sixth IAHS Scientific Assembly at Maastricht, The Netherlands, July 2001, IAHS Publication 269, pp. 11–17

Batmanghelidji (2004) *Your Body Many Cries For Water Beta 3/C/ Importance Of Water* 3. Htm.

BBC News World (2007) *Healthy water living*: BBC World News online Edition Accessed February 1st; 2007, at http//news.bbc.co.uk/2/hi/Africa/40730063.stm.

Bello A.A. and Makinde V. (2009) Delineation of the Aquifer in the South-western part of the Nupe basin, Kwara State, Nigeria. *Academic Arena Journal*, 2009 1 (3)

Bernard, J. (2003) *Definition of Main Hydrological Parameter and Electrical Methods for Groundwater Magnetic Resonance Methods For Groundwater:* Short Notes on the Principle of Geophysical methods for Groundwater investigation. Terraplus.com

Benkabbour, B., E.A. Toto and Y.Fakir, 2004. Using DC resistivity Method to Characterise the Geometry and Salinity of the Plioquaternay Consolidated Coastal Aquifer of the Mamora Plain, Morocco. Environ. Geol., 45: 518-526.

Binay, K. and Uday K. (2010). Integrated Approach using Remote Sensing and Geographic Information System Techniques For Mapping of Ground Water Prospects in Lower Sanjai Watershed, Jharkhand. *International Journal of Geomatics and Geosciences*. Volume 1, No 3, 2010

Blench R., (2003). Forcast and Farmers; Coping with Climate Variabilty; The Use of Seasonal Forcasts in Southern Africa. Ashgate Studies in EnvironmentalPolicy and Practice, Hampshire, P.59

Bobba A.G., Bukata R.P and Jerome J.H (1992) Digitally Processed Satellite Data as a Tool in Determining Potential Groundwater Flow System. *Journal of Hydrology* 281 (1-2) 3-22

Bonsor Helen (2012) Huge Water Resource Exists Under Africa. *Journal of Environmental Research Letters of* British Geological survey and University College London (ULC) 11 (8).

Brunner P, Bauer P., Eugster M, Kinzelbach W (2004) Using Remote Sensing to Regionalize local Precipitation Recharge Rates Obtained from the Chloride Method. *Journal of Hydrology 294:241–250*

Buddemeier R.W and Schloss J.A (2000) *Groundwater storage and flow*, a USGS Publication Funded by Kansas Water Plan Fund Last Revision 11/21/2000.

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

Carlo, T. (1998) *Groundwater Exploration by Satellite Remote Sensing in the Syrian Arab Republic:* Part 1, General organisation of Remote sensing Syrian Arab Republic.

Chandra, A.S.B., Giridher, M.V.S.S. and Viswanadh, G.K. (2010) *Identification of Groundwater Potential Zones Using RS And GIS* .Department Of Environmental Information Study and Analyses EISA Institute Of Geography Hoag Quoc Viet R.D Cau Giay, Hanoi Vietnem.

Chandra, C., Dewashish, K., Shakeel, A., Jerome, P. and Benolt, D. (2008) Contribution of Geophysical Methods in Exploration and Assessment of Groundwater in Hard Rock Aquifers. *The third international conference on water resources and arid environments and the 1st Arab water Forum.*

Charles and Richardson (2010) Estimation of Groundwater Potential Zones Using Remote Sensing and GIS and Mapping IIS Quality *3rd Annual Conference Geospatial Intelligence Manama Bahrain,* April 2010

Cheng-HawLee, Wei-Ping C. and Ru-HuangLee (2006) Estimation of Groundwater Recharge Using Water Balance Coupled with Baseflow-recordestimation and Stable-base Flow Analysis. *Journal of Environmental Geology* no 51 PP. 73- 82

Cherkauer, D.S. (2004). Quantifying Groundwater Recharge at Multiple Scales Using PRMS and GIS. Ground Water 42(1):97–110

Choudhury, P.R. (1999). *Integrated Remote Sensing and G.I.S. Techniques for Groundwater Studies in Part Of Betwa Basin* PhD. Thesis (unpublished) Department of Earth Sciences, University of Roorkee, India.

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

Clarke K (2001) Getting Started with Geographic Information Systems. 3rd edition, Prentice Hall, NJ

Clarke, R. (1991). Water: The International Crisis. Earthscan Publications Ltd., London, 193 pp

Cloudia O, Diane P. and Grenville D. (2006) *Earth Lab, Exploring The Earth Sciences; Second Edition*. Brooks Cole Cengage Learning Prints Japan.

Coker J.O, Makinda V. and Olowefola J.A (2008) Geoelectrical Investigation of Groundwater Potentials of Oke-Bada estate, Ibadan SW Nigeria. *Proceeding of the Third Conference on Science and National Development P* 119-131

Corwin DL, Loague K, Ellsworth TR (1998) GIS-based Modeling of Nonpoint Source Pollutants in the Vadose Zone. *Journal of Soil and Water Conservation* 53(1):34–38

Crist, A. S. (2005) An Analysis of Accessibility and Pricing of water supply in Rural Watersheds: A case Study of Kakamega District Kenya. *FWU Vol: 3 Tropical Integrated Watershed management- Proceedings.*

Custodio E. (2002) Aquifer over Exploitation: What Does it Mean *Hydro geological journal* 10:254 – 277.

Dasgupta, S. Sikdar, P.K, (1992). Groundwater Potential in the Upper Catchment of the Silai river basin. Bankura District, West Bengal. *Indian Journal of Earth Science,* 19(2-3) pp. 128-135.

David R., John P.K. and Scott M. (1997) Geologic, Geophysical and Hydraulic Investigation for a Supplemental Municipal Groundwater supply, Danville, Illinois *cooperative Groundwater Report 18*

Dawodu, M.O., 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.

DeMers MN (2000) Fundamentals of Geographic Information Systems. 2nd edition, John Wiley & Sons, Inc. New York

DeVantier B.A. and Feldman A.D. (1993) Review of GIS Applications in Hydrologic Modeling. Journal of Water Resources Planning and Management, ASCE 119(2):246–261

Domenico P.A and Schwartz, F.W (1990) *Physical and Chemical Hydrogeology*. John Wiley and Sons New York.

