ASSESSMENT OF GROUNDWATER POTENTIAL FOR RURAL WATER SUPPLY IN PARTS OF KANO STATE, NORTHERN NIGERIA

BY

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DECLARATION

I, Tasi'u Yalwa Rilwanu hereby declare that this dissertation with a title ''Assessment of groundwater potential for rural water supply in parts of Kano State, Northern Nigeria'' The results in this Thesis are records of my research work under the supervision of Prof. E.O. Iguisi, Dr A. L. Bello and Prof. I.A Jaiyeoba. The literature and secondary information cited in this work are fully acknowledged in references and text. This work has not been presented for the award of degree or any certificate in any University or any Institution.

Tasi'u Yalwa RILWANU ....

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CERTIFICATION

This Thesis entitled '' ASSESSMENT OF GROUNDWATER POTENTIAL FOR RURAL WATER SUPPLY IN PARTS OF KANO STATE, NORTHERN NIGERIA'' by Tasi'u Yalwa Rilwanu, meets the regulations governing the award of the degree of Doctor of philosophy of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This thesis is dedicated to my father Mal. Rilwanu Ahmad, my mother Hindatu Muhd Lawal, my late brother Sabi'u Rilwanu and the entire family of Mallam Rilwanu Ahmad.

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ABSTRACT

Assessment of groundwater potential for rural water supply in parts of Kano State, Northern Nigeria was undertaken. The study area extends from latitudes $10^{o}3^{'}$ N to $12^{o}3^{'}$ and longitude 7^{o} $35^{'}$E to $9^{o}20^{'}$E. Water supply situation was evaluated, nature of hydrogeology was assessed, groundwater potential was mapped and characterised. A total of 16 rural areas were selected, 394 respondents were successfully interviewed on water supply situation, Vertical Electrical Sounding (VES) survey was conducted in the 16 villages, samples of aquifer materials were collected from the 16 rural areas and analysed in the laboratory where aquifer parameters were determined. Pumping tests were also conducted in the sixteen rural areas, water levels and groundwater tables were determined. All the six thematic layers were weighted and overlaid using Analytical hierarchy process (AHP). The result indicates that the most common source of drinking water in rural areas of Kano south and central is open well with responses of 17.0% and 18.8% respectively. It was discovered that the major source of drinking water in the rural areas of Kano State is open wells with 41.4% of the total responses. It was deduced that water supply is inadequate with 60.7% responses, water scarcity is more pronounced in rural areas of Kano south and north. Nature of hydrogeology indicates that areas with lower contours less than 340m to 340m, lower slope values of 0^{o}-3^{o}, high aquifer parameter, and high drainage density are areas with high discharge low draw down, low water table and promising groundwater potential. VES survey result indicates that all the curves are "A" type ($p1<p2<p3$) of between 3 to 4 layers, in wet season 8 curves were found to be of high prospects, 2 moderate and 6 with low while in dry season 9 curves were found to be high, 7 low with no moderate. It was established based on water table data that there is abundant occurrence of groundwater in Kano state that can be used to supply water to the rural dwellers. In weighted overlay five groundwater potential zones were identified as follows very high 27.3%, high 35.7%, moderate 6.2%, low 25.9% and very low 4.9%. Among the six factors it was established that lineament line density is the most significant in terms of groundwater potential with a weight of 46%, the dominant lineament orientations are NW-SE, NE-SW and N-S and vegetation is the least with 3%. Very high, high to moderate groundwater potential zones are characterised by good environmental conditions, low draw down and high discharge and low water table values. In view of the findings of the study it is recommended among other issues that rural areas of Kano south and Kano north should be given special treatment regarding water supply through adequate water provision and low yielding bore holes are the best options in areas of low to very low groundwater potential because high yielding boreholes may dry up completely.

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ABBREVIATIONS AND SYMBOLS

S	=	Composite suitability score
Wi	=	Weight of each Factor
Cj	=	Boolean Factor
$\sum$	=	Sum of weighted Factors
$\prod$	=	Product of Strains
Ω (Ohm-m)	=	Ohms per metre
C1,C2	=	Current electrodes
P1,P2	=	Potential electrodes
Vt	=	Total volume of soil or rocks
Vs	=	Volume of Voids
K	=	Hydraulic conductivity
(Ss)m	=	Specific Storage
P	=	Porosity
Sy	=	Specific yield
%	=	Percentage
GWPZS	=	Groundwater Potential Zones
GWPZM	=	Groundwater potential Zones Map

MCE = Multicriterian Evaluation

RS = Remote Sensing

GIS = Geographical Information Systems

PAN = Panchromatic

ITD = Inter Tropical Discontinuity

VES = Vertical Electrical Sounding

SRTM = Shuttle Radar Topographic Mission

DEM = Digital Elevation Model

ETM = Earth Thematic Mappser

NMR = Nuclear Magnetic Resonance

GPS = Global Positioning System

AHP = Analytical Hierarchy Process

AR = Apparent Resistivity

SPSS = Statistical Packages for Social Scientist

KNARDA = Kano State Agricultural and Rural Development Agency

WRECA = Water Resources and Engineering Construction Agency

RDD = Research and Documentation Directorate

MRCD = Ministry of Rural and Community Development

DFFRI = Directorate of Food Roads and Infrastructures

LVIA	=	Lay Volunteer International Association
FAO	=	Food and Agricultural Organisation
TNDA	=	Tanzania National Data Achieves
WUP	=	Water Utilities Practitioners
USDA	=	United State Department of Agriculture
UNEP	=	United Nation Environmental Programme
UN/WWAP	=	United Nation /World Water Assessment Programme
UNECA	=	United Nations Economic Commission for Africa
WHO	=	World Health Organisation
WMO	=	World Metrological Organisation

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Water as one of the natural resources required for the survival of man, animals and plants is unevenly distributed on the earth's surface and below the earth's surface. There are a lot of variations in terms of both quantity and quality of natural water whether surface or underground. Yet people and animals need clean potable water to survive. The major sources of clean water are tap, borehole, hand pumps, open wells, streams and rivers. In the absence of available good water, people begin to use unsafe sources and encounter some health problems. Pimentel *et al* (1997) states that about 90% of the diseases occurring in developing countries result from lack of clean water. It is also predicted that by the year 2025, many African countries will experience water scarcity (WMO, 2002 and 2008). United Nation Environmental Programme (2006) reports that, degradation of groundwater is one of the most serious water resources problems in Africa and that is why its management is crucial.

Groundwater is a precious resource of limited extent. For the good use of it, proper prospecting, management and assessment is required. Due to the increasing number of people living in cities and rural areas as a result of increase in world population; it becomes necessary to scout for other alternative sources of fresh water. One of these sources is groundwater which collects in aquifers that occurs above fresh rocks. In the Basement Complex terrain, groundwater occurs either in the weathered mantle or in the joints and fracture system in the unweathered rocks (Olorunfemi and Olorunmiwo 1985, Ako and Olorunfemi, 1989, Olayinka and Olorunfemi, 1992 in Oguntade and Ariyo, 2009).

Successful exploitation of groundwater requires in an environment a proper understanding of the area's hydrological and geological characteristics. Nature of hydrological characteristic of an area determines the groundwater quantity and quality of that area. These characteristics also determine the level of water in the aquifer. It is also stated that the water table is a function of topography and climate and the flow pattern of ground water is a function of climate, topography and geology. These three terms are called hydrological environment (Toth and Ophori, 1989).

Thapa, Ravindra and Sood (2008) also reported that to evaluate groundwater potential zones of an area various parameters namely lithology, slope, lineaments, hydro geomorphology, land use and land cover need be understood. A lineament is a linear feature whose parts are aligned rectilinear or in a slightly curvilinear relationship, which differs a lot with neighbouring features and most probably reflects a subsurface phenomenon (Singhal and Gupta, 1999). Information on soil also forms important input in mapping groundwater potential zones. For example, coarse soils are generally permeable while fine textured soils indicate less permeability (Thapa *et al.*, 2008). Timothy, Jerome, Mattwa and Robert (1994) also pointed out that groundwater potential zones can be obtained using remote sensing and GIS through interpretation of data based on geologic, hydro geologic, topographic, vegetation and soil maps interpretation. Sander, Minor and Chesley (1997) added that lineaments are often visual on remote sensing data as topographic, drainage, vegetation, or soil tonal anomalies. These factors are very essential in assessing groundwater potential of an area with the help of ground truthing. Thematic layers important for assessing groundwater potential of an area include geology, geomorphology, hydrogeology/landforms, drainage density, lineament density; lithology, slope and land cover (Tesfaye, 2010).

The alarming degradation of water monitoring systems and the obsolescence of in situ measurement equipment in developing countries necessitated additional new solutions to improve water governance based upon reliable, comprehensive and timely water information (Meijerink, 2007). These are achievable through satellite imageries interpretation and mapping. It is reported by

Meijerink (2007) that different aspects of current global climatic changes affect the water cycle; satellite remote sensing provide a valuable global overview that can monitor changes in rainfall, extent of water bodies, vegetation and at a more local level to identify zones of groundwater potential. Kluge, Ilmberger, Von and Aesbach (2007) used Radon-122 analysis to trace and quantify groundwater inflow in lakes in Germany. This method is so important and useful there due to the nature of chemical flow in the environment especially in the ground. Determination of aquifer properties, pumping tests, yield and static water level assisted in successfully mapping, delineating and characterizing groundwater potential zones (Alkali, Gadzama and Yusuf, 2011).

Remotely sensed data and GIS are playing increasing role in the field of hydrology, groundwater resource development and management. Remote sensing provides multi-spectral, multi temporal and multi sensor data of the earth's surface (Choudhury, 1999). These tools are very effective in delineating groundwater potential zones, and recharge zones. Modern tools of GIS, Remote sensing and Multicriterian analysis using AHP and groundtruthting can provide efficient method for delineating groundwater prospect zones in an area and can establish relationship between geological characteristics and yield data in an area (Kavidha and Elangovan, 2013).

However, the use of GIS and remote sensing technology involves large amounts of spatial data their wise management of the information in arriving at useful and valid results. It was reported by Shakeel, Ramaswamy and Abdin (2008) that groundwater occurrence being a sub surface phenomenon, its identification and location is based on indirect analysis of some directly observed terrain features like geological geomorphologic features and their hydrologic characters and wise interpretations.

Satellite remote sensing provides opportunities for better observation and more systematic analysis of various geomorphic units' lineaments features following the integration with the help of GIS to demarcate the groundwater potential zones with the aid of ground truthting. Observation of alluvial

structures can also serves as an indicators of groundwater potential. For example, Srivastava and Murthy (1992) demonstrated that alluvial fans, river terraces, palaeochannels, flood plains and other alluvial features are good indicators of groundwater potential zones.

1.2 STATEMENT OF THE RESEARCH PROBLEM

The increasing demand for drinking water in rural areas of Kano State resulting from exponential population growth rate, primed the need for increased water supply. Many efforts have been made by various governments to make water available in the rural areas through construction of dams and reservoirs, water treatment plants such as Tiga water treatment plant, Watari water treatment plant and recently Tamburawa treatment plant in addition to hand dug wells. Water resources development plan was developed in Kano for 15 years 1970-1985 (Ahmed, 2003), with the intention of increasing water supply in rural areas of Kano State. Boreholes were also constructed through KNARDA Borehole programme. It is reported by Sara and Charles (1988), that between 1983 and 1986 1,000 rural communities were provided with boreholes by KNARDA in old Kano State and out of 429 bore holes constructed in1988 for rural water supply only 364 were successful. In another development, a total of 1,737 Bore holes were completed during Phases I, II and III of the programme under the supervision of Wardrop Engineering Inc (Wardrop, 1990). The purpose of this is to reduce water shortage in the rural areas of Kano.

Despite these efforts water supply is still in short supply in virtually all rural areas of Kano State. Some of the bore hole projects have failed due to inappropriate techniques used for their citing. Supply of drinking water in the rural areas of Kano is focused mostly on harnessing and exploiting surface water. This is because the area is mostly underlain by the Basement Complex rocks with probably low permeability and thus poor aquifers due to inadequate information on groundwater

condition. This resulted into shortage of water which resulted into taking water from any kind of water source (Plate: 1.2, 1.2 and 1.3).

The major division in the geology of Kano state is between the Chad formation sedimentary units which occupy about one third of the state and Basement Complex out cropping in the other two thirds of the state and also underlying the Chad sediments (Wardrop, 1990). For these reasons groundwater prospecting and exploitation is difficult and neglected in the study area.

Surveys of groundwater in Kano State were conducted by WRECA, MRCD, DFFRI and KNARDA in 1980s (Wardrop, 1990). These surveys provide geophysical data based on boreholes drilling. These Geophysical data are inadequate due to their limited applications to areas outside the surveys areas. Beside; regional groundwater modelling studies in large semiarid regions are often hampered by field data scarcity, in both space and time. In such a case remote sensing can offer complementary datasets and guide further investigations (Jackson, 2002; Brunner *et al.*, 2004; Schmid *et al.*, 2005 in Leblanc (2007).

Most of the studies undertaken on groundwater in the study area were done using geophysical methods, and not complemented with remote sensing or GIS. Reynold (1987) conducted analysis on groundwater of Kano South based on geophysical investigation of over 200 rural villages and the study revealed that there is the need for more studies on groundwater due to insufficient data collection for development of rural water supply.

From available literature on groundwater prospecting in the study area, there is no previous study focusing on the use of remote sensing and GIS in assessing groundwater resource potential in rural areas of Kano State. If groundwater potential in rural areas of Kano state will be assessed using remote sensing, GIS and Multicriterian evaluation among others, it may assist in reducing water shortage from unsafe sources and the number of people drinking untreated water which causes water born diseases and probably death. Indeed there are many people without safe drinking water,

which result in many water borne diseases and consequently lead to deaths in developing countries (WMO, 2002).

Study of ground water potential is established by having idea or knowledge of water supply situation of the area under study. That is why Emmanuel (2012) uses interview in Ghana, Jasz (2011) adopted investigative and qualitative approach in Niassa province Mozambique and Chris (2005) among others who uses secondary data and questionnaire survey to study water supply situation in Kenya.

Remotely sensed information on topography, drainage, fracture patterns, is directly related to the presence or absence of groundwater (Thapa *et al.*, 2008). Amaresh, Singh and Prakash (2009) used remotely sensed data IRS1C LISS III geocoded of scale 1:50,000,Indian toposheet 63k/12 and8/k of a scale 1:50,000, Field data such as depth to water level pre and post monsoon data, geoelectrical sounding data and drilling data of Nagar block of Mirzapur district of Utter Pradesh. Polygons were created out of thematic maps by GIS. Their study arrived at dividing the study area in to excellent, very good, good, moderate, poor in terms of groundwater occurrence and suitable weights were assigned. In another development Wim, Karl and Gerrit in Norman, Lucas and Gerrit (eds) (2001) states that new technology is emerging to map and quantify the presence of water in the ground directly using nuclear magnetic resonance (NMR). This method is done through observation of Protons presence in water by applying a magnetic field process by the use of signals which are detectable. Detection of precession signal is therefore a direct indication of the presence of water below the surface. Likewise absence of the signal is an indication of absence of groundwater.

KhairulAnam, Juharimat and Ibrahim (2000) used Land Sat TM taken on 6th march, 1996 to predict groundwater potential zones in Langat basin India. They first of all obtained bore hole data and then analysed it based on annual rainfall ,lithology, lineament density, topography, elevation, slope

steepness, drainage density and soil types to arrived at classifying the study area into Very poor, Poor, Good, Very Good and Excellent in terms of groundwater potential. Also Goyal, Bharadwaj and Jugran (2009) remarked that factors such as Geology, Geomorphology, soil, lineament, lithology and vegetation of a selected area can be used together with interpretation of satellite images and selective ground truthing to identify areas of groundwater potential. Moore (1982), Shaban, Kwawlie and Abdullahi (2006), Ramaswamy and Abdin (2008), Shakeel *et al* (2008) and Sultan, Hatem, Santos and Abdul (2009) applied this method in their studies.

Carlo (1998) in his research on groundwater used Landsat Thematic Mapper because it is suitable for lineament and terrain analyses. In this case Geomorphologic data was compared with Landsat TM information and analysis was done through ARC info 3.4 GIS software. Jasrotia, Kumar and Saraf (2007) in their work at Jammu District in India states that the use of multidisciplinary data thematic maps were constructed using merge Image Linear Scanner (LISS) and panchromatic (PAN) remote sensing data. Aquifer parameters thematic layers were prepared from convectional field data, drainage network maps were superimposed over the artificial recharge zone maps by considering the terrain conditions and suitable areas for replenishing groundwater were identified. From these it can be seen that Landsat and thematic maps are useful in groundwater prospecting especially when combined with depth to water table data.

In another development, Arun, Kundu and Kundu (2009) conducted groundwater survey of part of India using survey India toposheet, thematic maps, Geomorphology, Soil, geology, remote sensing digital data set IRS 1B and groundwater data: depth to water level of 34 wells. Girish, Rameshwar and Argarwal (2009) applied remote sensing and GIS in groundwater studies at Bankar watershed using India Sat III data. They prepared geomorphologic and lineament map of the study area using vertical electrical sounding (VES) in different geomorphic units. Electrical resistivity values were assigned to different formations by calibrating resistivity with borehole data. Based on this, groundwater potential zones were identified. Oluwatola, Oluwatoyin, Moshood and Abel (2013)

delineated groundwater potential zones in SW Nigeria (Oyo, Ogun, Osun, Ekiti and Ondo States) using GIS weighted overlay method and borehole data. They arrived at three groundwater potential zones low, moderate and high. This indicates that survey of groundwater using remote sensing, GIS and integrated method may yield better result than the convectional geophysical techniques; particularly for large areas. Subin, Jose, Jayasree, Santhosh and Rajendra (2012) States that Vertical Electrical Sounding (VES) is mostly used for locating suitable sites for groundwater exploration.

Tesfaye (2010) uses integrated method in evaluating groundwater potential of Blilate river catchment south rift valley of Ethiopia through generation of thematic maps using GIS. The result was validated by selective ground trusth verification and four groundwater potential zones were identified which are high, moderate, low and poor. Also Sitender (2011) delineated groundwater potential zones of Medwat district Haryana India using Multicriterian Evaluation (MCE) and arrived at five groundwater potential zones which are very poor, poor to moderate, moderate to good, good to very good and excellent.

The use of remote sensing and GIS to complement geophysical surveys methods may assist in generating more reliable data on groundwater resources for rural groundwater development. The use of RS, GIS and integrated approach among others in evaluating groundwater potential zones in rural areas of Kano state will play a great role in solving its problems of water shortage or scarcity. At the same time use of integrated method will assist in generating more reliable data for groundwater development and planning in Kano state.



Plate1.1: Women and Children struggling to fetch water for domestic uses at Babawa

Source: Field Work, 2011



Plate 1.2: Green water as a major source of drinking water in Riruwai

Source: Field Work, 2011



Pate 1.3: Animal and people using the same source of water in Riruwai

Source: Field Work, 2011

The research questions for this study are as follows.

1. What is the nature of Water supply in the rural areas of Kano?
2. What is the nature of the hydrogeology of these areas?
3. What is the groundwater potential of the area?
4. What are the characteristics of the identified potential zones?

1.3 AIM AND OBJECTIVES

The aim of this study is to assess groundwater potential zones for rural water supply in Kano state Nigeria using GIS and remote sensing techniques.

The following objectives are set towards achieving the aim of this study, which are to:-

(i) Evaluate the present rural water supply situation in the study areas.

(ii) Assess the nature of hydrogeology of the areas.

(iii) Identify groundwater potential zones for rural water supply Development

(iv) Characterise the identified potential zones.

1.4 HYPOTHESIS

H_o – There is no enough groundwater in Kano State to be harnessed for rural water supply

H_1 – There is abundant occurrence of groundwater in Kano State that can be used to supply water to the rural dwellers.

1.5 JUSTIFICATION FOR THE STUDY

Water supply in the rural areas of Kano depends mainly on reservoirs, ponds and hand dug wells. Prior to the KNARDA borehole project, several government agencies shared the responsibility for the development of domestic water supplies in the state (Wardrop, 1990). Despite these efforts drinking water is still inadequate. This is due to increasing number of population and agricultural

expansion in the rural areas of the state. This resulted into taking untreated surface water from dams and ponds (Appendix 6a, 6b and 6c).

Groundwater prospecting using remote sensing and GIS in complement with geophysical method will be of great importance in solving water shortage problem and provides useful data for groundwater prospecting and drilling and it will at the same time help to reduce cost and time needed for extracting information. A study of this nature is expected to assist in selecting promising areas for father groundwater exploration. Integrated study of this nature can be cost effective for well sites selection. Assessment of groundwater potential of rural areas of Kano State will provide large volume of data which could be used for water resources development planning and management.

1.6 THE SCOPE OF THE STUDY

The research focuses on assessing groundwater potential of rural areas of parts of Kano State. These parts include Yandadi, Shuwaki, Dokadawa, Karofinyashi, Shakogi, Alajawa, Riruwai, Zainabi, Tudunkaya, Turawa, Fammar, Tarai, Babawa, Tumbau, Karfi and Kosawa.

A total of 16 sampling points were involved in the study from 16 rural Villages out of 8 Local Government areas selected from the 3 Senatorial Districts of Kano state (Table: 3.1). Coordinates, and geophysical data of each sampling point were measured in dry season and wet season of one single year. The variables considered in the study are resistivity values, apparent resistivity, layers configurations and depth. Responses on water supply situation are part of the variables of the study. Temporal scale for the VES survey is wet season 2011 and dry season 2012. Interview of respondents was undertaken in 2012. For nature of hydrogeology of the study area drainage and slope were considered. Aquifer parameters such as porosity, water content, hydraulic head, hydraulic conductivity, specific yield and specific storage were considered. Drawdown and discharge were also in cooperated from pumping test.

For the GIS and Remote sensing weighted overlay the following factors were involved in the study: - Lineament length density, Drainage density, Geology, Hydrogeology, Soil and Vegetation.

1.7 ORGANIZATION OF THE REST OF THE CHAPTERS

The entire work is organised and presented in six chapters as follows: - Chapter one deals with background of the study which comprises general introduction, definition of some terms and fundamentals of the study. Others are statement of research problem, justification of the study, research questions, aim and objectives and scope and limitations. Chapter two is literature review and conceptual framework. It touches definitions of important terms, importance of water to life as whole, historical development of water resources globally, in African context and Nigeria. Water scarcity problems and how it affects the entire world. Ground water development in the globe and in Nigeria, groundwater and rural water supply, groundwater potential and groundwater exploration, remote sensing and G.I.S application to groundwater exploration, groundwater exploration using integrated methods, recent studies using integrated approach, Groundwater Hydrology, Factors affecting Groundwater storage and Groundwater Quality.

Chapter three is about location of study area, physical and human settings of the study area and methodology of the research which includes type of data used in the study, sampling techniques, sources and techniques of data collection such as sources of water supply, nature of hydrogeology and depth to groundwater table using vertical electrical sounding data and weighted overlay analysis and characterisation of groundwater potential zones. In this chapter techniques of data analysis were presented. Chapter four deal with presentation of results. Chapter five presents general discussion on results relating it to the works of previous researchers. Lastly chapter six is the conclusion, summary and general recommendations with particular reference to the findings of the research work.

CHAPTER TWO: CONCEPTUAL FRAME WORK AND LITERATURE REVIEW

This chapter reviewed relevant literature related to the topic of study. It touches the importance of water to life, water resources development and water shortages, groundwater resources and development, groundwater and rural water supply, groundwater potential, groundwater exploration, remote sensing, GIS and geophysical methods applications to groundwater resource studies for development, Groundwater hydrology, factors affecting groundwater storage and groundwater quality.

2.1 CONCEPTUAL FRAME

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) Water scarcity is a topic of discussion globally especially in developing regions. Macdonald (2005), pointed out that there are still at least 1.1 billion people across the world that do 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, pores are completely filled with water. 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. 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.

In addition to other conventional methods remote sensing and GIS are used in groundwater exploration. Lillesan and Kiefer (2000) stated that remote sensing is the science of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation. The main reason for using remote sensing in groundwater exploration is cost effectiveness of well sites selection. Together with geophysical methods costs can be reduced considerably (Taylor *et al*, 1999). Integration of two or more technologies has proven to be an efficient tool in groundwater studies (Krishnamurthy *et al* 1996, Sander 1996, Kamaraju *et al* 1996, Saraf and Choudhury 1998).

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) stated that groundwater moves from higher elevations to lower elevations and from location of higher pressure to location of lower pressure. Groundwater recharge and storage to 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 (Memon, 1995) cited in Arnold *et al* (2000). Groundwater studies can be achieved using integrated approach that involves multiple methods.

Based on the above, many researchers applied conventional methods in groundwater exploration studies. Notably among them is Saumitra (2008) who used both geophysical, remote sensing and GIS data in groundwater exploration in India. Others who used the same approach are Babar (2001), Girish *et al*(2009), Goyal *et al* (2009), Carlo (1998), Srivastava and Muthy (1992) , Arun *et al* (2009),Charles and Richardson (2010), Nagarajan and Singh (2009), Peter *et al* (2011), LVIA (2012), Tesfaye (2010) and Shahid *el al* (2009).

2.2 IMPORTANCE OF WATER TO LIFE

Water is the most abundant solvent on the earth that support all forms of life. Over 70% of the earth surface is covered by water in Oceans, lakes, rivers, ponds, lagoons and other water bodies. Groundwater is part of the available water in the globe for human utilization. Animal and plant bodies contain water for their physiological systems and regulation of body temperature. Food and beverages contain significant amount of water within them. Water serves as coolants in heavy to light industries.

Water is very essential to life that is why people are looking for it at all cost for their domestic, industrial and other uses. The physical reality of life is defined by water; it is the essence of our existence and is therefore the most critical resource supplied by earth systems (Robert, 2007). If drinking water is scarce or absent, people can spend much time for carrying it to their houses. This is because water is a medium of life, since man drinks it and utilizes it in many ways. Batmanghelidji (2004) in his book 'Your body's many cries for water gives a wonderful essay on water and its vital role in health and life, he 'states since water we drink provide for cell functions and its volume requirements, the decrease in our daily water intake affect the efficiency of cell

activity ... as a result chronic dehydration causes symptoms that equal diseases...''Water is a basic ingredient of life.

It was reported by Tanner and Roades (2003) that the human body contains from 55% to 78% water, depending on the body size and to function properly, the body requires between one and seven litres of water per day to avoid dehydration. The intake takes place through drinking, eating of beverages and other foods that contain water. From philosophical point of view, internet secret text (2010) reports that ancient Greek philosopher Empedocles held that water is one of the four classical elements along with fire, earth and air, and was regarded as the ylem or basic substance of the Universe. The classical element of water also one of the five elements in traditional Chinese philosophy, along with earth, fire, wood and metal. These show how important water is to life.

Religions obligations are fulfilled in the presence of water, it is considered as a purifier in most religious of the world. Major faiths that incorporate ritual washing include Islam, Christianity, Hinduism, Rastafari movement, Shinto, Taoism, Judaism and Wicca, These happen in the form of washing (ablution, sacrament of Christianity called baptism and ritual washings of other religions (Marks,2001).

Generally water is regarded as life and life is regarded as water. Since all aspects of life depend on water for domestic, industrial, religious and agricultural uses, there is need to scout for available sources of water. Among the available sources groundwater seems to be the most important one. Water has always played and continues to play a central role in human societies.

2.3 WATER RESOURCES DEVELOPMENT

Water is the resource that sustains all life on earth and is a key element of sustainable development. Water is an infinite resource, worldwide there is an imbalance between water utilisation and water resources management. This imbalance has brought a veritable crisis with regard to water in many

regions of the world. Yatsuka (2002) reported that it is projected that by 2025, about 3.5 billion people-approximately 6.5 times as many people as in the year 2000- will live in water stressed countries. This indicates the level of water resource deterioration globally.

In most regions of the world, water availability has rapidly decreased for example in Asia water availability per capita ranks as least in the world with 4,200m3/capita per year a little more than half the world average of 7,000m3. In the year 2025, water availability per capita in Asian region and the rest of the world including africa will probably be between 15 and 35 less than that of 1950 (ADB,2001).

Water shortage and scarcity necessitated for world conferences on water. WHO report (1999) shows that ministerial conference on environment and Development in Asia and the Pacific (MCED) in the year 2000 identified conservation and integrated management of fresh water resources as one of the eight priority areas of the Asian region. Also ministerial declaration issued at the international conference on fresh water held at Bonn in December 2011 also made a call to the UN Secretary General to strengthen the coordination coherence of activities within the UN system on water issues in an exclusive manner. Outcomes of world water forum conducted by Global water partnership increases global awareness of water crisis and promote actions for sustainable use and development of water resources.

2.3.1 Water Resources Development in Africa

The increasing severity of water crises represents a real threat for sustainable development in the new millennium. The amount of water needed for development in the continent have increased but the population have tripled. Demand for water is set to grow markedly in coming decades due to population growth and need for more water to use. If water use continues to increase at the same rate, by 2025 almost 5 billion of the 7.5 billion inhabitants of the planet will live in areas where it will be difficult to satisfy basic water needs (UNECA, 2005). Africa is a continent with great

possibilities, but it also faces great uncertainties concerning exploitation and development of its water resources. Africa contains more than 57 international water ways covering more than 60% of the continent. However Africa also contains the largest desert in the world, the Sahara lying north of the equator. It also suffers from repeated and prolonged periods of drought. That is why it is necessary to develop and plan water resource of the African continent. It was discovered by scientists that the notoriously dry continent of Africa is sitting on a vast reservoir of groundwater. They argue that the total volume of water in aquifers underground is 100 times the amount found on the surface (Bonsor, 2012).

Africa's river systems have been the target of development planners since 1960s. Many rivers of the continent have been dammed for power generation, irrigation, flood control and water supply. Water resources development planning has been widely adopted in Africa, and often enough water resources development has come to be synonymous with river basin development (Adams, 1992). In spite of all these water shortage is still a problem in Africa.

2.3.2 Water resource Development in Nigeria

Water scarcity and water quality issues resulted into more concern on water resources in Nigeria. Mabogunje (1965) has reviewed the pattern of water resources development in Nigeria especially during the colonial period. He added that the primary aim is to do away with the problems of water shortage and quality deterioration. Today in Nigeria, less than 50% of the population have access to potable water supply and majority are from rural areas (WUP, 2001).

A number of water development plans were established all with intention of solving problems relating to water. The first modern water supply scheme in the country was established in Lagos in 1915 and by 1953, 27 other water works had been built in various parts of the country(Ayoade,1975) most of the schemes suffered from lack of finance which lower their performance. Water consumption of the country also increased as a result of increase in population

for example Ayoade (1975) states that the total water consumed in Nigeria rose 13.8 million gallons in 1953 to over 57 million gallons in 1960.

National Development plans from 1962 to date have invested much on water resources development but still there is need for more planning and development. Nigeria has demonstrated the need for proper management and planning of country's water resources. A comprehensive geographical survey is necessary in order to assess the extent of groundwater and exploit it for effective rural water supply (Douglas, 1973).

2.4 WATER SHORTAGE

Water is an essential resource for life and good health. Lack of water to meet daily needs is a reality today for one out of three people around the world. Globally, the problem is getting worse as cities and population grow and the needs for water increase in agriculture, industry and household. Water scarcity is a topic of discussion globally especially in developing regions. 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. Many of these people live in rural areas and are among the poorest and most vulnerable to be found anywhere in the world. In India water supply and sanitation continue to be inadequate, despite longstanding efforts by various levels of governments and communities at improving coverage (Ayush, 2010).

In sub Saharan Africa, 300 million people have no access to safe water supplies out of which approximately 80% live in rural areas (Macdonald, 2005).This resulted into sufferings and under developments. It was reported by Timorthy *et al* (1994) that lack of adequate potable and agricultural water supplies inhibits the progress of developing countries and is the cause of considerable hardship to humans worldwide. In another development Lean, Hinrichen and Markhem (1990), established that West African countries experience lack of safe and adequate water for their inhabitants; 25 to 50 percent of the population do not have access to safe water

supplies. The trend is so everywhere, as population figures are increasing water demand also is greatly increasing thereby causing shortage.

As population increases and development calls for increased allocation of groundwater and surface for domestic, agricultural and industrial sectors, the pressure on water resources intensifies, leading to tension, conflicts among users and excessive pressure on the environment. UNDP (2006) reported that people in the slums of developing countries typically pay 5-10 times more per unit of water than do people with access to piped water. In another development WMO (2008), revealed that by 2025, 1800 million people will be living in countries with absolute water scarcity and two-thirds of the world population could be under stress condition.

For poor people, water scarcity is not only about droughts or rivers running dry. Above all, it is about guaranteeing the fair and access they need to sustain their lives and secure livelihood. In Nigeria water scarcity as far back as even before the colonial period when people migrate from one part of the country to another in search of water. It is established that only 27.4% of the total population of the country was served with improved water supply in 1974, in the country, with rural population, accounting for not more than 0.30% (Oyebende, 1977 in Sheka, 2005, cited in Nura and Sabo, 2011).

2.5 GROUNDWATER RESOURCE AND DEVELOPMENT

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, pores are completely filled with water. Trimmer (2000) defines groundwater as water that naturally occurs in porous rock materials underground.

Groundwater is a critical underlying resource for human survival and economic development in extensive drought-prone areas of south-eastern, east and western Africa especially where the average is less than (say) 1,000 mm/a (Stephen, Albert and Hector, 2002). Robert (2007) lamented that groundwater is a resource that make up an impressive 90% of the fresh water that is readily available for human use. This is one of the reasons why groundwater is regarded as major source of drinking water in most parts of the world. United States of America has one of the safest water supplies in the world but yet the quality of drinking water has continuously been deteriorating. U S G A (2006) report that 49% of the US population depend on groundwater for its drinking water supply from either a public source or a private well. At present ¾ of the public water supply in Germany is taken from groundwater sources and only ¼ is taken from surface water (Theogeoge, 1997).

In India groundwater accounts for large percentage of water used for irrigation and drinking for example Aditi and Tushaar (2002) states that over 60% of water supply in India is from groundwater, that is why it is regarded as poverty reduction tool in rural areas.

The potential importance of groundwater as a resource is indicated by estimates of the world's water balance. Demenico and Schwartz (1990) revealed that according to most estimates, saline oceans and seas account for 94% to more than 97% of the world's water, while another 2% is held in glaciers and polar ice caps. Although groundwater constitutes a few percentages by volume of the total water at or near the earth's surface (...) thus, it becomes apparent that groundwater makes up the world's utilisable freshwater resources, 95% or more by volume.

Groundwater is widely used because of its high quality. Groundwater development unfolds rapidly once a minimum level of technology and energy become widely available (Shah, 1993). Groundwater use is becoming more apparent than surface water for example UN/WWAP (2003)

concludes that groundwater use often brings large economic benefits per unit volume, because of ready local availability, drought reliability and good quality requiring minimal treatment.

2.5.1 Groundwater Resource Development in Nigeria

Provision of safe drinking water and basic sanitations are within the framework of the United Nations Millennium Development Goals (MDGs). This is only possible through development of water resource of any nation. In Nigeria, like in all parts of the world, surface water development is invariably associated with various health and environmental consequences which include drainage up-set, collapse of dams, spread of diseases and flood. This necessitate government embark upon groundwater resource development. In 1917 Nigerian Geological Survey was established and one of its objectives is to search for groundwater in northern Nigeria. The following organisations are at the forefront in the timely efforts of groundwater resource management: The Earth Summit, the World Water Forum, World Bank, WHO, UNESCO, FAO, UNICEF and UNDP (Nwankwoala, 2011).

Global Survey of Nigeria was carried out in early 1950s by government with intention of developing groundwater resources. First national development plan (1962-1968) resulted into the establishment of river Niger and Lake Chad basin commissions. In 1973 and 1974 Sokoto Rima and Lake Chad Basin authorities were established for developing groundwater resources. The establishment of Federal Ministry of Water Resources in 1975 brings about extensive groundwater development. All these efforts are to develop water supply delivery in line with United Nations International Drinking water supply and sanitation decade (IDWSSD).

Establishment of National Borehole Project in 1980 and formation of Department of Food, Roads and Rural Infrastructure (DFRRI) between 1986 and 1994, Petroleum Trust Fund (PTF) water project between 1995- 1999 improved the nations access to water supply and of recent constituency

water projects by senates, members of house of representatives and members of states house of assembly.

Data on groundwater in Nigeria is inadequate for development. According to Ajayi, Sonuga, Alibon and Oloke (2003) lack of data and information for planning and shortage of manpower among others are the major obstacles to groundwater development in Nigeria.

Population growth rate and industrial development increase water demand in Nigeria and last and reliable option is groundwater. Nwankwoala (2011) reports that groundwater use in Nigeria is characterised by uncoordinated development and supply to all sectors: rural and urban users, small and large scale users, industrial and agricultural users. This shows that there is the need for formulation of efficient and effective policies on groundwater through data collection and organisation for adequate water supply. Improvements of groundwater supply in areas of formulation of adequate, efficient and effective water policies, funding and appropriate infrastructure as well as monitoring and evaluation (Custodio, 2002).

All over the world, groundwater formation varies with geologic formations depending on location and others factors like climate. Ifabiyi (2005), stated that 50% of the Nigeria's population and majority of rural scattered communities are found in places underlain by Basement Complex Rocks where dam construction will be an unnecessary exercise in view of the dispersed nature of settlements. Also Faniran and Omorinbola (1980) in Ifabiyi (2005) states that in Nigeria sedimentary regions are ascribed to have higher groundwater resources...Basement complex regions have appreciable quantity of water in them. This shows that groundwater development is necessary for overall national development. The cost of development of groundwater is cheaper than that of surface water and the quality of the water reasonably good requiring only minimal treatment in a readily used form (Offodile, 2000).

Groundwater development is an excellent option for sustainable water supplies in Nigeria. However, to achieve a sustainable supply, planning is required this needs hydrological and hydro geological data, as well information on water demand and general socioeconomic conditions (Onugba and Yaya, 2008).

2.5.2 Groundwater and Rural Water Supply

Water supply in rural areas depends mostly on groundwater sources. In the areas of shallow water deposits hand dung wells are sunk to supply the water need by the local inhabitants. Aditi and Tushaar (2002) reports that groundwater has emerged as the primary domestic water source and poverty reduction tool in India's rural areas.

Over much of Africa, groundwater is the only realistic water supply option for meeting dispersed rural demand (Macdonald, 2005). In Bangladash it was reported by Pramanik (1989), that groundwater is the main source of water supply especially in rural areas. In USA groundwater is regarded as the major source of rural water supply. Groundwater is an important resource in much of the Midwestern USA. It supplies drinking water for over 95% of the rural population and over 50% of the urban population (Bernard, 2003).