Donald, M.N. (1967) Implication of non-response for the interpretation of mail questionnaire data. *Public opinion quarterly Journal*, 24(1) 99-114

Douglas I. (1973) *Water Resources in evaluating Human Environment* (edited by Dawson J.A and Doorakamp J.C) Arnold London

Du Preez J.W. and Barbar, W. (1965). The Distribution and Chemical Quality of Groundwater in Northern Nigeria G.S.N. Bulletin No. 36. Pp 12-20

Dubey OP, Sharma DC (2002) Integrated Remote Sensing and Factor Analytic GIS Model for Evaluating Groundwater Pollution Potential. www.GISdevelopment.net (accessed on July 24, 2003)

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 Geographical Information System. Proceedings of the 3rd International Conference on Hydroinformatics, 24–26 August 1998, Copenhagen, Denmark Vol. 1, pp. 505–510

El-Baz, F., Hamida, I., Kusky, T. and Fielding, L. (1995) *Groundwater Potential of the Sinai Penunsula Egypt*: United State Agency for International Development,Cairo Egypt.

Emmanuel, A. (2012) *Sustainability of Rural Water Supply Services in Ghana User Perception from 13 Districts*: Community water And Sanitation Agency (CWSA) Ghana fact Sheet.

Emmanuel, O.J., Olayinka, O., Odeyemi, O. and Oladotun, O. F. (2011) Geoelectrical Investigation of the Groundwater Potential of Moniya area, Ibadan. *Journal of Geology and Mining Research* 3 (3) 54-62

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

Envuladu, E.A., Chingle, M.P., Banwat, M.E., Lar, L.A., Yusuff, O.E., Audu, S, Dakhin, A and Zoakah, A.L (2012) The Quality of Drinking Waters in Jos Metropolis, North Central Nigeria. *Jos Journal of Medicine* 6(1).

Evans TA, Djokic D, Maidment DR (1993) Development and Application of Expert Geographic Information System. *Journal of Computation in Civil Engineering*, ASCE 7(3):339–353

Ezeh CC, Ugwu GZ (2010). Geoelectrical Sounding For Estimating Groundwater Potential in Nsukka L.G.A. Enugu State, Nigeria, *Int. J. Phys. Sc*., 5(5): 415-420.

Falconer J.D., (1911). The Geology and Geography of Northern Nigeria. *Macmillian, London. Pp 33-45.*

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.

Faust, N. Anderson W.H., and Star J.L. (1991) Geographic Information Systems and Remote Sensing Future Computing Environment. Photogrammetric Engineering and Remote Sensing 57(6):655–668

Federal Ministry of Water Resources (2000), *www.siteresources.worldbank.org/sanitation*.

Fetter, C.W (1994) *Applied Hydrology* (3^{rd} edition): Macmillan College Publishing Company, New York.

Flockhart DE, Sham CH, Xiao Y (1993) Maximizing the Value of Information for Groundwater Protection: three test cases. Water Resources Bulletin, AWRA 29 (6):957–964

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

Freeze, R.A. and Cheery, J.A. (1979) *Groundwater:* Prentice Hall, Englewood Cliffs, N.J p.604

G.N.S. (1994). Geological Map of Nigeria. Publish in 1994.

Gada, A.M. (2006) *Investigation of Groundwater Potential Using Vertical Electrical Sounding in Gada town Sokoto State* an Unpublished Msc thesis Department of geography ABU, Zaria.

Gay, L.R. and Diehl, P.L. (1992) *Research Methods for Business and Management*: New York Macmillan

Girish, K. M., Rameshwar, B. and Argarwal, A.K. (2009) Integration of Remote Sensing and Electrical Sounding Hydrogeological Exploration-a Case Study of Bakhar Water shed, India. *Hydrological sciences Journal* 54 (5)

Goodchild M.F. (1993). The State Of GIS for Environmental Problem-Solving. In: Goodchild M.F., Parks B.O., Steyaert LT (eds), *Environmental Modeling with GIS*, Oxford University Press, New York, pp. 8–15

Goodchild MF (1992) Geographical information science. *International Journal of Geographical Information Systems* 6(1):31–45

Gossel W, Ebraheem AM, Wycisk P (2004) A very large scale GIS-based Groundwater Flow Model for the Nubian sandstone Aquifer in Eastern Sahara (Egypt, northern Sudan and eastern Libya) *Hydrogeology Journa*l 12(6):698–713

Gouri, S.B., Sailesh, S. and Babita, P. (2012) Deciphering Prospective Groundwater Zones of Morobe Province, Papua New Guinea. *International Journal of Engineering Research and Applications (IJERA)* ISSN: 2248-9622www.ijra.com 2 (3 May-June 2012, pp752-766

Goyal S, Bharadwaj RS, Jugran DK (1999) Multicritaria Analysis Using GIS for Groundwater Resource Evaluation in Rawasen and Pilli Watersheds, U.P., India. www.GISdevelopment.net (accessed on Dec. 7, 2014)

Grant, F.S. and West, G.P. (1965) *Interpretation Theory in Applied Geophysics.* Mc Grew-Hill New York

Griner AJ (1993) Development of a Water-supply Protection Model in a GIS. Water Resources Bulletin, AWRA 29(6):965–971

Gustafsson. P. (1993). Higher Resolution Satellite Data and GIS as a Tool for Assessment of the Groundwater potential of a Semi-arid Area. *Proceedings of the Ninth Thematic Conference on Geologic Remote Sensing* Vol. 1 pp 609-619

Hadithi MA, Shukla DC, Israil M (2003) Evaluation of Groundwater Resources Potential in Ratmau-Pathri Rao 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

Hagbert, E.C. (1968) Validity of Questionnaire Data Reported and Observed Attendance in an Adult Education Programme. *Opinion Quarterly, 2 (5)* 453-456

Haggett, P., Andrew, D.C. and Allay, F. (1977) *Principle of Physical Geology,* 2ndEdition*:* The English Language Book Society and Nelson.

Hazell, J.R.T. Cratchley C.R. and Jones C.R.C. (1992).The Hydrogeology of Crystalline Aquifers in Northern Nigeria and Geophysical Techniques Used in their Exploration. In: Wright, E.P. and Burges, W.G. *A Publication of Geological Society Publication* No.66.

Hsin-Fu, Y., Chang-Haw, L., Kuo-Chin, H. and Hsun, P.O. (2009) GIS for the Assessment of the Groundwater Recharge Potential Zone. *Journal of Environmental Geology,* 58 (10) 185-195 spriger- verlag SE Taiwan.