In sub-Saharan Africa the trend is the same with the rest of the world. It was reported by Macdonald and Davies (2000), that groundwater has proved the most reliable source for meeting rural water supply demand in sub-Saharan Africa. He made mention of four (4) main hydrological environments in sub-Saharan Africa which are good for rural groundwater supply. They are as follows:-

- Crystalline basement occupies about 40% of land area of sub Saharan Africa; with 220 million people living in rural areas depending on it for drinking water. The water occurs in either weathered sediments or fractured rock.

- Volcanic rock hydrological environment occupying 6% of the total land area of sub-Saharan Africa with a rural population 45million people depending on it for drinking water. The water occurs in paleosoils.
- Consolidated sedimentary environment which occupies 32% of the total land area of sub-Saharan Africa. About 110 million people in the rural population depend on it. Here the groundwater is little.
- Unconsolidated sedimentary environment which occupy 22% of the total land area of sub Saharan Africa with rural population of about 60 million people depend on it. The groundwater occurs in sand and gravels.

In Nigeria the trend remains the same. It was reported by Onugba and Yaya (2008), that despite the abundant water resources in the country, the current water supply coverage in rural areas is 40-50% for which groundwater is the most widely used option. It is therefore agreed that in Nigeria groundwater provides the only realistic water supply option for meeting dispersed rural demand. The totality of rural life depends primarily on groundwater for the survival of the rural populace. These make it important to study groundwater situation in rural areas for rural water supply and development.

2.6 GROUNDWATER POTENTIAL

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

Rai (2008) states that for sustainable groundwater development of an area, delineation of aquifers is pre-requisite for the assessment of regional and local groundwater potential. Assessment of groundwater potential in Nigeria was conducted through delineation of aquifers by many researchers. Okoro *et al* (2010) for instance, evaluated groundwater potentials in parts of escarpment areas of south-eastern Nigeria.

2.7 GROUNDWATER EXPLORATION

Groundwater exploration means searching or investigating the presence or absence of groundwater. Increasing demand on groundwater necessitated experts and researchers in the field of hydrological studies to look for more ways of groundwater exploration. In many parts of the world groundwater abstraction has exceeded safe yield, resulting in over exploitation and overstressing of the aquifer. Therefore the quantum of available groundwater resource has to assess accurately for its optimum extraction and utilization (Charles and Richardson, 2010).

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. Bobba *et al* (1992) identified areas with relatively warm groundwater on aircraft thermal imagery recorded during the winter in Ontario and Canada and related them to either shallow aquifers or discharge areas of deeper flow systems.

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. Julius (2009), uses schlumberger array method with borehole data to study groundwater potential and recharge zones in parts of Delta state. In this 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 hand-

dug wells data, elevation and locations were taken using GPS. The result revealed that 4 to 5 layer configurations were identified and weathered basement is the promising area of groundwater potential. Coker, Makinda and Olowefola (2008) conducted groundwater exploration in Oke-Bada Estate parts of Ibadan. In the study VES survey was carried out and borehole data was also used to validate the result. Four to Three layer configurations were identified. The curves were revealed to be of H, HA, QA and KH types. 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.

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. 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 and the major curves are A, H, KH and HA. Weathered basement is the zone of high recharge. In another development 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. 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).

2.7.1 Remote Sensing and GIS Applications to Groundwater Exploration

In addition to other conventional methods 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. The main reason for using remote sensing in groundwater exploration is cost effectiveness of well sites selection. Together with geophysical methods costs can be reduced considerably (Taylor *et al*, 1999). Information on geology, geomorphology, land management and soil classes are mapped using remote sensing and GIS to identify potential groundwater zones. Raghu and Venkata (2009)

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. Candra *et al* (2010) also uses 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 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).

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. Prasad, Modal, Pallavi, Nandakumar and Singh (2008) have used RS and GIS techniques for groundwater exploration. In hard rock terrains remote sensing and GIS are very suitable in groundwater exploration. 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.

2.7.2 Groundwater Exploration Using Integrated Methods

Groundwater exploration yield a very good result if different methods are applied one in complementary to another. Use of geophysical methods alone may yield an incomplete result likewise remote sensing and Geographical information system without groundtruthing. The integration of remote sensing tools with GIS will provide an even greater hydrogeologic understanding by combining remotely acquired spectral information with other data including geophysical (Timothy, 1994). Combination of remote sensing, GIS and other methods has shown promise for groundwater development in other regions of Africa (Gustafsson, 1993).Solomon and Fredrick (2006) uses integrated approach to study groundwater in hard rock areas of Eritrea.

Integration of two or more technologies has proven to be an efficient tool in groundwater studies (Krishnamurthy *et al* 1996, Sander 1996, Kamaraju *et al* 1996, Saraf and Choudhury 1998). For effective groundwater exploration and exploitation it is important to study the different parameters in an integrated approach. The integration of multiple data sets, with various indications of groundwater availability, can decrease the uncertainty and lead to 'safer' decisions on groundwater (Sander 1996).

Groundwater exploration in hard rock terrain is a complex task. The term hard rock commonly applies to hard and dense rocks that the main part of the groundwater exists and flows in secondary structures, mainly fractures. Crystalline rock types such as meta-volcano-sedimentary, gneiss, meta-igneous and igneous predominate but volcanic rocks are also included in the concept hard rock from a hydrogeological point of view (Olofsson, Jacks, Knutsson and Thunvik (2001). To overcome this complexity, the integrated approach based on advanced application of remote sensing and GIS lead to itself as an efficient and effective result-oriented method for studying the development and management of water resources. Integrated studies using convectional surveys along with Satellite image data interpretation techniques and geographical information system

(GIS) technology are useful, not only to increase accuracy of the result but also to reduce the bias on any single theme (Srinivasa , 2003).

Based on the above, many researchers applied conventional method in groundwater exploration studies. Notably among them is Saumitra (2008) uses both geophysical, remote sensing and GIS data in groundwater exploration in India. Others with the same approach are Babar (2001), Girish et al(2009), Goyal et al (2009), Carlo (1998), Srivastava and Muthy (1992) , Arun et al (2009),Charles and richardson (2010).

Nagarajan and Singh (2009) assessed groundwater potential zones of Kattakulathur district in India using GIS, Remote Sensing and wells data. Thematic maps such as geology, geomorphology, soil hydrogeological group, landuse land cover and drainage maps prepared from DEM has been generated, Toposheet of scale 1:2,000 was used to produced slope map of the study area. Arc GIS 9.2 was used to analyse the data using weighted overlay. The result indicates that 3 groundwater potential zones maps were identified as good, moderate and poor with 49.70km^2, 261.61km^2 and 46.04km^2 respectively and the result was validated using wells data. Peter *et al* (2011) used integrated approach to delineate groundwater recharge sites of Sadat industrial City of Egypt in which a number of factors were integrated using weighted overlay method in Arc GIS Boolean logic true or false method, slope map was developed through DEM and SRTM. Factors considered include distance to production wells, distance to roads, and depth to groundwater, pollution risk, and proximity to waste treatment. Suitable and non suitable areas were identified; flat areas are areas of good recharge because water concentrates while steep slope areas are areas of poor recharge because water drains easily. LVIA (2012) determined groundwater potential of Moyale Teltele Sub basin in Oromia Ethiopia using AHP analysis. Thematic layers including geology, geomorphology, lineament, litholology, vegetation, landuse land cover, drainage density and hydrogeology were integrated. Five groundwater potential classes were identified. Suja and Krishna (2009) uses the same method of MCE to study groundwater potential of Kanya Kumari and

Nambiyar in India. The study involved overlay analysis of thematic layers of slope, lineament, lithology, rainfall data, drainage density and geomorphology, weights were assigned to each thematic layer. The result indicates that poor, moderate, good and very good groundwater potential zones were identified. They concluded that areas of high drainage density, high lineament density, of sandy loam soil, loam soils, dense vegetation, low slope values, coastal plain, valley fills and ridge, valley complex are areas of promising groundwater potential.

2.7.3 Resent Groundwater Studies Using Integrated Approach

Most of the recent studies using integrated approach were undertaken in developed regions of the world, some were done in Asian region with very few in Africa and Latin America. Part of the studies include the one undertaken by Nezar *et al* (2012) in Jordan where land- sat 7 ETM+ of 90m resolution was used to analysed factors such as lineament length density, drainage length density, geological formations, elevation and slope steepness together with bore holes data. Dem was used in generating drainage network maps. It was discovered that 7% of the study area is of higher groundwater potential, 79% is of moderate and 14% is of low potential. It was also discovered that areas of higher relief are of low potential and lower areas are of higher potential, this is based on the standard of Anthony and Doreen (1977) who stated that areas of low slope values are areas of more groundwater prospects and classified conditions of groundwater occurrence based on slope as follows (Table 2.2).

Table 2.2 Classification of slope based on groundwater condition

S/N	Slope	Explanation	Relationship with groundwater
1	0^o - 2^o	Level or almost level	No much runoff, water percolates and forms groundwater
2	2^o - 3^o	Gentle	Runoff increases and groundwater reduces
3	3^o - 5^o	Moderate	Much run off Low groundwater
4	5^o - 18^o	Moderately Steep	Very much Runoff little groundwater
5	$>18^o$	Very Steep	Total Runoff no infiltration insignificant groundwater

Source: Anthony and Doreen (1977)

Shahid *et al* (2009) uses geophysical data, G.I.S and remote sensing in the assessment of groundwater potential of Midnapur District in India. Data obtained from VES surveys are interpolated for the estimation of the subsurface parameters. The parameters are contoured using krigging method and thematic maps were prepared. The result shows that 18% of the study area is of higher prospect, 39% is of moderate prospect and 43% is of poor prospect.

In another development KhairulAnam *et al* (2000) identified groundwater potential zones in Langat basin India using integrated method. Land Sat TM and borehole data were integrated and analysed based on annual rainfall, lithology, lineament density, topography, elevation, slope steepness, drainage density and soil types. The result indicates that the study area is 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 , geoelectrical 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 have been assigned to each category of class using G.I.S. The study area was categorised into excellent, very good, good, moderate and poor groundwater potential zones. 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 in to very low, low moderate and high in terms of groundwater potential. Of recent Kavidha and Elangovan (2013) conducted an integrated study of groundwater in Erode District India. The study involves the use of Wenner array method of VES survey and weighted overlay analysis of GIS and remote sensing. The result indicates that 4-5 layers were identified. Ground water potential zones identified include very good, moderately-good, good and poor and the zones are as follows very good 1%, moderately good 20%, moderate 69% and poor 10%.

In another development study of this nature was also undertaken by 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.

Recent studies in Nigeria have indicated the importance of integrated approach to groundwater exploration. Anudu *et al* (2011) conducted research on groundwater potential in Wamba Nassarawa State Nigeria. The thematic maps used are slope map, Drainage density, contour map and lineament density. The result indicated that lineament and drainage are the most important factors of groundwater identification in the area. Abel and Moshood (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 is 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. Shahid *et al* (2000) uses weighted overlay analysis and study groundwater potential of Bengal India. Three groundwater potential classes were identified and thematic layers such as geology, lineament, soil, drainage density and slope were found to be important. Also Sitender (2011) studied groundwater potential of Haryana India Weighted overlay method and five classes of groundwater potential were identified based on geology, lineament density land use land cover, geomorphology, drainage density and slope.

2.8 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, much 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 intergranular 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 there is the one conducted by Buddemeier and Schloss (2000) in West Fork white river basin at Kansas. In this study potentiometric meter measurement of water level was undertaken using transect, well data and yield. Result of their study indicates that groundwater supply in the basin are obtained from unconsolidated and bedrock aquifer systems. In the study seven unconsolidated aquifer systems are identified, nine bed rock aquifer systems are identified and groundwater level elevations in the basin ranges 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.

In another development Kadam and Sankhua (2012) studied groundwater hydrology of Upper Karha watershed in India. In the 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. In groundwater hydrology, study of groundwater fluctuation is very significant since it is through that quantitative evaluation can be made for development. Marshal et al (2008) undertake 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 in 1994 was estimated. Result of their study indicated that precipitation is 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, it was discovered that groundwater discharge was caused by geologic factors, summer groundwater is approximately 4,000ft^3/s and estimated groundwater use in the area is 30ft^3/s.

2.9 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. 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 to 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 Memon (1995) cited in Arnold *et al* (2000). Climatic elements and geophysical factors are not the only factors that determine groundwater movement and storage. Groundwater storage depend not only on precipitation but also meteorological conditions, as well as on 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- HauLee, Wei-ping and Ru-huanglee, 2006).

Many researches were conducted on groundwater storage, movement and recharge. Most of these studies were based on the stated factors. David *et al* (1997) conducted study on groundwater storage at Danville in Illinois. The researchers use driller's logs, sample descriptions, down hole geophysical logs, information from IEPA and EER data. The result indicates that thin upper layer of reverse seismic refraction is having velocity of approximately 1,25ft/s, middle layer 5,743 to 6,947ft/s and lower layer is 8,244 to 11,833 ft/s. In another development Arnold *et al* (2000) conducted study of groundwater storage and recharge of Upper Mississippi river basin using two methods of water balance component of SWAT model and daily stream method and data was obtained from USGS after every 5 years from 1961 to 1980. The result shows that the USGS

measurements are in close agreement with SWAT simulated and normalised recharge curves were plotted for recharge, surface runoff, base flow and soil ET. A study of groundwater storage was undertaken in Taiwan by Chang-HawLee *et al* (2006) the study uses water balance approach together with base flow record estimation, stable base flow analysis, long term mean annual rainfall data, BFI was calculated using daily stream flow data and mapping was carried out by GIS and geostatistics. Their result indicates that mean annual groundwater is below 0^{o} at western edge and total groundwater recharge is 18 billion tons per year.

2.10 GROUNDWATER QUALITY

In water resources and hydrology groundwater is considered as the cleanest water that requires little or no treatment, because it believed that it is naturally filtered by rock layers and overburden soils. But looking at its sources which are domestic waste water, industrial and other surface waste and clean waters and looking at layers of rocks it path through of different chemical composition, it is of important to consider groundwater quality after the quantity. Freeze and Cherry (1979) states that the order in which ground water encounters strata of different mineralogical composition can exert an important control on the water chemistry.

Water is a solvent that contains dissolved minerals from the rock with which it comes in contact with. Groundwater may contain dissolved minerals and gases that give it the tangy taste enjoyed by many people, and they can express it. But groundwater without these minerals it will give an insipid taste. The most common dissolve minerals in groundwater are sodium, calcium, magnesium, potassium, chlorine, bicarbonate and sulphate in water chemistry these substances are called common constituents. If quality of these dissolved minerals exceed 1,000 mg/L then it is not considered desirable for drinking (Thomas, 2003).

Groundwater quality is like that of surface water because it involves physical, chemical biological parameters. In most areas of the world groundwater quality is better than surface water quality.

Generally the quality of groundwater in Nigeria is better than that of surface water in terms of health criteria but much of the groundwater is corrosive, and some areas have iron, nitrate or fluoride concentration above WHO guideline values (Ince *et al*, 2010). Because of the corrosives nature of groundwater it necessitates the use of stainless steel and plastic materials for water supply equipments. The use of such equipments is to protect water systems from being corroded and to protect the water from contaminants. Groundwater can be contaminated by biological agents depending on the sources. Shallow well can be exposed to contamination from sewage system thereby increasing the risk of presence of water born diseases. For example it is reported by Envuladu *et al* (2012) that all the wells they studied in Jos plateau Nigeria didn't meet quality standard of NAFDAC and WHO in terms of turbidity (TNU).

CHAPTER THREE: THE STUDY AREA AND METHODOLOGY

3.1 STUDY AREA

3.1.1 Location and extent

Kano state extends from latitudes $10^{o}3^{'}$ N to $12^{o}\ 3^{'}$ N and longitude $7^{o}35^{'}$ E to $9^{o}20^{'}$ E (Figure: 3.1). It is made up of 44 Local Government Areas. Out of which 38 are in the rural areas of the state. The total land area of the state is about 20,760sq km (Research and Documentation Directorate Kano, 2009). The total population in 2006 national census is about 9,386,820 people (N. P .C report, 2009).

3.1.2 Geology and landforms

Rural areas of Kano are located on the High Plains of Hausa Land. The areas are underlain by the Basement Complex Rocks of Precambrian era. These Basement Complex Rocks form part of the pan African mobile belt and lies between the West African craton and the Tuareg shield. Earlier workers have intricately linked the overall emplacement of the Nigerian Basement Complex to the earliest orogenic events that affected the African continent. The basement complex rocks include gneisses, migmatites and metasediments of Precambrian ages that have been intruded by a series of pan African age rocks. These rocks have been variably metamorphosed and granitised through tectonometamorphic cycles, so that they have largely converted to migmatite and granite-gneiss (Oyawoye, 1964). Also Sara and Charles (1988) pointed out that the geology underlying parts of Kano State is the basement complex and consisting of variety of metamorphic and igneous rocks ranging in age from Precambrian to Jurassic. Metamorphic rocks are migmatite, gneiss, schist and some quartzite which have been deformed structurally into antiforms, synforms and down faulted blocks.

There are deposits of some mineral resources in the study area such as tin and columbite at Riruwai Doguwa Local Government Area, Kaolin at Gwarzo and Shanono. In the northern extreme of the state comprising Dawakin Tofa, Dambatta, parts of Minjibir and Gezawa Local Government Areas consist of Chad formations which are made up of mostly clay and sands (Research and Documentation Directorate Kano Report, 2009).

The landforms of the study area include Granitic outcrops, hills in form of Ruwares, Residual Hills, and River Valleys all which are distributed within the state and a water fall at Zainabi in Riruwai Doguwa Local Government Area.(Figure: 3.1, 3.2 and 3.3).

Interms of morphology Sara and Charles (1988) divided Kano state into three geomorphic units as follows:-

● North and Central: - which comprises of flat terrain, rare rock outcrops and few broad valleys which are well developed. Weathering profile is mature and lateritic duricrusts are widespread. The depth in fresh bed rock is greater than 40m

●Southeast:- This is an intermediate area in which weathering profile is usually not truncated by erosion, but fresh bedrock is commonly only a few meters below static water level

●West:-This area is drained by head waters of major river valleys that tend be narrow and incised. Inselberges, tors and rock paramonts are common and fresh bed rock is found near the surface.

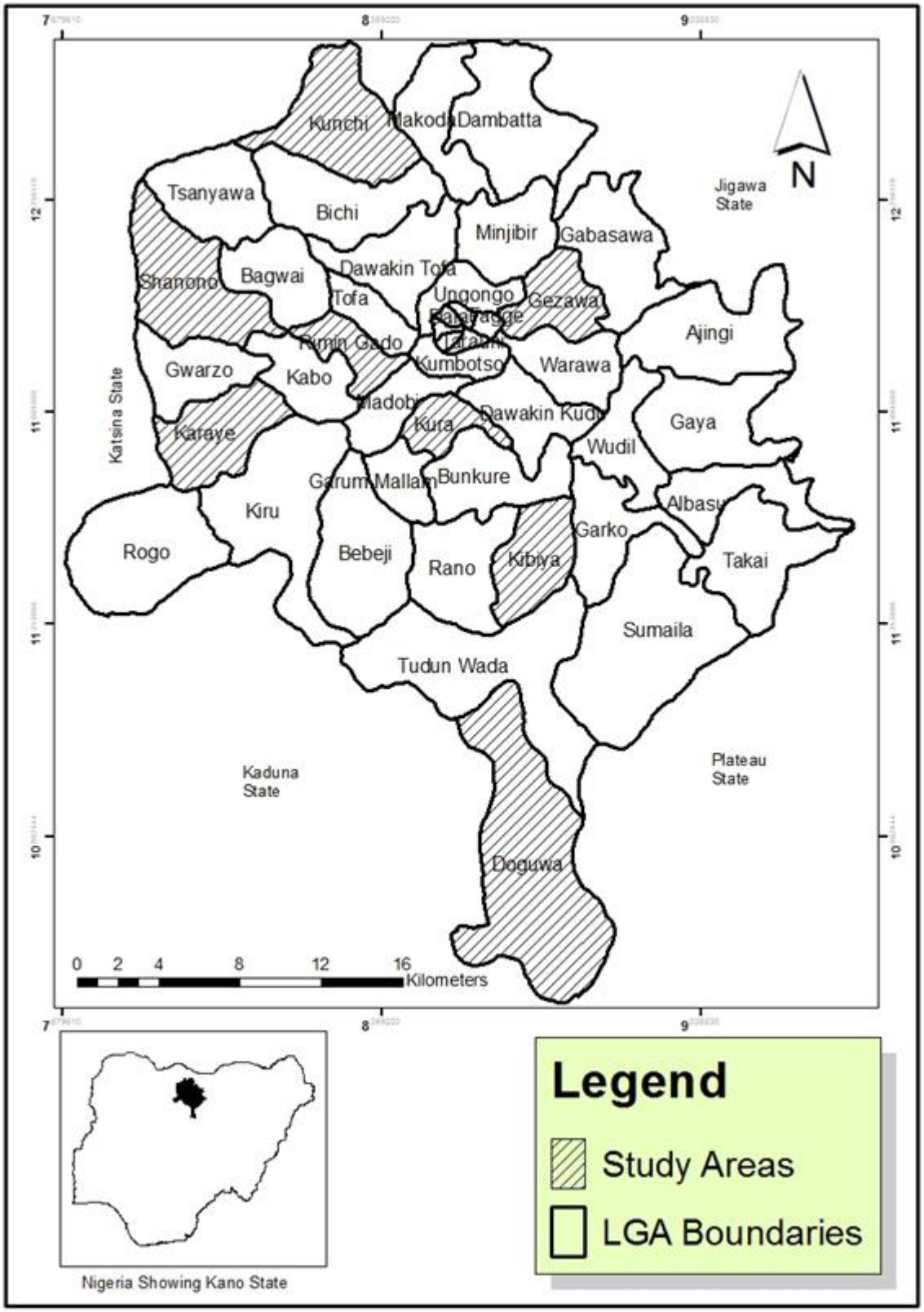
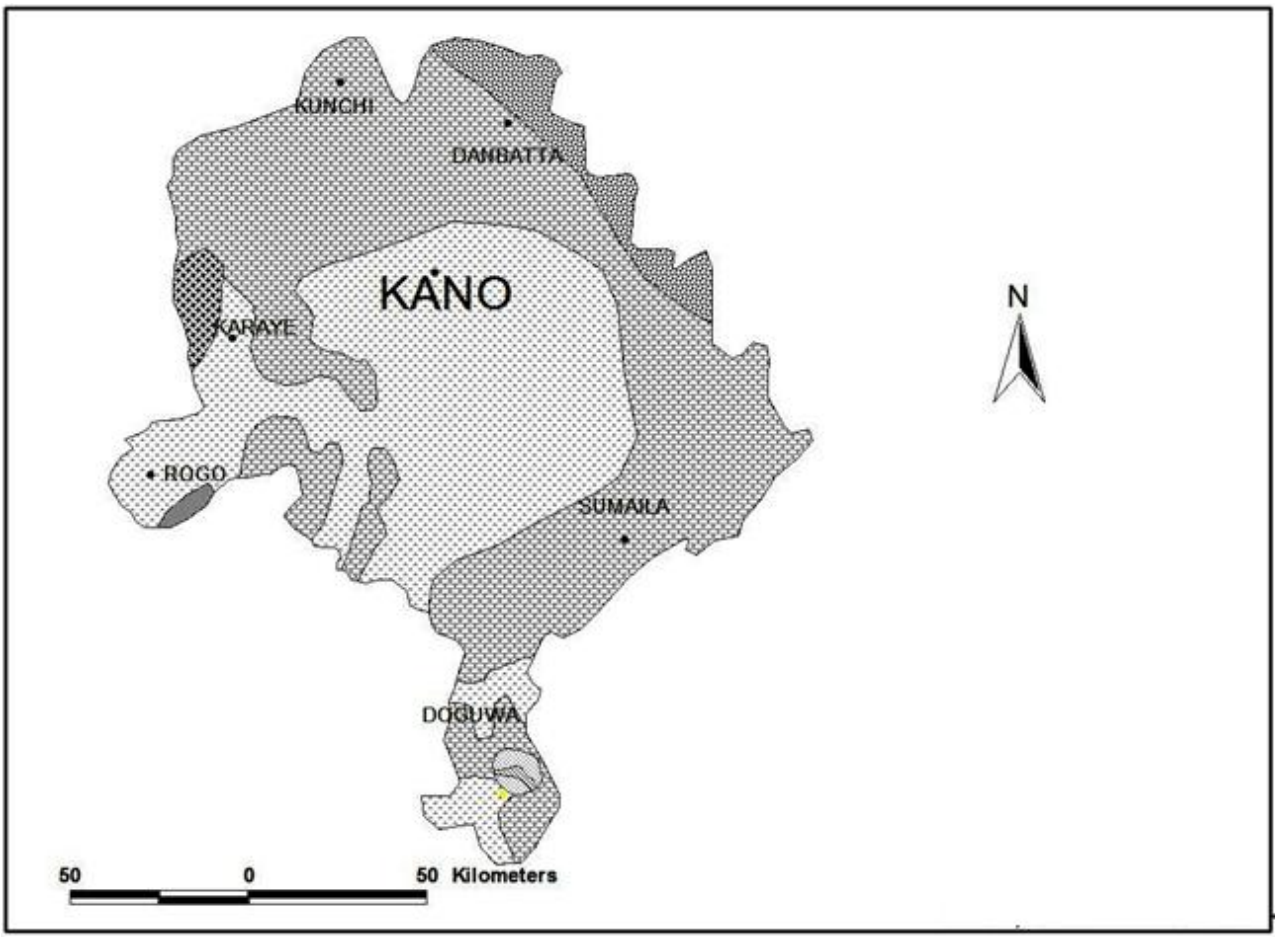


Figure 3.1 Map of the Study Area

Source: Department of geography Bayero University Kano, 2011



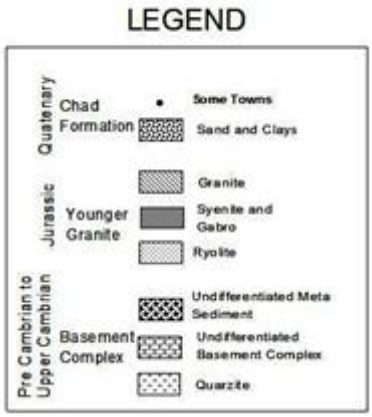
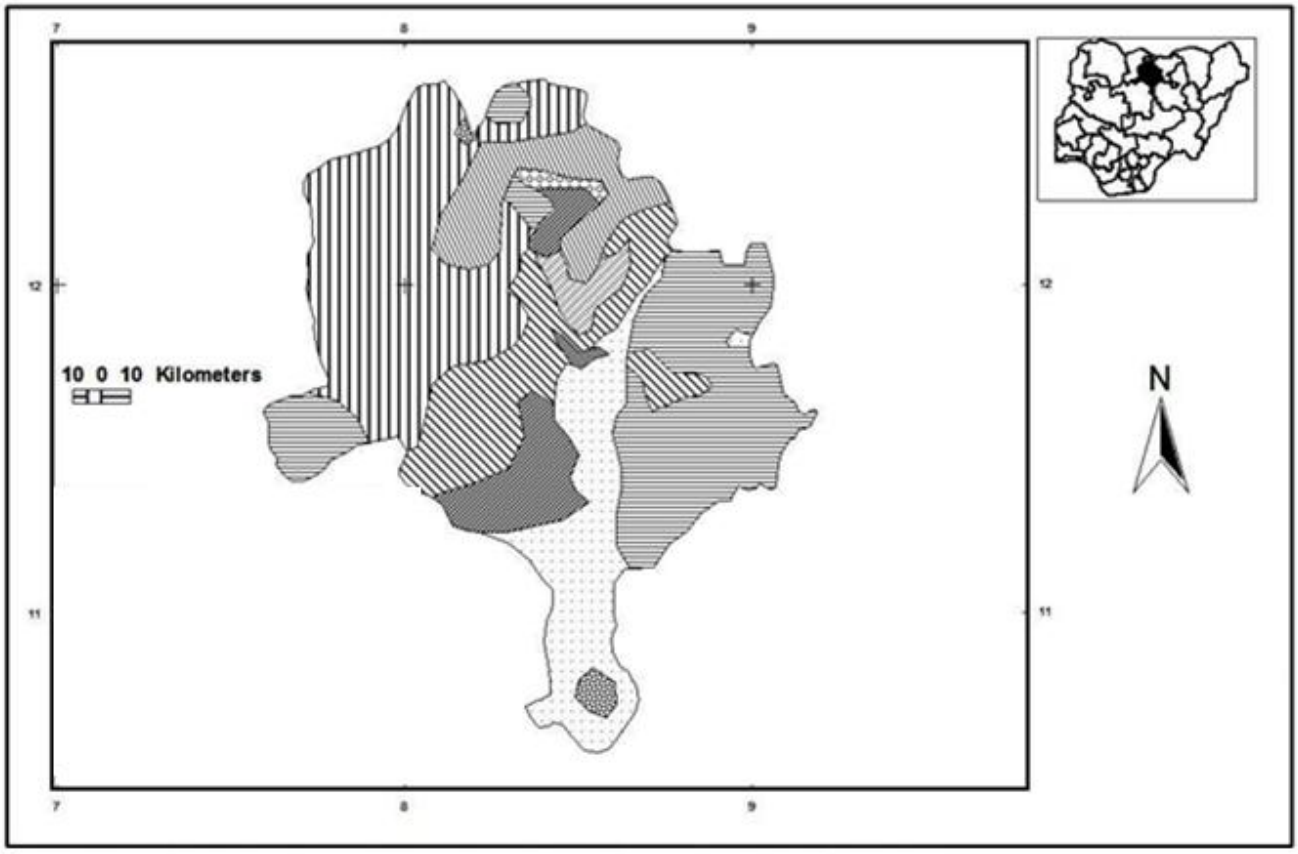


Figure 3.2 Geological Map of Kano State

Source: GIS Lab Geography Department, Bayero University Kano



LEGEND



Figure 3. 3 Hydro-Geological Map of Kano State

Source: GIS Laboratory Geography Department, Bayero University Kano. Adopted from Kano State Agricultural and Rural Development Authority (KNARDA) Rural Water Supply Report (1956)

3.1.3 Climate

Kano State is located in the tropics, a region characterised by alternating wet and dry conditions, with annual rainfall of 850mm occurring between April/May and September/October with peak in July and August. The climate of Kano is also described as seasonally arid and in southern Kano rainy season average is about 150 days May to October. Mean annual rainfall in the southern parts is about 1000mm and in the north it is 635mm (Sara and Charles, 1988).

The climate of Kano is described as Aw by Koppen, with both annual and seasonal variabilities...wet years and dry years may record between 850 and 750mm (Olofin, 1987:14). The temperature varies by warm to hot seasons with the occurrence of the Harmattan between November and February. The climate of Kano state is characterised by four seasons which are dictated by the movement of ITD that control north easterlies and south west easterlies. The four seasons are:-Hot and dry season (*Rani*) it is between February, March and early May, warm and wet season (*Damina*) it is between May to September and it is characterised by surface runoff available for steam flow, warm and dry season (*Kaka*) it is normally around October to November it is referred to as harvest season. And lastly there is cool and dry season (*Bazara*) it is around December to February and it is dominated by the action of north easterlies that brings hamattan.

3.1.4 Hydrology and Drainage

The study area is underlain by the Basement Complex Rocks which are hard and impervious in nature with rivers that flow in north-south direction. Ahmed (2003) reported that there is a considerable relationship between groundwater and drainage pattern with the highest network of rivers in the Basement Complex areas. However the small areas of Chad sediments in Dambatta and Gaya Local Government Areas are expected to have more groundwater and limited Channel development (Figure: 3.4).

In the Basement Complex areas of Kano State two hydrological areas can be identified by USDA (1968), as reported by Ahmed (2003) that the rivers of Kano State are located in the upland areas. The rivers include River Kano, River Challawa, River Iggi and Gaya. The second hydrological areas include the Gari area which comprises of River Gari, Thomas and Jakara. The upland areas receive rainfall of over 800mm annually while the Gari area receives annual rainfall of less than 800mm.

Several dams have been constructed to meet the rural water supply demands. About 25 small to large dams have been constructed including: Gari dam, Wasai dam, Kafin-Ciri dam, Chalawa Gorg dams, Ruwan-Kanya dam, Watari dam, Kanye dam, Gude dam and the Bagauda Lake dam... (Ahmed, 2003).

Together with such rivers as River Kano, River Watari, River Chalawa, River Wudil, River Dudduru Gaya. They form the major hydrological systems that have the potential for rural water supply development. The stream flow in Kano state is characterised by seasonality, river flow is rising and falling in response to rainfall occurrences. The high flow exceeded 10% of the times are recorded mainly in July and August in response to rainfall events 30mm or more (Ahmed, 2003). (Refer to Figure: 3.4 for river, dams and drainage characteristics).

In Kano region groundwater regime was more favourable in both urban and rural areas in those days (1960s to 1980s) according to history. It is reported by Ahmed (2003) that groundwater regime was more favourable before the decades of 1960s to 1980s. Level of well is between 10-12m deep in uplands mostly southern parts of Kano and about 2m in the lowland fadama areas but now 20-25m in uplands and 8m in low land fadama areas mostly northern parts of Kano state.

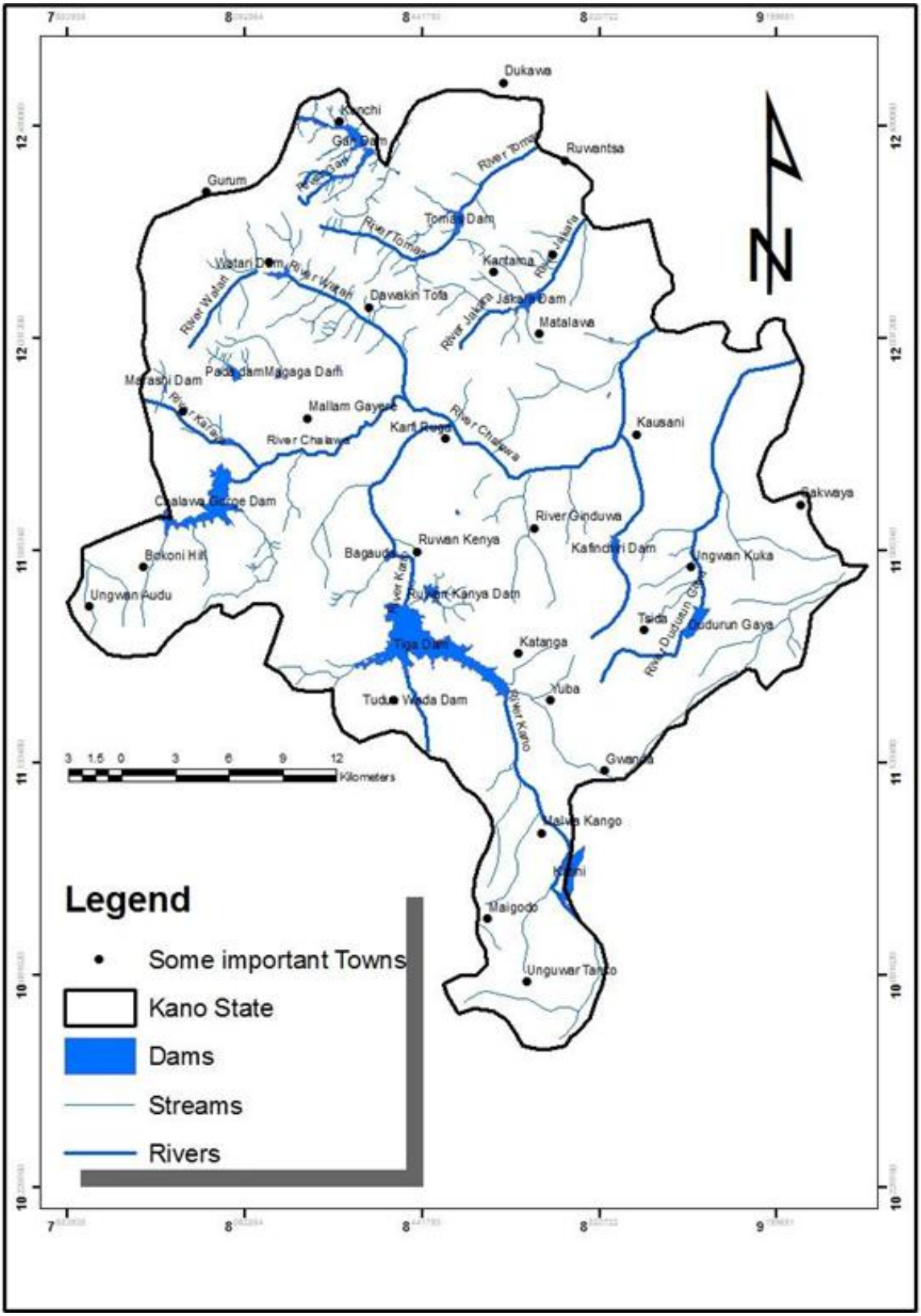


Figure 3.4 Drainage map of the study Area

Source: GIS Laboratory Geography Department, Bayero University Kano

3.1.5 Soil and vegetation

The vegetation of the Study area is Sudan Savanna type. Olofin (1987) observed that the natural vegetation of the study area is tropical grassland characterised by scattered trees which hardly exceed 20 metres high. The grasses are annual and hardly exceed one metre in terms of height. The common tree species include *Acacia Albidda (Gawo), Vitex Doniana (Dinya), Acacia senegalancies (Dakwara), Balanites aegyptiaca (Aduwa), Hyphene the baica (Kaba), Borrasus aethiopum (Giginya), Anilotica (Bagaruwa), Diospyros mespiliformis (kanya), Leiocarpus (mark), ,Khaya Segalensis (Madaci), Ziziphus spina-chrisli (Kurna), Piliostigma thonningii (Kalgo), Guiera Senegalenses (sabara) silk cotton tree (Rimi), Tamarindus indica (Tsamiya) Adansonia digitata (Kuka), Pekia bigloboza (Dorawa), cambratum species and shear butter (Kadanya), Moringa Oleifera (Zogale) among others.* Most of the tree species in Kano state are having economic and medicinal value. The vegetation has become modified to a high degree at the extreme North-Eastern part of the state due to human agricultural activities. Thus, the current vegetation is looking more of semi arid in character. In the southern parts, Guinea savannah is dominant. Though the vegetation of Kano is derived from Sudan Savanna and has been greatly disturbed by cultivation and other human activities (Sara and Charles, 1988).