Ifabiyi I.P (2005) Spatial Pattern of Groundwater Contribution to Total Runoff in the Upper Kaduna Catchment: A Hydro Geographic study: *Zaria Geographer, 16 (1) 2005 Department Of Geography ABU Zaria* 106 – 121

Ince, M., Bashir, D., Oni, O.O.O., Awe, E.O., Ogabechi, V., Kerve, K., Adeyinka, M.A., Olufolabo, A.A., Ofordu, F. And Kehindo, M. (2010) *Rapid Assessment of Drinking*

Water Quality in the Federal Republic of Nigeria. Country Report of a Pilot Project Implementation in 2004-2005.

Iserhien-Emekeme R.E., Atakpo E.A., Emekeme O.L., Anomohanran O. (2004). Geoelectric Survey for Ground Water In Agbede, Etsako West L.G.A., Edo State, Adv. Nat. Appl. Sc. Res., 2(1): 65-72.

Jacobson, R.R.E. and Macleod, W.N. (1977) Geology of Liruei, Banke and Adjacent Younger Granite Complex, *geological Survey of Nigerian Bulletin* no 33. 117

Jain, P. K. (1998): Remote Sensing Techniques to Locate Ground Water Potential Zones in Upper Urmil River Basin, District Chatarpur-central India. *J Ind Soc Remote Sens*. Vol. 26, No. 3, pp.135–47.

Jansz, S. (2011) A Study into Rural Water Supply Sustainability in Niassa Province, Mozambique, Water Aid (www.wateraid.org/publications)

Jasrotia, A.S., Kumar, R. and Saraf, A.K. (2007) Delineation of Groundwater Recharge Sites using Integrated Remote Sensing and GIS in Jammu District India. *International Journal of Remote Sensing,* 28 (22). Tailor and Francis,Inc Bristol.PA.USA.

Jonson, P.O. (1959) Development of the Sample Survey as Scientific Methodology. *Journal of Experiential Education* vol. 27 P167-176

Julius O.O., (2009) Geoelectric Investigation of Groundwater Resources and Aquifer Characteristics in Utagba-Ogbe Kingdom Ndokwa Land Area of Delta State, Nigeria. *Journal of Environmental Vol. 2(3), Pp. 38-46*

Kadam A.K and Sankhua R.N (2012) Groundwater prospecting Mapping using G.I.S Techniques with Spatial Reference to ARCCN-RUNOFF in Upper Karha Watershed India. *India Water Week 2012- water, Energy and Food Security: call for solution* 10-14 April 2012 New Delhi

Kamaraju, M., Bhattacharya, A., Reddy, G., Rao, G., Murthy, G. and Rao, T. (1996) Ground-Water Potential Evaluation of West Godavari District, Andrha Pradesh State, India. *A GIS Approach to Groundwater Journal,* 34(2) 318-325.

Kartic B. and Jatisankar B. (2012). Ground Water Potential Mapping in Dulung Watershed using Remote Sensing & GIS techniques, West Bengal, India. International Journal of Scientific and Research Publications, Volume 2, Issue 12, December

Kavidha, R. and Elangovan, K. (2013) Delineation of Groundwater Prospective Zones by Electrical Resistivity Method in Erode District Tamilnadu India. *Indian Journal of Environment,* 2 (1) 14-18

Kehinde I., Seun O., Kola A., Abdullah A. (2013). Assessing Groundwater Potential Zones in Basement Complex Terrain Using Resistivity Depth Sounding, *Journal of Science* vol 1pp 11-32

Khairul-Anam, Juharimat, A. and Ibrahim, A. (2000) *Groundwater Prediction Potential Zone in Langat Basin Using the Integration of Remote Sensing and GIS:* Malasian Centre for Remote Sensing (MACRES) No.13 Jalantun Ismail, 50480 Kuala Lumpur 2 University Kebagsaen Malasia.

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.

Khandri, S.F.R., Patil, G.P. and Rajan, Z. (2008) *Estimation of Aquifer Parameters in Basaltic terrain and the Application of Wireless Sensor Networks, Chikaldhra region, Amravati district, Maharashtra, India:* Centre for statistical Ecology and Environmental Statistics, Pennsylvania State University.

Kluge, T., Ilmberger, J. , Von R.C. and Aeschbach, H. (2007) *Tracing and Qualifying Groundwater inflow into Lakes using Simple Method for Radon 222 Analysis*. Institute for Environmental physics University Heidelberg, Heidelberg Germany www.hydrol-earthsystem-sci.net/11/162/2007

Koch M., Mather P.M. (1997). Lineament Mapping for Groundwater Resource Assessment: a Comparison of Digital Synthetic Aperture Radar (SAR) Imagery and Stereoscopic Large Format Camera (LFC) photographs in the Red Sea Hills, Sudan. Int. J. Rem. Sens., 27: 4471-4493.

Kolja, R. (2007) *Hydraulic Parameters Estimation Using Aquifer Test, Specific Capacity, Ocean Tides and Wave Set up for Hawai I aquifer*. PhD Dissertation Geology and Physics University of Hawai, India.

Kollent, R. (1969) *Hydrogeoelectrical Investigation in Gombe town and its environments NorthEastern Nigeria*: Offix resistivity interpretation programme, Compass geophysical instrument Colorado.

Krejcie, R.V. and Morgan, D.W. (1970) *Determining Sample Size for Research Activities, Educational And Psychological Measurement*, 30, Pp 607-610

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): pp 204–215

Krishnamurthy, J., Kumar, N.V., Jayaraman, V. and Manivel, M. (1996) An Approach to Demarcate Groundwater Potential Zones Through Remote Sensing and GIS. *Geographic Information System International Journal of Remote Sensing*, (17)1867-1885.

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): Pp 2595–2618

Lambert D., and David J., (1998). Groundwater Penetrating Radar for Archeological Investigation Canada. Third Edition.

Lar U.A., (2007). Geology and Mineral Resourses of Plateau State. *Published in Nigeria by Jos University Press Limited, Pp 29-30.*

Lean G.D Hinrichen, and markhem A. (1990) *Atlas of the Environment, Prentice Hall Press*, New York P. 30 – 31

Leblank, M. (2007) Remote Sensing For Groundwater Modelling in Large Semi-Arid Areas Lake Chad Basin Africa. *Hydrology Journal,* 15(1) 9710

Lillesand, T.M. and Kiefer, R. (2000) *Remote Sensing and Image Interpretation, 4th edition:* New York wiley, cop ISBN 0-471255-7.