The soil of the region is tropical Ferruginous rich in sand, while the zonal soils are also influenced by human manipulation to varying degrees (Olofin,1987) Areas in the extreme West or South West are characterised by clayey loamy soils. The soils are deep, well drained except for hydromorphic soils and poorly structured soils. The texture of soils in Kano state ranges from sandy loam in the south to loamy sand in the north (Ahmad, 2003). Soils at the hills lopes are predominantly skeletal with no horizon differentiation because they are younger soils or undeveloped soils. At the valley bottom and flood plains of the study areas riverine alluvial soils and aeolian deposits occur. (Figure 3.5)

A brown and reddish brown soil called xerosols occurs in the extreme southern parts of the study area (Ahmad, 2003).

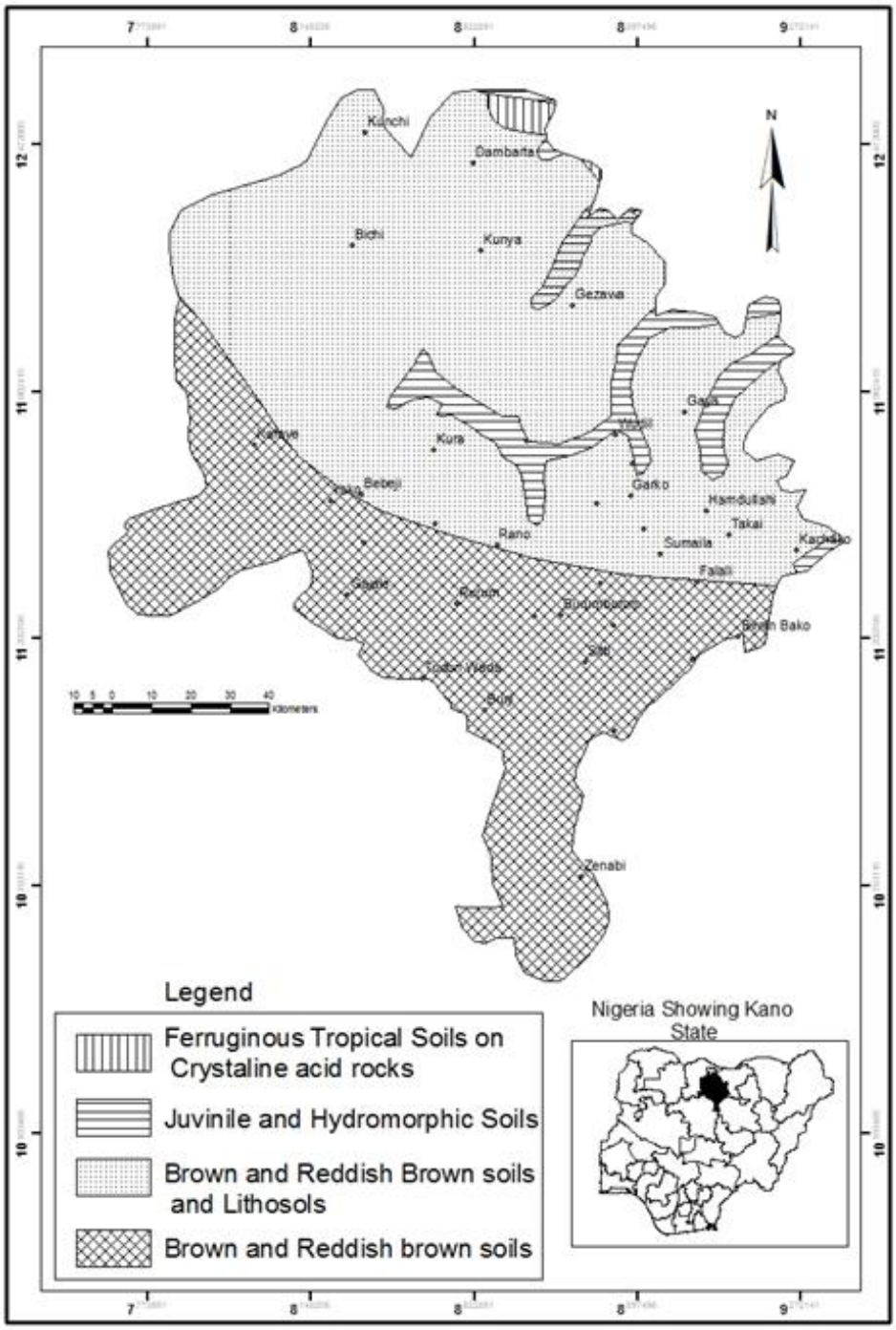


Figure 3.5 Soil Map of Kano State

Source: GIS Laboratory Bayero University, Kano

3.1.6 Population Land use and Settlement

Drinking water in any community is to serve the human population in the area; its scarcity may lead to low population likewise its availability may lead to high population growth. Kano state is inhabited by Hausa Fulani and people of other tribes at Sabongari and Fagge areas of Kano city. In 2006 the population of Kano state was 9,563682 and density of 441 persons per square kilometres. Large population concentrates in the Kano metropolitan Local Government areas. Population of some of the rural areas in 2006 census is as follows Kunchi 111,018 with density of 396, Karaye 141407 with density 396 and Kibiya 136, 736 with density of 178. This indicates that population is growing rapidly in both rural and urban areas of Kano State. Both Kano city centre and major towns of Kano State are densely populated.

The major land uses in Kano city are commercial activities, trading, industries and civil service among others while in the rural areas of the State more than 60% of the dweller either engage in farming or animal rearing. Other forms of businesses and local hand crafts are also very common in the rural areas of Kano State.

Water is the major ingredient of all forms of development in the study area, human population demand a lots of water for its commercial, agricultural, industrial and other activities for a complete survival. That is why rural and urban areas of Kano state need a sustainable and adequate water supply for development.

3.2 METHODOLOGY

3.2.1 Reconnaissance survey

Reconnaissance survey of the study area was conducted in December 2009 and January 2010. This reconnaissance visit enabled the researcher to be familiar with the study area in terms of its scope that is its extent, location of points, checking and updating what is on the existing maps. It was

during this reconnaissance visit that the researcher was able to plan the actual field work in terms of sampling and methods adopted during field work. Stratified random sampling was found to be suitable in selecting the local government areas because of their distribution in terms of senatorial districts and variation among the senatorial districts in terms of boreholes distribution and physical characteristics such as soil, vegetation and geology. It was discovered that it is suitable to select the villages using systematic random sampling and points using purposive. During this survey the researcher was able to arrange for the conduct of VES survey, Questionnaire survey, Pumping test survey and aquifer characteristics survey.

3.2.2 Sampling Techniques

(i) Areas selected for study are based on senatorial zones. Forty four (44) Local Government Areas in all out of these, thirty eight (38) are rural (Wardrop, 1990).

(ii) Using 20% of the 38 L.G.A s gives 8 L.G.A s for the study since the population is small. Selection of the 20% was based on the fact that for research in social science 10% should be selected from a large population but if the population is small then 20% may be required (Gay and Diehl, 1992). Krejcie and Morgan (1970) are also of this opinion. This is also based on the statistical argument of Arlosoroff *et al* (1987) and Hagget, Andrew and Alley (1977) who stated that for the validity of a research 20% of the total population should be selected. Also Ader, Mellerbergh and Hand (2008) suggested that sampling size should be small in order to improve quality and accuracy of the research work. In another development Donald (1967), Hagbert (1968), Johnson (1959), Miller and Smith (1983) recommend that the researcher take a random sample of 10-20% of non respondents sampling.

It was based on population differences among the three senatorial districts (Kano central 1918823, Kano North 2273598 and South 3042691), that the eight L.G.A s were selected on a 2:3:3 bases among the Kano central, northern and southern senatorial districts. The Settlement of the study area

is nucleated in the metropolis and major towns of the state. In most of the rural areas the settlement is either disperse, linear or farm estate.

The list of L.G.A s in each senatorial district is shown in Table 3.1 from this list, 2,3 and 3 L.G.A s are selected purposefully from these senatorial districts based on number of L.G.A s regarded as rural in each senatorial zone and based on population of each.

Within these selected L.G.A s, a list of rural settlements (wards) is shown in Table: 3.2, 20% of the villages in each selected L.G.A are adequate for sampling (Arlosoroff *et al.*, 1987 and Hagget *et al.*, 1977). The selected villages so selected are listed on Table: 3.2. The villages were arranged on basis of population size and then the ones with highest and lowest population were selected using systematic random sampling.

At the village level, one point was selected purposively. This was done based on the location of existing borehole, well or hand pump in the area. One open well was purposively selected in each village for collection of aquifer material samples. In each village also one borehole was purposively selected for pumping test.

Table 3.1 Lists of Local Government Areas in the Senatorial Zones and Selected Ones

Senatorial District	L. G. As	Selected L.G.A s
Kano North Senatorial zone	Bagwai,Bichi,Danbatta,D/Tofa,Gabasawa,Gwarzo,Kabo,Rimingado,Shanono,Tofa,Tsanyawa,Kunchi,Makoda	Shanono Rimingado and Kunchi
Kano central Senatorial zone	Dala,D/kudu,,Garunmallam,Gezawa,Kumbotso,Kura,Madobi,Minjibir,Ungoggo,Warawa	Kura and Gezawa
Kano south Senatorial zone	Ajingi,Albasu,Bebeji,Bunkure,Doguwa,Garko,Gaya,Karaye,Rogo,Kibiya,Kiru,Rano,Sumaila,Takai,Tudunwada,Wudil	Kibiya, Karaye and Doguwa

Source: Field work, 2010

Table 3.2 List of selected Local Governments and villages in the Study Area

Selected L.G.A s	List of villages in the selected L.G.As	Numberof villages(Wards)in each L.G.A	Selected villages in each L.G.A (20% of each using systematic random sampling based on population differences).
Kura	Sarkinkura,Kurunsumau,Tanawa,Dalili,Rigar Duka,Kosawa,Danhassan,Karfi, Kunshama,Gundutse	10	Karfi and Kosawa
Gezawa	Gezawa,Jogana, Tsamiya Babba,Gawo,Tumbau,Wangara, Sararingezawa,Ketawa,Mesar tudu,Babawa,Zango	11	Babawa and Tumbau
Shanono	Shonono,Dutse,Shakogi,Leni,Kokiya,Kadamu,Tsaure,Alajawa, Goron Dutse,Faruruwa	10	Shakogi and alajawa
Rimingado	Rimingado,Dokadawa,ButuButu,Yalwandanziyal,Sakaratsa,Tamawa,Karofinyashi,Gulu,D/Gulu,Zango,Dugurawa,Jili	12	Dokadawa and Karofin yashi
Kunchi	Shuwaki,Yandadi,Garin sheme,Kunchi,Matnfada,Kasuwarkuka,Shamukawa,Gwarmai,Risawa,Bumai	10	Yandadi and Shuwaki
Kibiya	Kibiya I ,Kibiya II ,Tarai, Kahu, Fassi, Nariya, Durba,U/gai, Kadiwa, Fammar	10	Fammar and Tarai
Karaye	Tudunkaya,Kwanyawa,Yola,Yammawa,Daura,Kurugu,Magajin gari,Magajin hajji,Turawa,Kafin dabga	10	Tudunkaya ,Turawa
Doguwa	Dariyashere, Maraku,Ragada,Zainabi,Dogon kawo,Unguwarnatsohu,Doguwa ,Ririwai,fagore,Tagwaye	11	Riruwai and Zainabi

Source: Field Work, 2010

(iii) For the selection of respondent's sample, Population data of the 16 selected villages which are all wards was obtained from 1991 population results which were projected to March, 2012 using exponential growth model. Out of this 3% of the households population were selected as a sample that is at 95% confidence interval and 5% confidence limit as adopted from Krejcie and Morgan (1970) who stated that in social science and educational research the general rule is that the relative acceptance margin of error in categorical data is 5% and continuous data is 3%. Selection of individual households for the interview was done using systematic random sampling technique with a sampling frame. The total sample selected is 475 from the whole villages or wards (Table: 3.3)

Table 3.3 Sample Population of Respondents

SN	Ward Name	LGA	1991 Pop.	ICGR for LGA	Popl. (projection) as of March, 2006	National Growth Rate Since 2006	Popl.(Projection) As of March 2012	H/H	Sample Size (3%)
1	Shuwaki	Kunchi	2,707	2.71059495	3,992	3.20	4,837	806	24
2	Yandadi	Kunchi	4,176	2.710594958	6,159	3.20	7,462	1244	37
3	Dokadawa	R/gado	4,499	3.81838435	7,777	3.20	9,423	1571	47
4	K/ Yashi	R/gado	1,117	3.81838435	1,931	3.20	2,340	390	12
5	Shakogi	Shanono	1,405	3.52294406	2,328	3.20	2,821	470	14
6	Alajawa	Shanono	1,124	3.52294406	1,862	3.20	2,257	376	11
7	Riruwai	Doguwa	4,683	4.152911315	8,493	3.20	10,290	1715	52
8	Zainabi	Doguwa	2,006	4.152911315	3,638	3.20	4,408	735	22
9	T/ Kaya	Karaye	1,597	3.174766904	2,517	3.20	3,050	508	15
10	Turawa	Karaye	1,028	3.174766904	1,620	3.20	1,963	327	10
11	Fammar	Kibiya	1,664	4.316716433	3,089	3.20	3,743	624	19
12	Tarai	Kibiya	8,084	4.316716433	15,008	3.20	18,185	3031	91
13	Babawa	Gezawa	1,494	4.193891305	2,725	3.20	3,302	550	17
14	Tumbau	Gezawa	1,794	4.193891305	3,273	3.20	3,965	661	20
15	Karfi	Kura	7,203	3.359355649	11,658	3.20	14,126	2354	71
16	Kosawa	Kura	1,292	3.359355649	2,091	3.20	2,534	422	13
			Total Sample						**475**

ICGR = Inter-Censal Growth Rate

The 1991 population is the actual census result, while the 2006 and 2012 populations are projected figures based on the exponential growth model

Sources: Adapted and Modified from NPC (1991).

3.2.3 Type of Data used in the Study

The types of data used in the research work are presented based on objectives. Each of the objectives is considered as a sub section and they are presented as follows:-

3.2.3.1 Sources of water supply situation

- For sources of water supply situation the following data was used:-Human responses or opinion through questionnaire administration and interview (475 questionnaires), Pictures or plates and observed information. A total of 394 respondents were successfully interviewed out of the total 475.

3.2.3.2 Nature of hydrogeology

- For nature of hydrogeology the data used include: - DEM, SRTM, Geology map, hyrogeological map, slope map, drainage map, Contour map, aquifer parameters data and pumping test data.

3.2.3.3 Groundwater potential assessment

- For groundwater potential assessment the following set of data was used:- VES data, Landsat ETM+ 2003, DEM of Kano, Geological map, Drainage map, hyrogeological map, Soil map, vegetation map, lineament map and SRTM.

3.2.3.4 Characterisation of groundwater potential zones

- The following data was used to characterised the groundwater potential zones:-Landsat ETM+2003, Weighted overlay map, SRTM data, and GPS data of the sixteen villages and pumping test results of sixteen boreholes, Geology, hydrogeology, soil, vegetation of the study area and aquifer parameters data.

3.2.4. Sources and Techniques of Data Collection

3.2.4.1 Sources of water supply

Self administered questionnaires were used to interview respondents in the rural areas of the state. This was done by the researcher and two research assistants. Four hundred and seventy five (475) questionnaires were used (Appendix: 1) a tape recorder was used during the interview session. A camera was used in snapping pictures which were used as plates. These methods were adopted from Christ (2005), Jansz (2011), Emmanuel (2012), Waller (1982) and Wardrop (1990) among others.

3.2.4.2 Nature of hydrogeology

Formation of drainage map of the study area was created using DEM of Kano State which was produced from SRTM data.

Slope map of the study area was prepared through the creation of DEM from SRTM and interpolation of spot height and contours in GIS environment as adopted from Anthony and Doreen (1977), Goyal *et al.*, (2009), Tesfaye (2010), Okoro *et al.*, (2010), Anudu, Essien, Onuba and Ikpokonte (2011) and Oluwatola *et al.*, (2013).

-Contour map was produced from DEM which was derived from SRTM
Formation of drainage map of the study area and drainage density maps were all achieved through derivation from DEM which was obtained from SRTM.

- Aquifer materials (soil and rock) were collected from 16 open wells in the selected villages closer to the sampling points. The materials were taken to the laboratory where porosity, water contentment, hydraulic conductivity and hydraulic head were determined. Specific capacity and specific storage were calculated.

- Porosity was determined through saturation method in which samples were poured into beakers and then water was added until it reaches the top of each material. Then the volume of void (water that enters into the material) is known and divided by the total volume of that material that is the aquifer material. Adopted from Vojko (2003), Ozcep *et al.*, (2005) and Freeze and Cherry (1979)
- Water content was determined using chemical titration method (Karl Fischer titration) where samples mass loss was determined through heating in the presence of an inert gas as adopted from Ozcep *et al.*, (2005). Hydraulic conductivity was determined using Lab device (rigid wall permeameter) where a chamber for holding sediments/soils was used to determined head of water in the medium from which discharge is measured. From that hydraulic conductivity K was determined.
- Hydraulic head was determined at the point of sample collection using stand pipe piezometer device by measuring the height of the water surface in the tube relative to the common datum, where 'h' hydraulic head was measured in terms of length. In that case total energy of fluid flowing through a pipe packed with sand was measured as the hydraulic head.
- Specific storage (Ss)m was determined from the existing data using formula (Ss)m= 1dmw/ma.dh----------(1)
  Where 1 is constant, dmw is the water content, ma is the mass of material and dh is the hydraulic head. Adopted from Munhong (1998), Freeze and Cherry (1979) and Ozcep *et al.*, (2005).
- Specific Yield (Sy) was obtained through calculation from the existing aquifer parameter data was obtained from the field or laboratory work. Adopted from Fetter (1994), Timothy (2006) and Freeze and Cherry (1979).
-

3.2.4.3 Groundwater potential Zone measurements and identification

Position of the 16 sampled rural areas was taken using G.P.S. This includes latitude, longitude and altitude which assisted in depth to water table measurement. Depth to groundwater level of 16 sampling points was obtained through measurement of depth to groundwater table in ohm/meter using Vertical Electrical Sounding (VES) and Schlumberger array table. The data was collected on seasonal basis i.e. twice in one single year. Sampling area was established in each selected rural area of Kano state (Girish et al, 2009), Mosuro *et al.*, (2012) and Nwankwo, Olasehinde and Osundele (2013).

During field survey earth resistance determinations were made using ABEM Terrameter SAS 300c. This is a portable microprocessor controlled integrated receiver and transmitter which provides a direct digital readout of resistance (Kollert, 1969). In each point earth resistance (R) was measured by inducing direct current or low frequency alternating current in to the ground using pair of metal electrodes(current electrodes). Another pair of electrodes (potential electrodes) measured the resultant potential difference. Generally, the current electrodes (c1 and c2) and the potential electrodes (p1 and p2) were arranged in a linear array (plate 3.1). The VES readings of the points were taken on the displayed meter. The readings were recorded on a log-log graph recording sheet as adopted from Mohammad (1984), Olorunfemi and Fasuyi (1993), Srinivasa and Jugran (2003) and Gada (2006). Refer to plate 3.1 showing researcher taking VES readings. Water levels were obtained from Pumping tests which were conducted at 16 selected boreholes very close to the sampling points in 2011 and 2012. The water tables of 2011 and 2012 were obtained from this result trough subtracting water levels from altitudes above mean sea level.