LVIA (2012) *Groundwater Potential Zone Mapping Using GIS and Remote Sensing- Moyale-Teltele Sub Basin, Dire, Arero, Yabelo And Teltele Woredas Borena Zone of Oromia Regional State, Ethiopia*.MAB Consult- Consulting Hydrogeologist and Engineers.

Macdonald, A.M. (2005) *Developing Ground Water a Guide for Rural Water Supply:* ITDG Publishing Http://Www, Development Book Shop.Com/

Macdonald A.M and Davies J. (2000) *a Brief Review of Groundwater for Rural Water Supply in Sub Saharan Africa*. NERC British Geological survey.

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.

Madan, K.J. Alivia Chowdhury, V.M. and Stefan P. (2007) Groundwater Management and Development by Integrated Remote Sensing and Geographic Information System: Prospects and Constraint pp 428-432

Magaji J.Y., and Chup C.D., (2011). Effects of Abattoir Waste on Water Quality in Gwagwalada-abuja, Nigeria. *Ethopia Journal of Environmental Studies and Management EJESM Vol. 5 no 4 (Suppl.2).*

Magesh, N.S., Chandrasekar, N. and John, P.S. (2011) Delineation of Groundwater Potential Zones in Theni District Tamil Nadu, Using Remote Sensing, GIS And M.I.F Techniques. *India International Journal of Applied Earth Observation,* Centre for Geotechnology Manonmanian Sundravar University Truvenvali, Tamil Nadu, 62 (9) 7012.

Mallo, S.J., (2007) "Reclamation of Mine-out Areas": A case of the Jos Plateau. Nigerian Mining Journal Vol.3 No1.

Mandal, D.K. (2011) Identification of Groundwater Potential Zone, in and Around Dehra Doon Using Index Overlay Method. *Indian Cartographer Journal,* 31 (5) 190

Mark, willian E (2001). *The Holy Order of Water Healing Earth Waters and Ourselves.* Bell pond Books Great Barrington ISBN 0 – 088010483.

Marshall W., Gannett K., Kenneth E., Lite J.R., David S., Morgan B. and Charles A. C. (2008) Groundwater Hydrology of the Upper Deschutes Basin, Oregon. *USGS Water Resources Investigation Report 00-4162 U.S Department Of Interior.*

Mathew Becker W. (2006) Potential For Satellite Remote Sensing of Groundwater: *Groundwater Association Journal*, 44 (2) March – April 306 – 318.Buffalo State University New York

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

Meijerink, A.M.J. (2007) *Remote Sensing Applications to Groundwater:* IHPVI, Series on Groundwater No. 16, a UNESCO Publication.

Miller, L.E. and Smith, K.L. (1983) Handling Non Response Issues Related to Water. *Journal of Extension*, 21 (3) 21-50

Mobogunje, A.L., (1965). *Water Resource and Economic Development.* In Ecology and economic development in Africa (Edited by D.W brockenshe) university of Califonia press.

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.

Mohammad A., Mehdi Z., Timothy M.K., (2009). The Effect of Active Tectonics on Aquifer Creation, *A Case Study; Isfahak District, Eastern Iran*.

Moore, G. (1982) *Groundwater Applications of Remote Sensing*: Open- File Report 82– 240 US. Department Of Interior Geological Survey, Eros Dada Centre Sioux Falls South Dakota.

Mosuro, G.O., Ayolabi, E.A., Ogungbesan, G.O., Bayewu, O.O., Oloruntila, M.O. and Olorunfemi, O.A. (2012) Geophysical Delineation of Groundwater Potential in Basement Complex Terrain: A Case Study of Imopo and Environs, South Western Nigeria. *Journal of American Science, 3(2) 36-44*

Mukherjee S. (2008) *Role of Satellite Sensor in Groundwater Exploration MDPI* (http://www.mdpi.org) retr. 25/03/2012

Munhong, C. (1998) Assessment of hydraulic Properties in an Unconfined Alluvial Aquifer Near Grand Island Nebraska, *Jawra 1 Journal of the American Water Resources Association*, 34I (3) 603-616National population Commission (2009) *Annual report year book:* NPC Nigeria.

Murugesean B., Thirunavukkarasu R., Senapathi V.,Balasubramanian G., (2012). “Application of Remote Sensing and GIS analysis for Groundwater Potential Zone in Kodaikanal Taluka, South India”. Earth Sci. 7(1): 65-75.

Myers, V.I. and Moore D.G. (1972) Remote Sensing for Defining Aquifers in Glacial Drift. Proceedings of the 8th International Symposium on Remote Sensing of the Environment, Environmental Research Institute of Michigan, Ann Arbor, MI, pp. 715–728

Nagarajan, M. and Singh, S. (2009) Assessment of Groundwater Potential Zones Using GIS Technique. *Journal of Indian Society of Remote Sensing*, 37(10) 69-77

Narayana LRA (1999). Remote Sensing and its Applications. Universities Press (India) Ltd., Hyderabad, pp. 215.

Narendra, K., Nageswara R.K. and Latha P.S. (2013). Integrating Remote Sensing and GIS for Identification of Groundwater Prospective Zones in the Narava Basin, Visakhapatnam Region, Andhra Pradesh. *Journal Geological Society of India* Vol.81, pp.248-260.

Nefedov K.E. and Popova T.A. (1972). Deciphering of Groundwater from Aerial Photographs. Amerind, New Delhi

Nezar, H., Ali, E. and Barakat, M. (2012) An Integrated Approach to Groundwater Exploration using Remote Sensing and Geographical Information System in Jordan. *Water Resource Protection Journal,* September 2012.

NRSC (2007), Manual for Ground Water Prospects Mapping using Remote Sensing techniques and Geographic Information System. Rajiv Gandhi National Drinking Water Mission Project.