Land sat ETM + 2003 with resolution of 28.5m was used to map out the study area using VES survey results, then GIS. was used to assessed the ground water potential through overlaying factors of the study which include lineament, drainage density, geology, hydrogeology, soil and vegetation

which were obtained from the land sat ETM + 2003 and maps. This was achieved using weighted overlay method of Analytical Hierarchy Process (AHP) nine point scales as adopted from Carlo (1998) Goyal *et al.,* (2009), Tesfaye (2010), Shahid, Nath and Roy (2000), Sitender (2011) and Emmanuel, Olayinka, Odeyemi and Oladotun (2011).

The parameters of each of the factors were given weight and related to groundwater potential weighted overlay method adopted from El-baz and Hamida (1995), Goyal *et al.,* (2009), Tesfaye (2010) and Gouri *et al.,* (2012). Groundwater potential zones map (GPZM) was obtained through overlaying all the thematic maps, weights were assigned to each according to their relative importance to groundwater. Weights of various parameters in each of the factors were determined and maps were reclassified to compare the factors and groundwater potential zones.

Finally Kano State map with the rural villages was overlaid over the groundwater potential zones map to assess groundwater condition of each rural village. On GWPZM all the sixteen rural areas were displayed on the map so as to show the zone where they fall.

3.2.4.4 Characterisation of the groundwater potential Zones

Aerial extent of each groundwater zone was determined using extension of ARCGIS 3D Analyst

Pumping tests were conducted at 16 selected boreholes very close to the sampling points in 2011 and 2012. The sixteen pumping test results (appendix 5) were used to characterise the five identified groundwater potential zones as adopted from Kandri, Patil and Rajan (2008), Emmanuel et al (2011), Tesfaye (2010) and Oluwatola *et al.,* (2013)

Factors such as Geology, soil, Hydrogeology, Lineament and vegetation were used to characterise the five groundwater potential zones base on differences that exist between them as adopted from Tesfaye (2010) and Sitender (2011).

3.2.5 Techniques of data analysis

For the successful analysis of the results the following steps were followed:

3.2.5.1 Sources of water Supply

Interview result was coded in Microsoft excel. The result was transferred to SPSS for calculation of totals, means and standard deviation. Charts and graphs were also produced all using the SPSS package.

3.2.5.2 Nature of hydrogeology

Digitization of Hydro geological map was achieved using Arc view GIS 3.2a software which came up with the nature of hydrogeology in the rural areas of Kano.

- Slope map was interpreted based on standards of Anthony and Doreen (1977)
- Digitised DEM was used to produce drainage density map of the study area.
- Digitised DEM was also used to generate contour map of the study area.
- For the analysis of aquifer parameters the following formulas were used
- Porosity (n) = Vt – Vs/Vt =Vv/Vt---------- (2)

  Where: - Vt is the total volume of soil or rock samples, Vs is the volume of openings (voids).

- The porosity determined by equation was multiplied by 100 in which the result is expressed as a percentage (Table: 3.4).

Table 3.4 Determination of porosity from laboratory test results

S/N	Volume of container (cm^3)	Volume of material (cm^3)	Vv/V	Vv/Vx100%
1	$150cm^3$	$27\ cm^3$	0.18	18%
2	$150cm^3$	$28.5\ cm^3$	0.19	19%
3	$150cm^3$	$27\ cm^3$	0.18	18%
4	$150cm^3$	$27\ cm^3$	0.18	18%
5	$150cm^3$	$30\ cm^3$	0.20	20%
6	$150cm^3$	$26.3\ cm^3$	0.175	17.5%
7	$150cm^3$	$7.5\ cm^3$	0.05	5%
8	$150cm^3$	$15\ cm^3$	0.10	10%
9	$150cm^3$	$13.5\ cm^3$	0.09	9%
10	$150cm^3$	$25.7\ cm^3$	0.171	17.1
11	$150cm^3$	$16.5\ cm^3$	0.11	11%
12	$150cm^3$	$28.5\ cm^3$	0.19	19%
13	$150cm^3$	$29.3\ cm^3$	0.198	19.8
14	$150cm^3$	$18\ cm^3$	0.12	12%
15	$150cm^3$	$33\ cm^3$	0.22	22%
16	$150cm^3$	$30\ cm^3$	0.20	20%

Source: Laboratory Analysis, 2013

- Water content: - Using the laboratory results the following formulae was used in determining water content as follows: -

  W= m/d since density= m/v that is using p/frac {W-D}{D}----------(3)

  Where p is fraction of total evaporable moisture content of sample, W is the mass of original sample and D is the mass of dried sample. Adopted from Ozcep et al (2005)

- Hydraulic conductivity: - The formulae used in calculating hydraulic conductivity is
- K= -Q /AI----------(4)

  Where K= hydraulic conductivity, A= cross sectional area of the sample, I= dh/dl= gradient and

  Q= discharge of the medium material obtained in lab.

- Specific yield was calculated using the formula: - Sy= Vw/V x 100---------- (5)

  where Sy is specific yield, Vw is the water content and V is the total volume of material and moisture content.

  -Specific storage (Ss)m was calculated using the formular (Ss)m= 1dmw/ma.dh----------(6)

  Where 1 is constant, dmw is the water content, ma is the mass of material and dh is the hydraulic head. Adopted from Freeze and cherry (1979).

3.2.5.3 Analysis of groundwater potential zones

Sounding data in the form of earth resistance measurements were converted to apparent resistivity values by multiplication with the geometric factor. The conversion was done using this formula

Pa = ΔV/I. 2∏r ---------- (7)

Where ΔV/I = is the resistivity in ohm-m obtained from direct VES measurements at the field and 2∏r = Geometrical factor (G) fixed for a given electrode configuration, therefore G was calculated

using the formula $G = \frac{[(AB/2)^2 - (MN/2)^2]}{2[MN/2]}$ ----------(8)

Where AB = Current electrode spacing and MN = spacing between potential electrodes of the Schulumberger. This formula was adopted from Grand and West (1965).

The resistivity values were plotted on a log-log graph of standard scale as a function of half current electrode separation (AB/2) i.e. the use of logarithmic coordinates (Appendix: I). The curves were interpreted using Achie law adopted from Bernard (2003) who stated that to identify the presence of groundwater from resistivity measurement, one can look to the absolute values of the ground resistivity, through this law for a particular range of values. For fresh water resistivity is between 10- 100 ohm-m, for a usual targeted aquifer resistivity can be between 50- 2000 ohm-m. VES and Schlumberger array methods were used to create contour using Arc view 3.2a GIS soft ware. Water table was obtained from this formula:- Swl = E – Dwl----------(9)

Where Swl= the true or uniform water level or static water level, E = the surface elevation with respect to mean sea level and Dwl = the depth from the surface of the earth to the water in the hand-dug wells (Direct bore hole logging).

Ground water potential zones were categorised into very high, high, moderate, low and very low using Extension Arc view spatial analyst GIS soft ware. In this case data base was created for each location and then linked with maps such as lineament map, drainage density map, Geology map, hydrogeology map, of the study area. These two were established and tie together then what is at each location was predicted through GIS Query using Arc view 3D Analyst.

Spatial Analyst extension of Arc GIS 9.3 was used for converting the features to raster and also for final analysis individual themes were assigned weights. Multicriterian based weighted overlay analysis techniques were employed to determine the potential groundwater zones as adopted from Tesfaye (2010), Kavidha and Elangovan (2013), Goyal *et al.*, (2009), Ronald (2011), Suja and Krishna (2009), Shahid *et al.*, (2000), Stender (2011), LVIA (2012) and Oluwatola *et al.*, (2013).

AHP weighted Linear combination formulae was used as

$S = \sum_{wi} X_i X \prod_{cj}$ ---------- (10)

Where

S = is the composite suitability score

Wi =weighs assigned to each factor

Cj = constant (Boolean factor)

$\sum$ = sum of weighted factors

$\prod$ = product of constraints (1- suitable, 0- unsuitable)

Various thematic maps were reclassified on the basis of weight assigned and processed using the ''Raster calculator'' function of spatial Analyst Extension of ArcGIS 9.3 for integration analysis. The procedure adopts a simple arithmetic to integrate the various factor maps by averaging of the weight to produce a final groundwater potential map of the study area. The GIS output was validated using the VES survey result bearing simple method of comparing tabulated data.

Water table of 2011 and that of 2012 was compared using Students't' test in GIS environment (SPSS soft ware) to ascertain how abundance groundwater is in the study area.

Groundwater potential zone of one location was compared with another location using GIS overlay method in Arc view spatial Analyst soft ware.

The final groundwater potential zone maps of the area was produced and categorised based on factors used.

3.2.5.4 Characterisation of groundwater potential Zones

Areal extent and percentage of each zone was calculated using spatial analyst ARC GIS 9.3 soft ware for the purpose of characterisation.

Pumping test results used for the characterization of the groundwater potential zones were analyzed using Numerical method of Singh and Gupta as in Khadri *et al.,* (2008). Where Average drawdown and discharge at 30 minutes were calculated and tabulated for the 16 villages.

Tabulation method was adopted to further characterise the groundwater potential zones according to environmental characteristics using ARCGIS software as adopted from Tesfaye (2010) and Sitender (2011).



Plate 3.1 **Researcher taking VES readings at Karaye LGA**

Source: Field Work, 2011

CHAPTER FOUR: RESULTS

4.1 GENERAL OBSERVATIONS

Results of the present water supply situation in the rural areas of Kano State show that the water supply is inadequate. Results of nature of hydrogeology of the rural areas was presented show that low drainage density areas are dominated by younger granites, low values of aquifer parameters and low groundwater potential. Higher drainage density areas are dominated by Older Granites, high values of aquifer parameters and a higher groundwater potential. Weighted overlay results and VES results are in close agreement. Five groundwater potential zones were characterised and presented all in this chapter.

4.2 PRESENT WATER SUPPLY SITUATION IN RURAL AREAS OF KANO

The results of present water supply situation of Kano State include analysed data of human opinion and observation obtained from interview of respondents in the rural areas.

4.2.1 Responses on Common Sources of Drinking Water

A total of 394 respondents were successfully interviewed out of the total sample of 475 from the 16 rural villages. Table 4.1 shows responses on common sources of drinking water in the study area. The result indicates that in Kano north, river is the common source of rural water supply with the highest responses of 49 (12.4%) followed by reservoirs 8.9% and open well 5.6%. In Kano central and Kano south, open well is the common source of drinking water with highest responses of 74 (18.8%) and 67 (17.0%) respectively followed by reservoirs and tap. In the whole state open well recorded the highest responses of 163 (41.4%) followed by river with 77 responses (19.5%), reservoir with 63 responses (16.0%). Hand pump wells recorded the least responses.

Table 4.2 show results of interview on the water sources used in the rural areas of Kano State, where 121 respondents (30.7%) indicate that they use reservoir water, 68 respondents (17.3%) states that they use water from the river, 42 respondents (10.7%) rely on open well, 10 respondents (2.5%) state that they use bore hole water while 23 respondents (5.5%) pointed out that they depend on tap water. Among the rural villages households in Karfi Kano Central 33 (8.4%) depend on reservoir which record the highest responses of 33 (8.4%), Karofinyashi in Kano North depend on river water with 12 responses (3.0%), Babawa in Kano central depend on open well with 12 respondents (3.0%) and Tarai in Kano South uses bore hole and tap with responses of 6 (1.5%) and 18 (4.6%) respectively.

Table 4.1 Distribution of Respondents according to Sources of Drinking water

Senatorial Zone	Common Source of Water															
	Open Well		River		Hand Pump		Bore hole		Reservour		River &Well		Tap		Total	
	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%
Kano North	22	5.6%	49	12.4%	0	0.0%	16	4.1%	35	8.9%	0	0.0%	0	0.0%	122	31.0%
Kano South	74	18.8%	13	3.3%	11	2.8%	10	2.5%	27	6.9%	9	2.3%	24	6.1%	168	42.6%
Kano Central	67	17.0%	15	3.8%	5	1.3%	9	2.3%	1	.3%	7	1.8%	0	0.0%	104	26.4%
Total	163	41.4%	77	19.5%	16	4.1%	35	8.9%	63	16.0%	16	4.1%	24	6.1%	394	100.0%

Source: Field Survey, 2012

Table: 4.2 Distribution of respondents according to sources of water supply

Village	Sources of water supply												Total	
	Not Applicable		Reservoir		River		Open Well		Bore hole		Tap			
	F	%	F	%	F	%	F	%	F	%	F	%	F	%
Shuwaki	16	4.1%	3	0.8%	0	0.0%	2	.5%	0	0.0%	0	0.0%	21	5.3%
Yandadi	10	2.5%	17	4.3%	1	0.3%	1	.3%	0	0.0%	0	0.0%	29	7.4%
Doka/D	23	5.8%	11	2.8%	0	0.0%	1	.3%	0	0.0%	0	0.0%	35	8.9%
K/Yashi	0	0.0%	0	0.0%	12	3.0%	0	0.0%	0	0.0%	0	0.0%	12	3.0%
Shakogi	6	1.5%	0	0.0%	8	2.0%	0	0.0%	0	0.0%	0	0.0%	14	3.6%
Alajawa	3	0.8%	1	0.3%	7	1.8%	0	0.0%	0	0.0%	0	0.0%	11	2.8%
Riruwai	20	5.1%	7	1.8%	8	2.0%	0	0.0%	0	0.0%	0	0.0%	35	8.9%
Zainabi	2	0.5%	8	2.0%	1	0.3%	10	2.5%	0	0.0%	0	0.0%	21	5.3%
T/Kaya	3	0.8%	11	2.8%	1	0.3%	0	0.0%	0	0.0%	0	0.0%	15	3.8%
Turawa	0	0.0%	0	0.0%	4	1.0%	6	1.5%	0	0.0%	0	0.0%	10	2.5%
Fammar	8	2.0%	5	1.3%	1	0.3%	0	0.0%	0	0.0%	5	1.3%	19	4.8%
Tarai	18	4.6%	24	6.1%	2	0.5%	0	0.0%	6	1.5%	18	4.6%	68	17.3%
Babawa	0	0.0%	0	0.0%	5	1.3%	12	3.0%	0	0.0%	0	0.0%	17	4.3%
Tumbau	0	0.0%	1	0.3%	11	2.8%	7	1.8%	0	0.0%	0	0.0%	19	4.8%
Karfi	12	3.0%	33	8.4%	7	1.8%	3	0.8%	0	0.0%	0	0.0%	55	14.0%
Kosawa	9	2.3%	0	0.0%	0	0.0%	0	0.0%	4	1.0%	0	0.0%	13	3.3%
Total	130	33.0%	121	30.7%	68	17.3%	42	10.7%	10	2.5%	23	5.8%	394	100.0%

Source: Field Survey, 2012

4.2.2 Major Sources of Drinking Water

Table 4.3 shows responses on the major sources of drinking water in the rural villages of Kano State. The result shows that in rural villages of Kano north, surface water recorded the highest responses of 94 (23.9%) followed by groundwater, then tap. In Kano south groundwater recorded highest responses of 79 (20.1%) followed by surface water then taps and in Kano central surface water is leading with 216 responses (54.8%) followed by groundwater then tap water.

Table 4.3 Responses on major sources of drinking water in the Senatorial Zones of Kano State

Senatorial Zone	Major Source							
	Ground Water		Surface Water		Tap Water		Total	
	F	%	F	%	F	%	F	%
Kano North	23	5.8%	94	23.9%	5	1.3%	122	31.0%
Kanocentral	45	11.4%	56	14.2%	3	0.8%	104	26.4%
Kano South	79	20.1%	66	16.8%	23	5.8%	168	42.6%
Total	147	37.3%	216	54.8%	31	7.9%	394	100.0%

Source: Field Survey, 2012

4.2.3 Distance to Water Sources

Table 4.4 show responses on trek distance from houses to water sources. It indicates that most of the respondents in the sixteen rural villages stated that they obtained their drinking water in less than 500m distance from home that is 267 respondents (67.8%), 40 respondents (10.2%) used to travel for about 500m to obtained water, 34 respondents (8.6%) obtained their drinking water in about 1km distance and 5% of the respondents pointed out that they obtained their water at zero distance. Figure 4.1 show the variation of responses among the three senatorial districts in terms of distance travelled to get drinking water. It can be observed that most of the respondents get water from less than 500m distance that is 97 respondents (79%) in the Kano north , 83 respondents (49%) in Kano south and 87 (83%) in Kano central respectively. The result also indicate that in Kano north 29 (17%) of the respondents state that they have to walk for 2 kilometres to get water, in Kano south 14 respondents (8.3%) and in Kano Central 8 respondents (8%).