Nwankwo, L.I., Olasehinde, P.I. and Osundele, O.E. (2013) Application of Electrical Resistivity Survey for Groundwater Investigation in a Basement rock Region: A case study of Akobo Ibadan, Nigeria. *Ethiopian Journal of Environmental Studies and Management,* 6(2), 2013 http://dx.doi.org/10.4314/ejesm.v6i2.2

Odusanya B.O. (1989). An Empirical Resistivity Model for Predicting Shallow Ground Water Occurrence in the Basement Complex. Pp. 183. Unpublished M.Sc Thesis, Department of Geology University of Ibadan.

Offodile M.E (2000) *The Development and Management of Groundwater for Water Supply in Nigeria*: Paper Presented At 2nd Fellows Workshop of MMGS on Monday 6th March 2000 Mean Services Ltd Jos.

Ogezi. A.E., (2007). Impact of Mining on Nigeria Environment. *In FEPA Monograph, Towards Pollution Abatement in Nigeria.*

Oguntade, A.K. and Ariyo, S.O. (2009) Remote Sensing Application to Groundwater Studies *on line journal of Earth Sciences,* 13(6): Medwell publishing 2010.

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 JEA, Asokhia MB (2005). Estimate of Groundwater in Parts of Niger Delta Area of Nigeria using Geoelectric Method, *Journal Applied Science. Environment*al Management. 9(1): 31-37.

Okoro, E.I., Egboka, B.C.E., Anike, O.L. and Enekwechi, E.K. (2010) Evaluation of Groundwater Potentials in Parts of the Escarpment area of South Eastern Nigeria. *International journal of Geomatics and geosciences*, 1(3), 2010.

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.

Olofsson, B., Jacks, G., Knutsson, G. and Thunvik, R. (2001) *Groundwater in Hard rock – a Literature review*. Excerpt from: Nuclear Waste State-of-the art Reports 2001 in Swedish Government Official Reports SOU 2001-35, 77pp.

Olorunfemi, M.O. and Fasuyi, S.A. (1993) Aquifer Types and the Geoelectric / Hydrogeologic Characteristics of Part of Central Basement Terrain, Niger State. *Journal of African Earth Science*, 16(1) 309-317

Oloruniwo M.A., and Olorunfemi, (1987). Geophysical Investigation for Groundwater in Precambrian Terrains: A case History from Ikare, South-western Nigeria. *Journal of Afrian Earth Sciences 6, Pp. 787-796.*

Olowofela J.A., Jolaosho V.O. and Badmus B.S. (2005). Measuring the Electrical Resistivity of the Earth Using a Fabricated Resistivity Meter, *European Journal. Physics.* 26: 501-515.

Oluwatola, A.I., Oluwatoyin, A. F., Moshood, N. T. and Abel, O. T. (2013) Delineation of Groundwater Potential Zones in the Crystalline Basement Terrain of SW- Nigeria: An Integrated GIS And Remote Sensing Approach, *Appl. Water Science Journal*, (4) 19-38. Springerlink.com.

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.

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

Omosuyi G.O., Adeyemo A., Adegoke A.O. (2007). Investigation of Groundwater Prospect Using Electromagnetic and Geo-electric Sounding at Afunbiowo, near Akure, South western Nigeria, *Pacific J. Sci. Technol.*, 8:172-182.

Omosuyi, G.O., Ojo J.S. and Enikanselu, P.A. (2003). Geophysical Investigation for Groundwater around Obanla – Obakekere in Akure Area within the Basement complex of South-Western Nigeria. *Journal of Mining and Geology*. 39(2):109 – 116.

Onugba A. and Yaya O.O (2008) *Sustainable Ground Water Development in Nigeria*. Taylor and francis Group, London UK.

Oseji J.O., Asokhia M.B., Okolie E.C. (2006). Determination of Groundwater Potential in Obiaruku and Environs Using Surface Geo-electric sounding. Environmentalist, 26: 301-308.

Onu, N.N., 2003. Estimats of the Relative Specific Yield of Aquifers from Geo-electrical Sounding Data of the Coastal Plains of Southeastern Nigeria. J. Technol. Educ. Nig., 8: 69-83

Onugba A. and Eduvie M, "Hydrogeology of Nigeria. Paper on Groundwater Workshop," Organised by United Nations Children's Fund, Jos, 2003, p.20.

Oseji J.O., Atakpo EA, Okolie EC (2005). Geoelectric Investigation of the Aquifer Characteristics and Groundwater Potential in Kwale, Delta State, Nigeria, *Journal of Applied Science,* 9:157-160.

Otezi E., (2006). Management Approaches for Nigeria's Water Resourses, *Journal of Mining and Geology 42(1)*

Oyawoye, M.O. (1964) The Geology of the Nigerian Basement Complex. *Journal of Nigeria Mining, Geology and Metallurgical Society,* 1 (2) 87-103

Ozcep F., Asci, M., Tezel, O., Yas, T., Alpaslan, N. and Gundogdu, D. (2005) *Relationship Between Electrical properties (in situ) and Water Content(in laboratory) of Some Soil in Turkey*: Geophysical Research Abstract 7.

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

Paterson NR, Bosschart RA (1987). Airborne Geophysical Exploration for Groundwater. Groundwater 25:41–50.

Peter, H.S., Rind, M.B., Ahmad, A., Hassan, M., Abdul, S. and Mohammed, N.E. (2011) Application of Overlay Weighted Model and Boolean Logic to Determine the Best Locations for Artificial Recharge of Groundwater. *Journal of Urban And Environmental Engineering,* 5 (2) 57-66 Journal-Uee.Org

Pimental, D., James, H., Erika, P., Omar, W., Hope, F., Leslie, M. and Sharon, A. (1997) Water Resources, Agriculture, the Environment and Society. An Assessment of the Status of Water Resources. *Bioscience Journa,l* 47 (2) 97-106

Pinder, G.F. (2002). Groundwater Modeling Using Geographical Information Systems. John Wiley & Sons, New York, pp. 248

Pramanik M.A.H (1989) *Water Resource Studies by Remote Sensing Techniques* in Bahgladesh, Bahgladesh Space Research And Remote Sensing Organization (SPARRSO) Agargaon, Shere Bangla Naga Dhaka, Bahgladesh.

Prasad R.K, Mondal, N.C, Pallavi B, Nandakumar M.U and singh V.S., (2008) *Deciphering Potential Groundwater zone In Hard Rock Through The Application Of G.I.S,* Environmental Geology.

Plateau Rural Water Supply and Sanitation Agency PRUWASSA., (2012). *www.prusawwa.org*

Raghu V. and Venkata S.M. (2009). Remote Sensing In Groundwater Exploration For Development Of Temple Tourism In Vemulawada, Karimnagar District, Andhra Pradesh: *Journal Of India Geophys. Union, 13(4) P. 183 +90*

Rai S.N (2008). Hydrological Studies Glimpse Of *Geosciences Research In India* Pp17 – 20

Ralph C. H. (1987) Basic Groundwater Hydrology. *U.S Geological Survey Water Supply Paper*. 2220 USGS Publication. United States Groundwater Printing Office.

Ramalingam M, Santhakumar AR (2002) Case Study on Artificial Recharge Using Remote Sensing And GIS. Www.Gisdevelopment.Net (Accessed On June 25, 2013)

Ramaswamy And Abdin (2008) Groundwater Dynamics in Hard Rock Aquifers. *Sustainable Management Optional Monitoring Network Design Paper,* 2 (3)23-28

Rampal KK, Rao KVG (1989) Groundwater Targeting Using Digitally Enhanced Imagery. Www.Gisdevelopment. Net (Accessed On July 24, 2013)

Ray, R.G. (1960) *Aerial Photographs in Geologic Interpretation*: USGS Prof. Pap No: 373

Revzon AL, Burleshin MI, Krapilskaya NM, Sadov AV, Svitneva TV, Semina NS (1983) Study Of The Desert Geological Environment With The Aid Of Aerial And Space Imagery. All-Union Sci. Res. Inst. Hydrol. Eng. Geol., Moscow

Robert, W. C. (2007) *An Introduction To Physical Geography* (8^{th} Edition) Prentice Hall Print England Republic

Ronald, C. E. (2011) *GIS Based Multicriterian Decision Analysis in Natural Resources Management:* Division of Spatial Information Science Graduate School Of Life And Environmental Sciences University Of Tsukuba, Japan

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

Salama RB, Ye L, Broun JL (1996) Comparative Study of Methods Of Preparing Hydraulic-Head Surfaces And The Introduction Of Automated Hydrogeological-GIS Techniques. *Journal of Hydrology* 185(1–4):115–136

Salama RB, Tapley I, Ishii T, Hawkes G (1994) Identification of Areas of Recharge and Discharge Using Landsat-TM Satellite Imagery and Aerial Photography Mapping Techniques. Journal of Hydrology 162(1–2):119–141

Sander P (2007). Lineaments In Groundwater Exploration: A Review Of Applications and Limitations Hydrogeology. J., 15: 71-74.

Sander, P., Minor, T.B. And Chesley, M.M. (1997) Groundwater Exploration Based on Lineament Analysis And Reproducibility Test. *Groundwater Journal Dubin,* 35(5)888-894 ISSN: 0017467X.

Sander, P. (1996) *Remote Sensing and GIS for Groundwater Assessment in Hard Rocks: Applications To Water Well Silting in Ghana And Botswana*, Phd Dissertation, Chalmers University Of Technology, Sweden, Publ. a 80.

Sander P, Chesley MM, Minor TB (1996) Groundwater Assessment Using Remote Sensing and GIS In A Rural Groundwater Project in Ghana: Lessons Learned. Hydrogeology Journal 4(3):40–49

Sara, B. And Charles, R.C. J. (1988) Combine ETM/VES Geophysical Methods for Sting Boreholes. *Groundwater Journal of Groundwater Development Consultant Ltd Cambridge*, 26 (1) Jan, 1988

Saraf, A.K. and Choudhury, P.R. (1998). Integrated Remote Sensing And GIS For Groundwater Exploration And Identification Of Artificial Recharge Sites. *International Journal Of Remote Sensing*, 19(10) 1825-1841.

Sarma B. and Saraf A.K. (2002). Study of Land Use-Ground–Water Relationship Using an Integrated Remote Sensing And GIS Approach. Http://Www.Gisdevelopment.Net.

Saumitra, M. (2008) Role of Satellite Sensor in Groundwater Exploration,. *Journal of Environmental Sciences, 2(3)* Jawaharlal Nehru University New Delhi.

Saykawlard S, Das Gupta A, Eiumnoh A, Chen X (2005) Prediction of Subsurface Water Level Change From Satellite Data. Hydrological Processes 19(4):947–954

Schaepman M, Itten KI, Schlapfer D,Kurer D,Varaguth S,Keller J (1995) Extraction of Ozone and Chlorophyll: A Distribution From AVIRIS Data. in Green RO (Ed), Summaries Of The Fifth Annual JPL Airborne Earth Science Workshop, AVIRIS Workshop, 23-26 January 1995, Pasadena, California, Jet Propulsion Laboratory, Vol. 1, Pp. 149–152

Sener A., Davraz A., and Ozcelik M., (2005). Geospatial Inestigation of Groundwater Potential Zones in Sokoto to Lake Chad. *Kubanni.abu.edu.ng:8080*

Shaban, A., Kwawlie, M. and Abdullahi, C. (2006) Use of Remote Sensing And G.I.S To Determine Recharge Potential Zones: The Case of Occidental Lebanon. *Hydrogeology Journal,* 14 (3)433-443

Shahid, S. and Kumar, K.N. (2009) GIS Integration of Remote Sensing And Electrical is Sounding Data For Hydrogeological Exploration. *Journal of Spatial Hydrology,* 2 (1). Bengal India.

Shahid ,S., Nath, S. K. And Roy, J. (2000) Groundwater Potential Modelling in a Soft Rock Area Using GIS. *International Journal of Remote Sensing*, 21 (9) 1919-1924

Shakeel, A., Ramaswamy, J. And Abdin, S. (2008) Application Of Remote Sensing And GIS in Groundwater Exploration. *Indian Society of Remote Sensing Journal*, 19 (4) 89-92

Shih SF, Jordan JD (1990) Remote-Sensing Application to Well Monitoring. *Journal of Irrigation and Drainage Engineering* ASCE 116(4):497–507

Shivraj PV, Jothimani P (2002) GIS Based Software Solution for Groundwater Studies: GWIS. www.Gisdevelopment.Net (Accessed On June 25, 2013)

Shukla S, Mostaghimi S, Shanholtz VO, Collins MC (1998) A GIS-Based Modeling Approach for Evaluating Groundwater Vulnerability To Pesticides. Journal of The American Water Resources Association, 34(6):1275–1293

Sikdar PK, Chakraborty S, Adhya E, Paul PK (2004) Land Use/Land Cover Changes and Groundwater Potential Zoning in and Around Raniganj Coal Mining Area, Bardhaman District, West Bengal: A GIS and Remote Sensing Approach. Journal of Spatial Hydrology 4(2):1–24

Singh AK, Prakash SR (2002) An Integrated Approach of Remote Sensing, Geophysics and GIS to Evaluation of Groundwater Potentiality of Ojhala Sub-Watershed, Mirjapur District, U.P., India. Www.Gisdevelopment.Net (Accessed On June 25, 2013).