Table 4.4 Distribution of Respondents according to distance to water sources

Village	Trek Distance															
	Not Applicable		<500m		500m		1km		2km		3-5km		>5km		Total	
	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%
Shuwaki	0	0.0%	14	3.6%	6	1.5%	1	.3%	0	0.0%	0	0.0%	0	0.0%	21	5.3%
Yandadi	0	0.0%	20	5.1%	9	2.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	29	7.4%
Doka/D	0	0.0%	28	7.1%	7	1.8%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	35	8.9%
K/Yashi	0	0.0%	12	3.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	12	3.0%
Shakogi	0	0.0%	14	3.6%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	14	3.6%
Alajawa	0	0.0%	9	2.3%	2	.5%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	11	2.8%
Riruwai	0	0.0%	27	6.9%	2	.5%	1	.3%	2	.5%	1	.3%	2	.5%	35	8.9%
Zainabi	0	0.0%	7	1.8%	3	.8%	9	2.3%	2	.5%	0	0.0%	0	0.0%	21	5.3%
T/Kaya	0	0.0%	13	3.3%	0	0.0%	1	.3%	1	.3%	0	0.0%	0	0.0%	15	3.8%
Turawa	0	0.0%	6	1.5%	0	0.0%	0	0.0%	4	1.0%	0	0.0%	0	0.0%	10	2.5%
Fammar	4	1.0%	6	1.5%	0	0.0%	5	1.3%	3	.8%	1	.3%	0	0.0%	19	4.8%
Tarai	16	4.1%	24	6.1%	9	2.3%	13	3.3%	2	.5%	3	.8%	1	.3%	68	17.3%
Babawa	0	0.0%	16	4.1%	1	.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	17	4.3%
Tumbau	0	0.0%	16	4.1%	0	0.0%	1	.3%	1	.3%	1	.3%	0	0.0%	19	4.8%
Karfi	0	0.0%	44	11.2%	0	0.0%	2	.5%	7	1.8%	2	.5%	0	0.0%	55	14.0%
Kosawa	0	0.0%	11	2.8%	1	.3%	1	.3%	0	0.0%	0	0.0%	0	0.0%	13	3.3%
Total	20	5.1%	267	67.8%	40	10.2%	34	8.6%	22	5.6%	8	2.0%	3	.8%	394	100.0%

Source: Field Survey, 2012

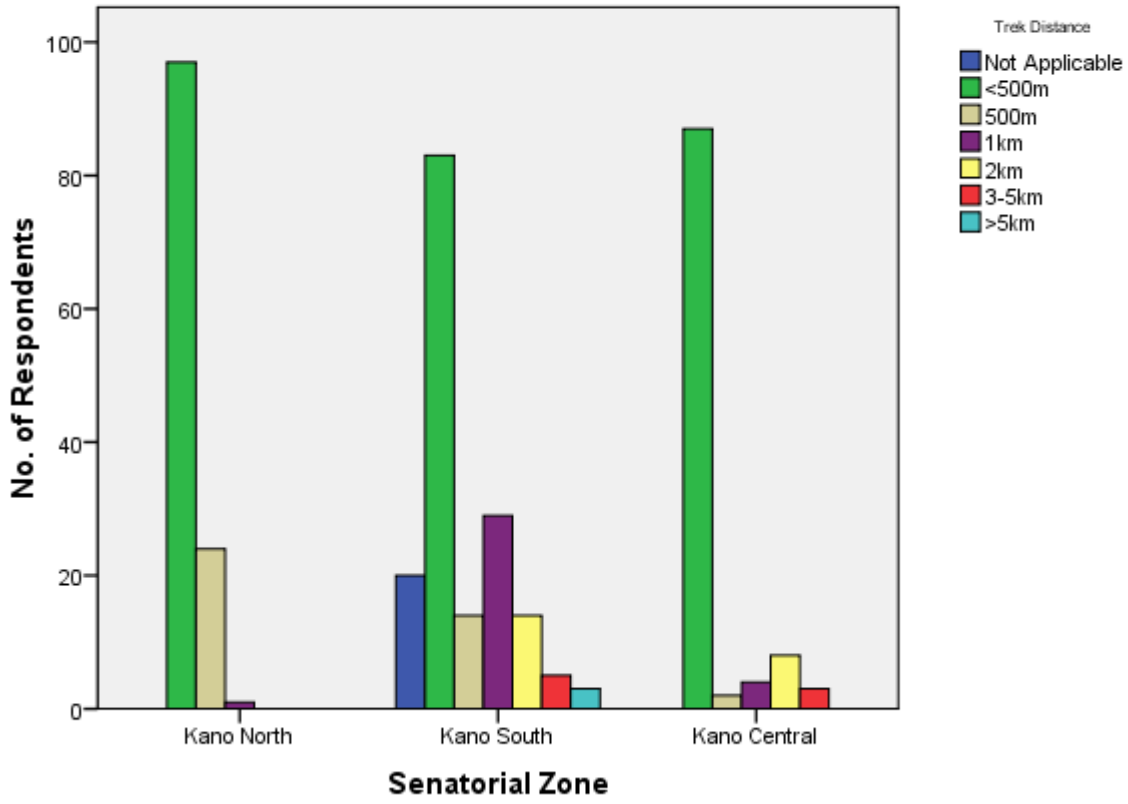


Figure: 4.1 Distance to water sources among the Senatorial Districts

Source: Data Analysis, 2012

4.2.4 Rate of water sources usage

Table 4.5 and Figure 4.2 indicate rate of water usage among the water sources in the rural areas of Kano state. Responses on pond as water source shows that 246 respondents (62%) stated that it is fairly used, 2 respondents (1%) said it is highly used and 29 respondents (7%) states that it is moderately used. This indicates that use of pond as source of drinking water is insignificant throughout the rural villages in the state. It is established that 69 respondents (18%) are of the opinion that reservoir water is highly used, 89 respondents(23%) are of the idea that it is moderately used and 74 respondents (19%) are of the idea that it is fairly used, this shows that

reservoir is one of the source of drinking water in the area. Responses on river indicates 100 respondents (25%) states that it is highly used, 94 respondents (24%) are of the opinion that it is moderately use and 140 respondents (36%) are of the idea that it is fairly used. 176 respondents (45%) indicate that open wells are highly used, 99 respondents (25%) established that it is moderately used and 81 respondents (21%) said it is fairly used. This indicates that open well is used more than any other source of water in the study area.

Responses on usage on hand pump shows that 34 respondents (9%) indicates that it is highly used, 19 respondents (5%) are of the idea that it is moderately used and 74 respondents (19%) said it is fairly used. Responses on bore hole operated by diesel engine indicate 20 respondents (5%) of the said it is highly used, 104 respondents (26%) said it is moderately used, 110 respondents (28%) are of the idea that it is fairly used and 160 respondents (41)% are of the opinion that bore hole operated by engines are not used at all in their rural villages. It is established that 338 respondents (86%) said they don't use solar bore hole as source of drinking water in their village because it is absent. 46 respondents (12%) said it is fairly used, 9 respondents (2%) said it is moderately used and 1 respondent is of the opinion that it is highly used. This shows that solar bore hole is not located in most of the rural villages. It can be seen that 295 respondents (75%) are of the idea that they don't use tap water at all, 11 respondents (3%) said it is moderately used, 29 respondents (7%) said it is fairly used and 59 respondents (15%) said it is highly used. This shows that tap water is relatively unused in the rural villages of Kano state.

Table 4.5 Responses on Water usage from the Sources

Source	Level of Usage								Total
	Highly		Moderately		Fairly		Not Use		
	People	%	people	%	People	%	People	%	
Pond	2	1	29	7	246	62	117	30	394
Reservoir	69	18	89	23	74	19	162	41	394
River	100	25	94	24	140	36	60	15	394
Open Well	176	45	99	25	81	21	38	10	394
Hand Pump	34	9	19	5	74	19	267	68	394
Borehole Engine	20	5	104	26	110	28	160	41	394
Borehole Solar	1	0	9	2	46	12	338	86	394
Tap	59	15	11	3	29	7	295	75	394

Source: Data Analysis, 2012

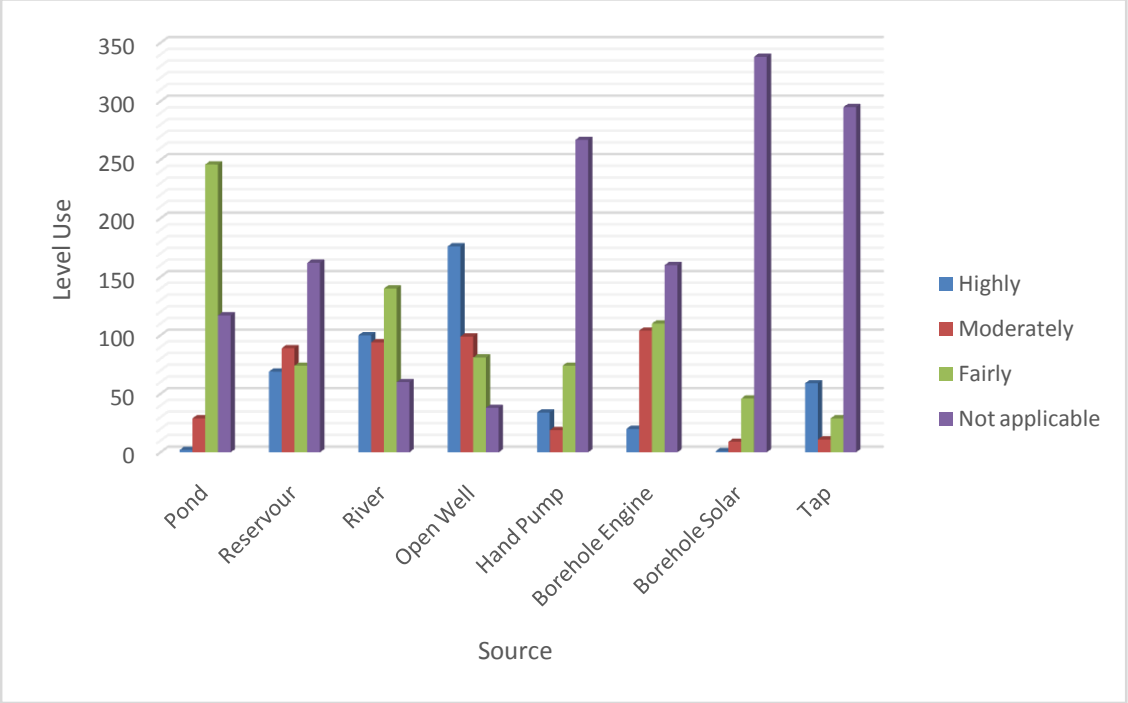


Figure 4.2 Level of water usages from the sources
Source: Data Analysis, 2012

4.2.5 Sources of water Provision

Table 4.6 indicate that most of the water sources are provided and controlled by individuals (house Holds) according to the opinion of 39.3% of the responses, followed by Government with 31.2%, nature 22.3% and the one with lowest responses is entrepreneurship with 2.5%. This shows that most of the water sources are open well controlled by individual households. Among the villages it can be seen that Shuwaki and K/yashi from Kano north recorded the highest responses on control of water sources by nature with 2.8% each. Karfi in Kano central recorded highest responses on provision of water sources by individual with 11.7%, Dokadawa in Kano north recorded the highest responses on provision and control of water sources by Government with 7.9% followed by Tarai and Riruwai in Kano south with 6.9% and 5.8% respectively. Entrepreneur recorded highest responses in Shakogi and Riruwai all with 0.8%.

Table 4.6 Distribution of Respondents according to sources of water provision

Village	Control of Water Source										Total	
	Nature		Individual		Community		Entrepreneur		Government			
	F	%	F	%	F	%	F	%	F	%	F	%
Shuwaki	11	2.8%	6	1.5%	0	0.0%	0	0.0%	4	1.0%	21	5.3%
Yandadi	9	2.3%	3	0.8%	0	0.0%	1	0.3%	16	4.1%	29	7.4%
DokaD/w	3	0.8%	1	0.3%	0	0.0%	0	0.0%	31	7.9%	35	8.9%
K/Yashi	11	2.8%	0	0.0%	1	0.3%	0	0.0%	0	0.0%	12	3.0%
Shakogi	8	2.0%	0	0.0%	3	0.8%	3	0.8%	0	0.0%	14	3.6%
Alajawa	8	2.0%	1	0.3%	1	0.3%	0	0.0%	1	0.3%	11	2.8%
Riruwai	9	2.3%	0	0.0%	0	0.0%	3	0.8%	23	5.8%	35	8.9%
Zainabi	3	0.8%	10	2.5%	7	1.8%	0	0.0%	1	0.3%	21	5.3%
T/Kaya	0	0.0%	13	3.3%	1	0.3%	0	0.0%	1	0.3%	15	3.8%
Turawa	6	1.5%	4	1.0%	0	0.0%	0	0.0%	0	0.0%	10	2.5%
Fammar	1	0.3%	10	2.5%	0	0.0%	1	0.3%	7	1.8%	19	4.8%
Tarai	2	0.5%	37	9.4%	0	0.0%	2	0.5%	27	6.9%	68	17.3%
Babawa	5	1.3%	11	2.8%	1	0.3%	0	0.0%	0	0.0%	17	4.3%
Tumbau	8	2.0%	9	2.3%	1	0.3%	0	0.0%	1	0.3%	19	4.8%
Karfi	3	0.8%	46	11.%	2	0.5%	0	0.0%	4	1.0%	55	14.0%
Kosawa	1	0.3%	4	1.0%	1	0.3%	0	0.0%	7	1.8%	13	3.3%
Total	88	22.%	155	39.3%	18	4.6%	10	2.5%	123	31.2%	394	100.0%

Source: Field Survey, 2012

4.2.6 Adequacy of Water Supply in Rural Areas of Kano

Table 4.7 indicates that 62.9% of the respondents said water supply is not adequate in their villages, 33.0% are of the opinion that water supply is adequate in their end and 4.1% of the respondents didn't responded to this question. Highest percentage of respondents that say water is not adequate is recorded in Karfi Kano central with 11.4% and Tarai in Kano south recoded highest percentage of yes with 6.6%. Figure 4.3 shows that in Kano north 86 respondent states that drinking water is inadequate, 36 said it is adequate. In Kano south 104 respondents believed that drinking water is

inadequate and 55 said it is adequate. In Kano central 58 respondents are of the view that drinking water is inadequate and 39 said it is adequate.

Table 4.7 Adequacy of water supply in the rural areas of Kano

	Adequacy of Water Supply							
	No response		Yes		No		Total	
Villages	F	%	F	%	F	%	F	%
Shuwaki	0	0.0%	5	1.3%	16	4.1%	21	5.3%
Yandadi	0	0.0%	18	4.6%	11	2.8%	29	7.4%
DokaDawa	0	0.0%	12	3.0%	23	5.8%	35	8.9%
K/Yashi	0	0.0%	0	0.0%	12	3.0%	12	3.0%
Shakogi	0	0.0%	0	0.0%	14	3.6%	14	3.6%
Alajawa	0	0.0%	1	.3%	10	2.5%	11	2.8%
Riruwai	0	0.0%	7	1.8%	28	7.1%	35	8.9%
Zainabi	4	1.0%	10	2.5%	7	1.8%	21	5.3%
T/Kaya	1	.3%	0	0.0%	14	3.6%	15	3.8%
Turawa	4	1.0%	6	1.5%	0	0.0%	10	2.5%
Fammar	0	0.0%	6	1.5%	13	3.3%	19	4.8%
Tarai	0	0.0%	26	6.6%	42	10.7%	68	17.3%
Babawa	0	0.0%	17	4.3%	0	0.0%	17	4.3%
Timbau	0	0.0%	15	3.8%	4	1.0%	19	4.8%
Karfi	7	1.8%	3	.8%	45	11.4%	55	14.0%
Kosawa	0	0.0%	4	1.0%	9	2.3%	13	3.3%
Total	16	4.1%	130	33.0%	248	62.9%	394	100.0%

Source: Field Survey, 2012

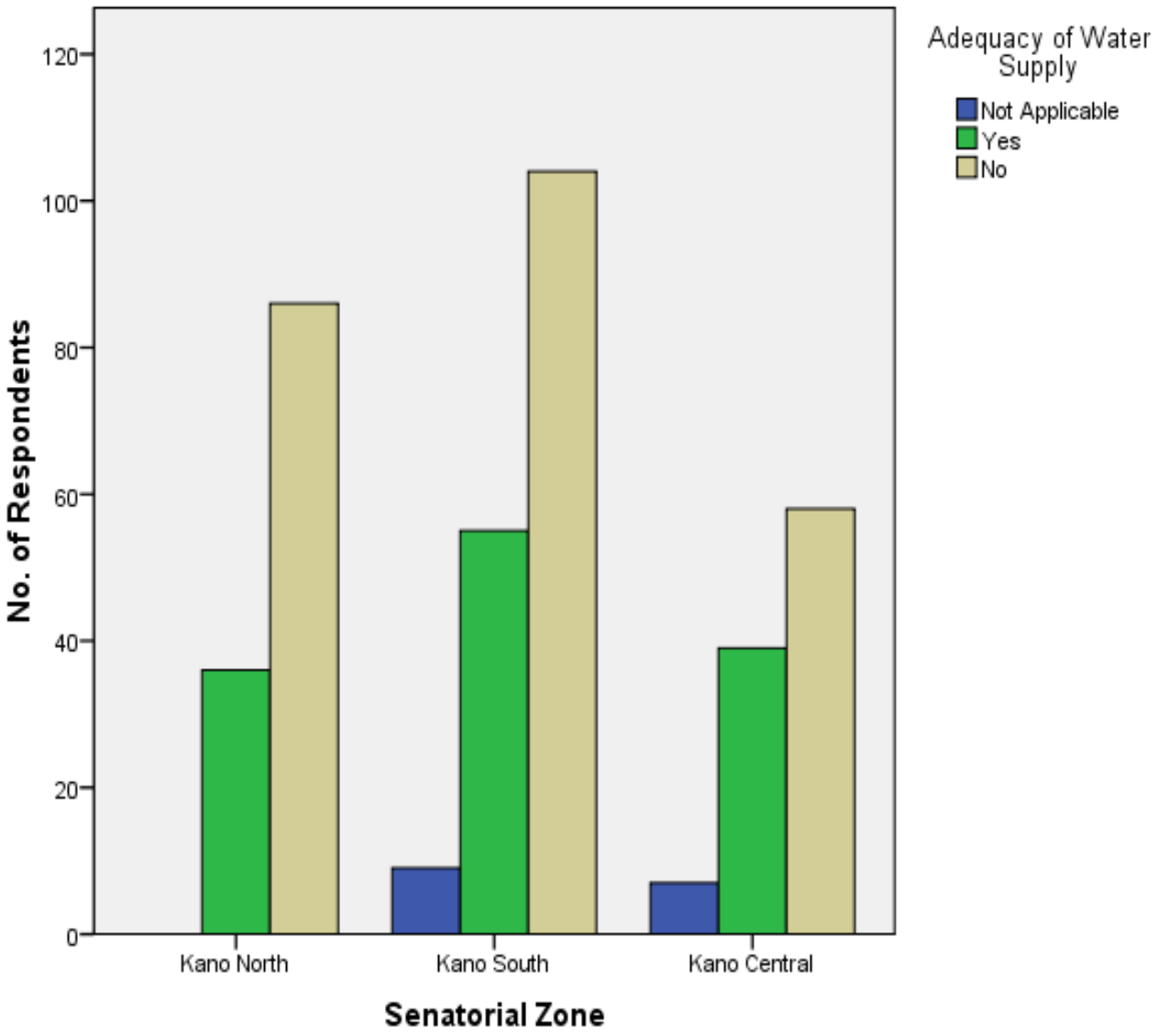


Figure 4.3 Adequacy of water supply Based on Senatorial District in Kano state
Source: Data analysis, 2013.

4.2.7 Purchase of Drinking Water in the Rural Areas.

Table 4.8 shows that 60.7% of the respondents said they buy water and only 39.3% said they don't buy water at all. Villages in Kano south recorded the highest number of respondents that said they buy water with 29.9% followed by Kano north with 16.5% responses and Kano central with 12.2% responses.

Table 4.9 outlines the amount of money spent by households in the rural villages of the state in which 33.0% of the respondents stated that they spend less than N100 (< $0.55) per day on drinking water, 18.0% spend up to N100 (< $0.55) , 11.7% N150 ($ 0.83) -N200 ($ 1.1), 2.5% N250 ($1.4) - N500($2.8) and 0.5% more than N500 (>$2.8). Rural villages in Kano south recorded the largest percentage of those that buy water at <N100 ($ 0.55) (15.0%). It can be seen that 34.3% of the respondents do not spend any amount on drinking water.

Table 4.8 Responses on Buying Drinking Water

Senatorial Zone	Do You Buy Water				Total	
	Yes		No			
	F	%	F	%	F	%
Kano North	65	16.5%	57	14.5%	122	31.0%
Kano central	56	14.2%	48	12.2%	104	26.4%
Kano South	118	29.9%	50	12.7%	168	42.6%
Total	239	60.7%	155	39.3%	394	100.0%

Source: Field Survey, 2012

Table 4.9 Responses on amount of money spend per day on drinking water

Senatorial Zone	If yes How Much													
	Not Applicable		<N100		N100		N150-200		N250-500		>500		Total	
	F	%	F	%	F	%	F	%	F	%	F	%	F	%
KanoNorth	57	14.5%	21	5.3%	30	7.6%	12	3.0%	0	0.0%	2	.5%	122	31.0%
KanoCentral	35	8.9%	50	12.7%	16	4.1%	3	.8%	0	0.0%	0	0.0%	104	26.4%
KanoSouth	43	10.9%	59	15.0%	25	6.3%	31	7.9%	10	2.5%	0	0.0%	168	42.6%
Total	135	34.3%	130	33.0%	71	18.0%	46	11.7%	10	2.5%	2	.5%	394	100.0%

Source: Field Survey, 2012

4.3 NATURE OF HYDROGEOLOGY

Results of the nature of hydrogeology are as follows, the result for the DEM in the study area is shown in Figure 4.4. The DEM indicates that Southern part of the study area is higher in terms of elevation with relief values of more than 767.9m and the lowest relief values of 383.3m are recorded in the northern parts. All places in the central are having moderate values of elevation. This indicates that south is the highest point which forms the watershed of the study area. North is the lowest point which form the down steam section of the study area.