Singh AK, Raviprakash S, Mishra D, Singh S (2002) Groundwater Potential Modeling in Chandrapraha

Singhal, B.B.S and Gupta, P.R. (1999) *Applied Hydrogeology of Fractured Rocks*: ISBN: 0-41275830-X.

Sitender, R. (2011) Delineation of Groundwater Potential Zones in Mewat District Haryana India. *International Journal of Geomatics and Geosciences*, 2 (1)

Small J.R., (1970). The Study of Landforms. A Textbook of Geomorphology, Cambridge Press, Cambridge, 477p.

Solomon S. and Fredrick Q. (2006) Groundwater Study Using Remote Sensing and Geographic Information System (G.I.S) in the Central Highlands of Eritrea. *Hydrogeology Journal of Eritrea Pp729-741*

Solomon S, Ghebreab W. (2006). Lineament Characterization and Their Tectonic Significance Using Landsat TM Data and Field Studies in the Central Highlands of Eritrea. *Journal of African. Earth Science.* 46: 371-378.

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

Srinivasa, R. And Juggran, D.K. (2003) Delineation of Groundwater Potential Zones and Zones of Groundwater Quality Sustainable for Domestic Purposes Using Remote Sensing and

Geographical Information System (GIS). *Hydrological Sciences Journal,* 48 (5) October, 2003, India.

Srivastava A (2002) Aquifer Geometry, Basement Topography and Groundwater Quality Around Ken Graben, India. *Journal of Spatial Hydrology* 2(2):1–8

Srivastava, J.B. and Murthy, C.D. (1992) *Study Of Palaeochannels Adjacent to Banda City through Remote Sensing and Their Hydrological Evaluation:* Proceedings of the National Symposium on Remote Sensing for Sustainable Development, *Pp.*136-143.

Stafford D.B. (1991). Civil Engineering Applications of Remote Sensing and Geographic Information Systems. ASCE, New York

Stephen, F., Albert, T. And Hector, G. (2002) *Groundwater Development in Sub - Saharan Africa A Strategic Overview of Key Issue and Major Needs.* World Bank Case Profile Collection No15 Subas

Stone DB, Moomaw CL, Davis A. (2001) Estimating Recharge Distribution By Incorporating Runoff from Mountainous Areas an Alluvial Basin in the Great Basin Region of the Southwestern United States. Ground Water 39(6):807–818

Subash, C., Dewashish, K., Shakeel, A., Jerome, P. And Benolt, D. (2008) *Contribution of Geophysical Methods in Exploration and Assessment of Groundwater in Hard Rock Aquifers*: The Third International Conference on Water Resources and Arid Environments and the 1st Arab Water Forum.

Subba, R.N, Chakradhar G.K.J., 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

Subin, K., Jose, R., Jayasree, R., Santhosh, K. And Rajendran, S. (2012) Identification of Groundwater Potential Zones in Palakkad District, Kerala through Multicriterian Analysis Techniques Using Geoinformation Technology. *Bonfring International Journal of Industrial Engineering And Management Science,* 2 (1) 62-68

Suja, R.S.R. And Krishnan, N. (2009) Spatial Analysis of Groundwater Potential Using Remote Sensing and GIS in The Kanyakumari and Nambiyar Basins India. *Journal of Indian Society of Remote Sensing,* 37 (4) 681- 692

Sultan, S.A., Hatem, M., Mekhemer, F., Santos, A.M. And Abdul A.M. (2009) Geophysical Measurements for Subsurface Mapping and Groundwater Exploration at the Central Part of the Sinai Peninsula, Egypt. *Arabian Journal for Science And Engineering,* 34(1A) 103-119

Tammaneni, K.R., Hanuman D.S., Malisethy J.G. (2006). Site Investigations for the Identification of a Groundwater Source for Sullurupeta, Andrha Pradesh, India, IAEG Publication, P. 36.

Tanner G.A and Road R. A (2003) Medical *Physiology* (2nd End) Baltimore: Lippineott Willions and Wilkins ISBN 0781719363. OCLC 50554808

Tanzania National Data Achieve (2010) *Water Supply And Sanitation in Tanzania*: Wikipedia the Free Encyclopedia.

Taylor, K., Minor, C., Timothy, B., Chesley, M., Matanawi, M. And Korblahh, M. (1999) Cost Effectiveness of Wellsite Selection Methods in a Fracture Aquifer, *Groundwater, Dublin* March/ April 1999 3 (2) 271. ISSN 0017467

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

Tesfaye, T.G. (2010) *Grounwater Potential Evaluation Based on Integrated GIS and Remote Sensing Techniques, in Bilate River Catchment: South Rift Valley of Ethiopia:* An Unpublished Msc Theasis Department of Eath Science Adis Ababa University.

Tewodros G., (2005). Contour Furrows for insitu Soil and Water Conservation, Tigray, Northern Ethopia. *Soil and Tillage Research 103: 257-264*

Thapa, R., Ravindra, K. And Sood, R.K. (2008) Study of Morphotectonics and Hydrogeology for Groundwater Prospecting Using Remote and GIS in the North West Himalaya, District Sirmour, Himachal Pradesh India. *International Achieve of the Photogrammetry Remote Sensing And Spatial Information Sciences,* 37 (B4) Beijing 227- 232

Theogeorg S. (1997) Water Protection Human Beings, a Triangular Relationship in Changing Times. *Journal of Applied Geography And Development.* No 49. Institute For Scientific Cooperation Tubingen Federal Institute for Scientific Republic of Germany Maier, Rottenburg.

Thomas, H. (2003) *Basic Concepts Of Groundwater Hydrology*: University of California Reference Sheet Division Of Agriculture And Natural Resources in Partnership with Natural Resources Conservation Service (NRCS) Http://Www.Nrcs.Usda.Gov

Timothy, B.M., Jerome, A.C., Mattwa, M.C. and Robert, B.K. (1994) *AN Integrated Approach to Groundwater Exploration in Developing Countries Using GIS and Remote Sensing*: U.S Army Corp an Engineer Topographic Engineering Center Alexandria, VA 22310

Timothy, J. A. (2006) *Determination of Aquifer Properties and Heterogeneity in a Large Coastal Sand Mass in Bribie Island, Southeast Queensland:* An Msc Thesis of Applied Science Queenland University of Technology Brisbane Queenland.

Todd D.K. and Mays L.W. (2005). Groundwater Hydrology. 3rd Edition, John Wiley & Sons, NJ, Pp. 636

Todd D.K. (1980). Groundwater Hydrology. 2nd Edition, John Wiley & Sons NY, Pp. 111–163.

Toleti B, Chandhary B. Kumar, K Saroha, G. Yadar M. Singh A. Sharma M. Pandey A. and Singh P. (2001) *Integrated Groundwater Resource Mapping in Gurgoan District* (Haryana) India Using Remote Sensing and GIS Technique.

Toth, J. And Ophori, D.U. (1989) Theoretical Analysis of Groundwater Flow in Small Drainage Basin. *Groundwater Journa,L* 27(2)

Trimmer, W.L. (2000) Measuring Well Water Level, *Extension Service:* Oregon State University Sea Grant Extension Ec 136.

Tsihrintzis VA, Hamid R, Fuentes HR (1996) Use Of Geographic Information Systems (GIS) In Water Resources: A Review. Water Resources Management 10:251–277

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

UN/WWAP (United Nation / *World Water Assessment Programme) (2003). UN World Water Development Report: Water for People: Water for Life. UNESCO (United Nations Educational, Scientific And Culture, Organization* and *Berghahn* Books, Paris New York Oxford.

UNEP (2006) *Groundwater Pollution in Africa:* Taylor and Francis/Balkema Publishing Company Yongxin Xu and Leiden (Eds) Breant Usher Netherlands.

UNESCO (2004). Groundwater Resources of the World and their Use. In: Zekster IS, Everett L.G. (Eds), IHP-VI Series on Groundwater, P. 6.

United Nation Economic Commission For Africa (2005) *Water Resource Development In North Africa* Summary Of The Sub Regional Report

United Nations Development Programme (2006). *Beyond Scarcity: Power, Poverty and the Global Water Crisis:* Human Development Report 2006, Human Development Office, UNDP, Palgrave Macmillan, and New York.

United State Groundwater Association Report (2006) *Ground Water Protecting Committee as Drinking Water* July, 2006.

USGS (1997). Geographic Information Systems. An Information Brochure, USGS, Reston, VA

USGS, (2002). Factors Affecting Ground-Water Exchange and Catchment Size for Florida Lakes in Mantled Karst Terrain: Water-Resources Investigations Report 02-4033

Van De Griend AA, Camillo PJ, Gurney RJ (1985) Discrimination of Soil Physical Parameters, Thermal Inertia and Soil Moisture From Diurnal Surface Temperature Fluctuations. Water Resources Research 21:997–1009

Van Der Laan F (1992) Raster GIS Allows Agricultural Suitability Modeling at a Continental Scale. GIS World, October, Pp. 42–50

Vasanthakumaran T, Shyamala R, Sridhar K (2002) Role of Remote Sensing and GIS in Identifying Artificial Recharge Zones of Upper Kolavarnar River Basin, Tamil Nadu. Www.Gisdevelopment.Net (Accessed On June 25, 2003)

Venkatesan, V., Krishnaveni, M., Kanunakaran, K. and Ravikumar, G. (2010) GIS Based Multicriterian Analysis for Assessement of Groundwater Potential and Land Suitability. *International Journal of Earth Sciences And Engineering*, 3 (2) 207- 224. Tanil Nadu India.

Voljko, M. (2003) Porosity Determination by Using Stochastic Method. *Automatica Journal ATKAA*, 44 (3) 155-162

Waller, R.M. (1982) *Groundwater and the Rural Home Owners*: Pamphlet of USGS Publications.

Wankwo L.I. (2011). 2D Resistivity Survey for Groundwater Exploration in a Hard Rock Terrain: A Case Study of MAGDAS Observatory, Unilorin, Nigeria, *Asian Journal of Earth Science.* DOI: 10.3923/Ages.2011.

Wardrop (1990) *A KNARDA Final Report-Rural Water Project:* Vol.II Wardrop Eng.

Waters P, Greenbaum P, Smart L, Osmaston, H (1990) Applications of Remote Sensing to Groundwater Hydrology. Remote Sensing Review 4:223–264

Watkins D.W., Mckinney D.C., Maidment D.R. and Lin M.D. (1996) Use of Geographic Information Systems in Groundwater Flow Modeling. *Journal of Water Resources Planning and Management*, ASCE 122(2):88–96

WHO (1999) *Would Heath Organization Annual Report* Observation (ICT) Hengelosestraat Netherland.

Wim, B., Karl, G.A. and Gerrit, H.C. (2001) in Norman K, Lucas J.L.F and Gerrit C. (Eds) *Principles of Remote Sensing. An Introductorytextbook.* International Institute for Geoinformation Science and Earth

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.

Yanet, L.A.J. (2012) *Assessment of Groundwater Potentials in Kaura and its Environs Parts of Sheets 167- SE and 168 SW Kaduna State, Nigeria*: Unpublished Msc Thesis Geology Department, ABU Zaria.

Yatsuka, K. (2002) Water for Sustainable Development in Asia and the Pacific. Asia Pacific Forum for Environment and Development*:* First Substantive Meeting Jan. 12 – 13, 2002 Bangkook, *Thailand Journal Of Water Resources.*

Yeshodha L, Rajakumara H. Arunachalam S. and Meenambal T. (2010). Modelling of Ground Water Potential Zones Using Remote Sensing and GIS Technique: A Case Study for Hosur Union, Krishnagiri District, Tamil Nadu, *India. Journal of Environmental Research and Development* Vol. 5 No. 1. Pp. 76-84.

Yisa J., and Jimoh T., (2010). Analytical Studies on Water Quality I Ogbomosho, Southwestern Nigeria. *American Journal of Mining and Metallurgy. 3(1): 21-28*