The results of spot heights and contour lines are presented in Table 4.10 and Figure 4.5 the highest contour is >580m and the lowest contour is 340m. Among the rural villages in Riruwai Doguwa Local Government area value of the contour is >580m above mean sea level, Zainabi 570m, lowest points are recorded in Kosawa, K/Yashi, Karfi, Babawa and Tumbau. The result also indicates that all areas with lowest contour values have more drainage concentration than areas with highest values.

Table 4.10 and Figure 4.6 show results of slope values of the study area. The highest slope values are >9 ^{o} and the lowest slope values are from 0- 3.0^{o}. Area with highest slope value is Riruwai with slope value >9^{o,} Tarai and Zainabi, are areas with slope values of between 6.0- 9.0^{o,} areas with moderate slope values of between 3.0- 6.0^{o} are Tumbau, Tudunkaya, Turawa, Kosawa and Fammar while areas with lowest slope values of between 0- 3.0^{o} are Shuwaki, Yandadi, Dokadawa, K/yashi, Shakogi, Alajawa and Karfi. It is deduced that areas with slope values of between 0- 3.0^{o} and 3.0- 6.0^{o} are areas ascribed to have higher drainage concentration i.e. more rivers and dams and more groundwater.

The results of drainage concentration or drainage density in the study area is presented in Table 4.10 and Figure 4.7 The highest value of drainage density in the study area is found to be 97.2km/km^{2} to 121.5Km/Km^{2} and the lowest is found to be 0- 24.30km/km^{2}. Areas with highest drainage density are Turawa, Karfi, K/Yashi and Tarai. Areas with Moderate drainage density are Kosawa and Yandadi while areas with lowest values of drainage density are Riruwai, Zainabi, Fammar, Dokadawa, Tudunkaya, Alajawa, Shakogi, Shuwaki and Tumbau. The result shows that drainage network is concentrated around River Kano Chalawa Duddurungaya and Gari. It is also observed that dendritic drainage pattern is the major drainage type in the area.

Table 4.11 and Figure 4.8 present results of aquifer parameters and it indicates that areas such as Babawa tarai, Yandadi, Karfi, Kosawa and Shakogi are areas with higher porosity of 19.8%, 19.8%, 19%, 22%, 20% and 20% respectively. These areas are having highest water content of 22^{cm3}, 20 ^{cm3,} 21 ^{cm3}, 21^{cm}, 19 ^{cm3} and 21.5 ^{cm3} respective. Highest values of specific yield are recorded in these villages of 12.7% to 14.7%. In the same locations highest values of hydraulic head of between 19m to 35.1m were recorded. Highest values of hydraulic conductivity and specific storage are recorded in these areas of around 3.21 x 10^{-1} to 7.73 x 10^{-1} and 0.0351^{-m} to 0.0181^{-m} respectively. Areas with moderate values of aquifer parameters are Alajawa, Turawa, Shuwaki and K/yashi with porosity values of 17.1% to 18%, water content of around 18cm3 to

18.5cm3, and specific yield with values around 12% to 12.3%. Hydraulic head and specific storage were found to be 7.73 x 10^{-1} and 0.0389^{m} respectively.

The result also indicates that Riruwai, Zainabi, Tudunkaya, Tumbau and Fammar are the areas with lowest aquifer parameters. Porosity was found to be around 5% to 12% , water content 3 cm^3 to 10$cm^{3,}$ specific yield 4% to 6% , hydraulic head 3.2m to10.1m and hydraulic conductivity and specific storage were found to be around 3.21 x 10^{-1} and 0.125^{-m} to 0.0624^{-m} respectively.

Table 4.10 Values of Contours, Slopes and Drainage density in the Selected Rural areas

S/N	Rural areas	Contours (m)	Slope values (in^{o})	Drainage density(km/km$^{2)}$
1	Shuwaki	360	0-3.0 ^{o}	0- 24.3
2	Yandadi	340	0-3.0 ^{o}	48.60- 72.2
3	Dokadawa	370	0-3.0 ^{o}	0- 24.3
4	K/Yashi	340	0-3.0 ^{o}	97.23- 121.51
5	Shakogi	360	0-3.0 ^{o}	0- 24.3
6	Alajawa	350	0-3.0 ^{o}	0- 24.3
7	Riruwai	>580	>9.0 ^{o}	0- 24.3
8	Zainabi	570	6.0-9.0 ^{o}	0- 24.3
9	Tudunkaya	390	3.0-6.0 ^{o}	0- 24.3
10	Turawa	390	3.0-6.0 ^{o}	97.23- 121.51
11	Fammar	470	3.0-6.0 ^{o}	0- 24.3
12	Tarai	480	6.0-9.0 ^{o}	72.9- 97.2
13	Babawa	370	0-3.0 ^{o}	24.3- 48.60
14	Tumbau	370	3.0-6.0 ^{o}	0- 24.3
15	Karfi	380	0-3.0 ^{o}	97.23- 121.51
16	Kosawa	390	3.0-6.0 ^{o}	48.60- 72.2

Source: Data Analysis, 2011

Table 4.11 Aquifer Parameters data of the Selected Rural Areas

S/N	Stations	Total Vol. cm^3	Porosity (n) in % Laborat. Vv/Vx100	Water content (w) (cm^3) laborat.	Specific yield (%) (Calc.)vw/V	Hydrau. head(m) measured	Hydraulic conduct. (From laborat.)	Specific Storage (Calc.) 1dmw/ma.dh
1	Shuwaki	150	18%	$20cm^3$	13.3%	18.1m	$4.93x10^{-3}$	0.0409^{-m}
2	Yandadi	150	19%	21 cm^3	14.1%	24.2m	$4.93x10^{-3}$	0.0304^{-m}
3	D/Dawa	150	18%	19 cm^3	12.7%	16.6m	$6.84x10^{-1}$	0.0424^{-m}
4	K/Yashi	150	18%	18.5 cm^3	12.3%	17.5m	$6.84x10^{-1}$	0.0392^{-m}
5	Shakogi	150	20%	21.5 cm^3	14.3%	25.5m	$6.84x10^{-1}$	0.0281^{-m}
6	Alajawa	150	17.5%	18 cm^3	12.0%	15.9m	$6.84x10^{-1}$	0.0430^{-m}
7	Riruwai	150	5%	3 cm^3	4%	3.2m	$3.21x10^{-1}$	0.1250^{-m}
8	Zainabi	150	10%	8 cm^3	5.3%	9.1m	$3.21x10^{-1}$	0.0586^{-m}
9	T/Kaya	150	9%	8 cm^3	5.3%	9.5m	$3.21x10^{-1}$	0.0624^{-m}
10	Turawa	150	17.1%	18 cm^3	12.0%	17.7m	$3.21x10^{-1}$	0.0396^{-m}
11	Fammar	150	11%	9 cm^3	6.0%	10.1m	$3.21x10^{-1}$	0.0540^{-m}
12	Tarai	150	19%	20 cm^3	13.3%	20.0m	$7.73x10^{-1}$	0.0351^{-m}
13	Babawa	150	19.8%	22 cm^3	14.7%	19.3m	$7.73x10^{-1}$	0.0389^{-m}
14	Tumbau	150	12%	10 cm^3	6.7%	9.6m	$7.73x10^{-1}$	0.0579^{-m}
15	Karfi	150	22%	21 cm^3	14.0%	35.1m	$6.84x10^{-1}$	0.0181^{-m}
16	Kosawa	150	20%	19 cm^3	12.7%	21.3m	$6.84x10^{-1}$	0.0297^{-m}

Source: Field and Laboratory work, 2013

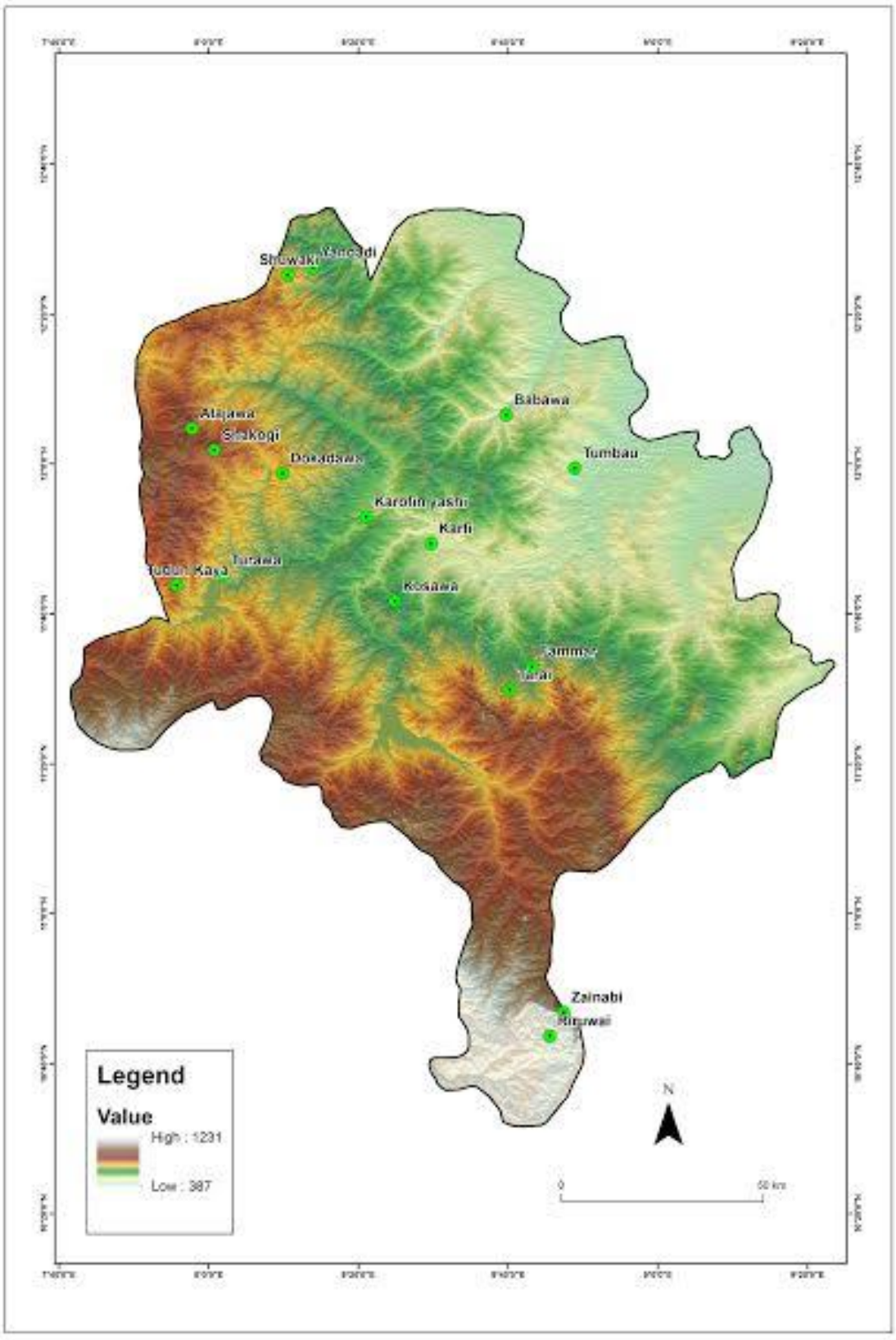


Figure 4.4 DEM of Kano state Developed from SRTM

Source: Data Analysis, 2011

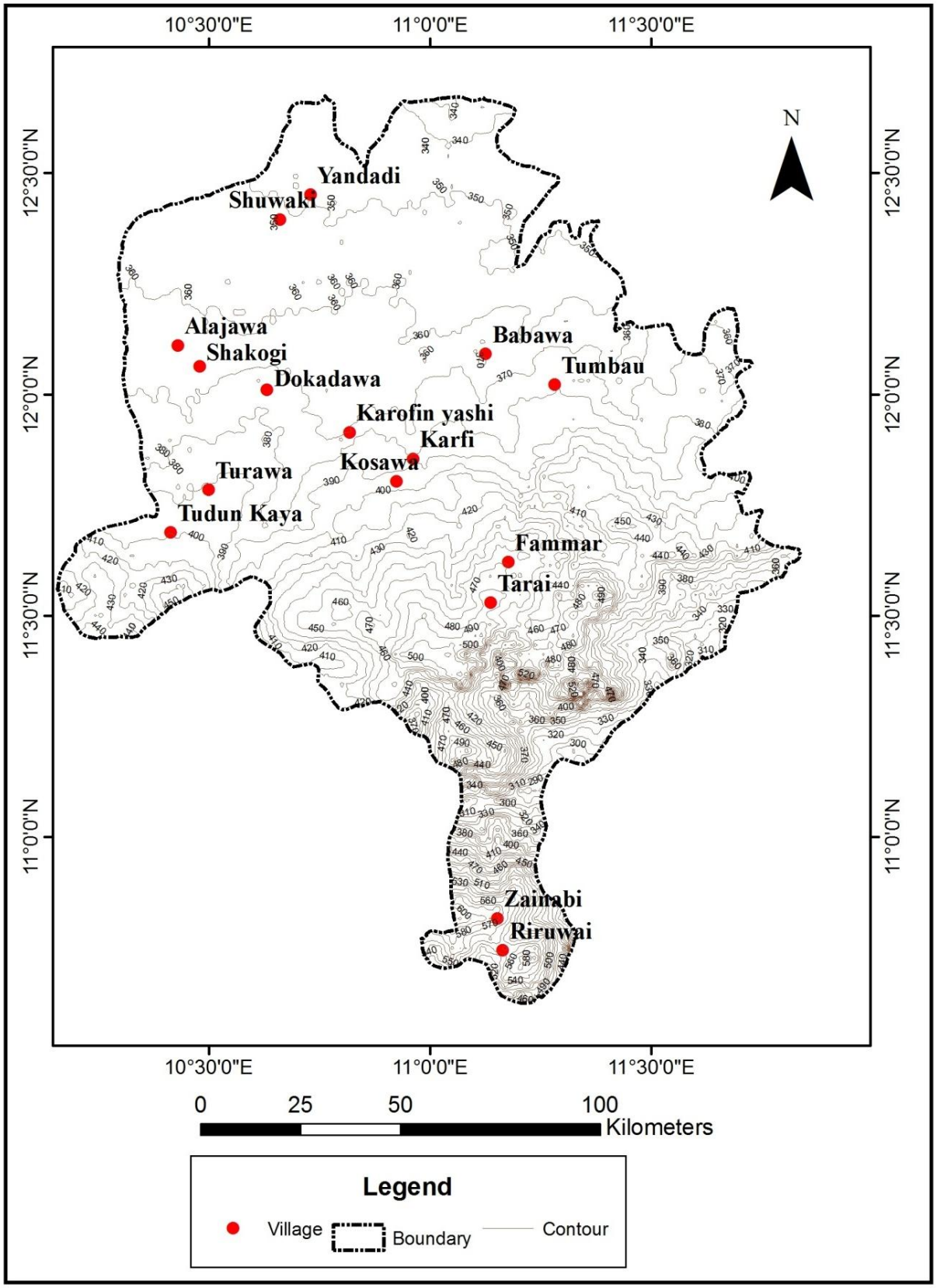


Figure 4.5 Contour map of Kano State extracted from DEM

Source: Data Analysis, 2013

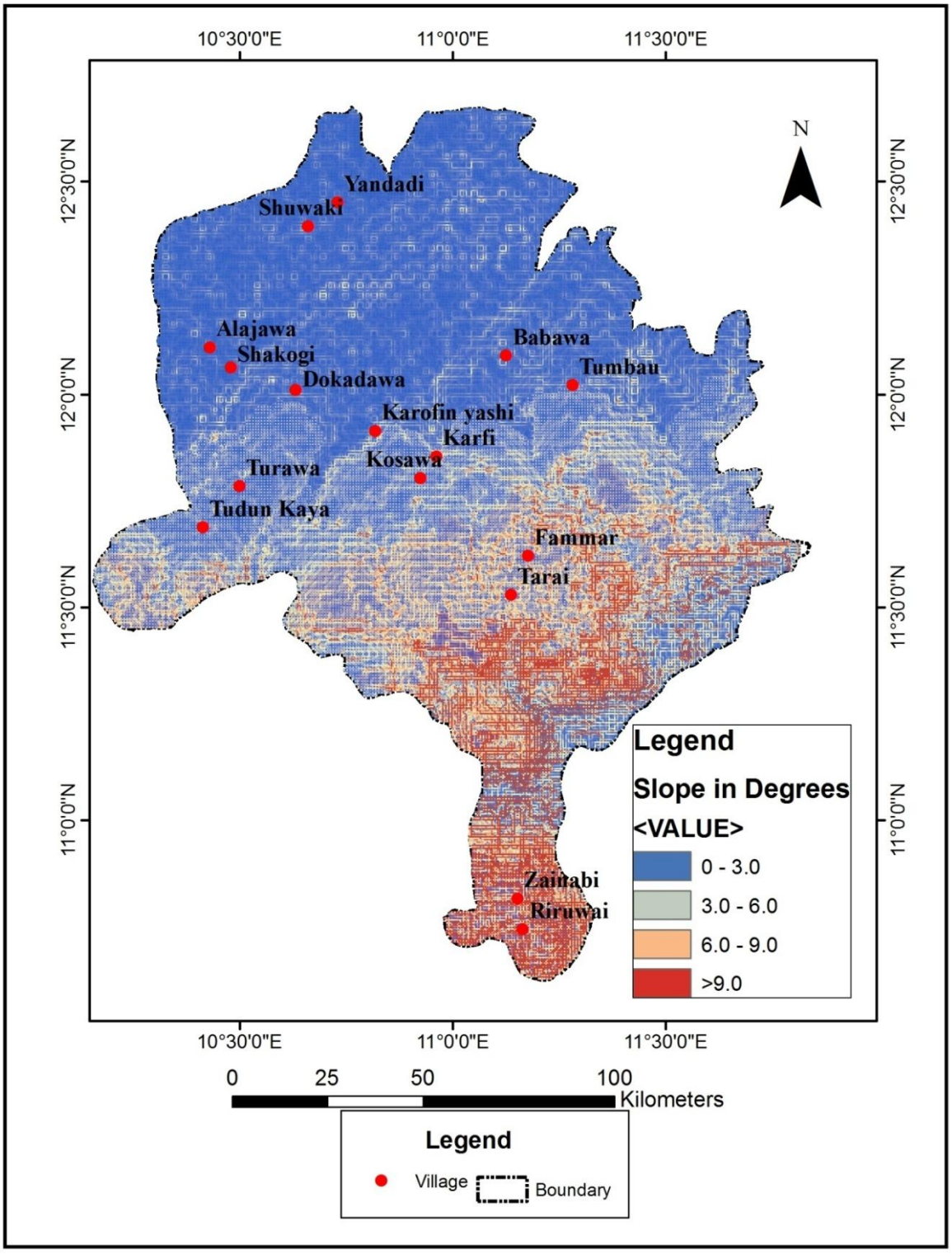


Figure 4.6 Slope map of Kano State extracted from DEM

Source: Data Analysis, 2013

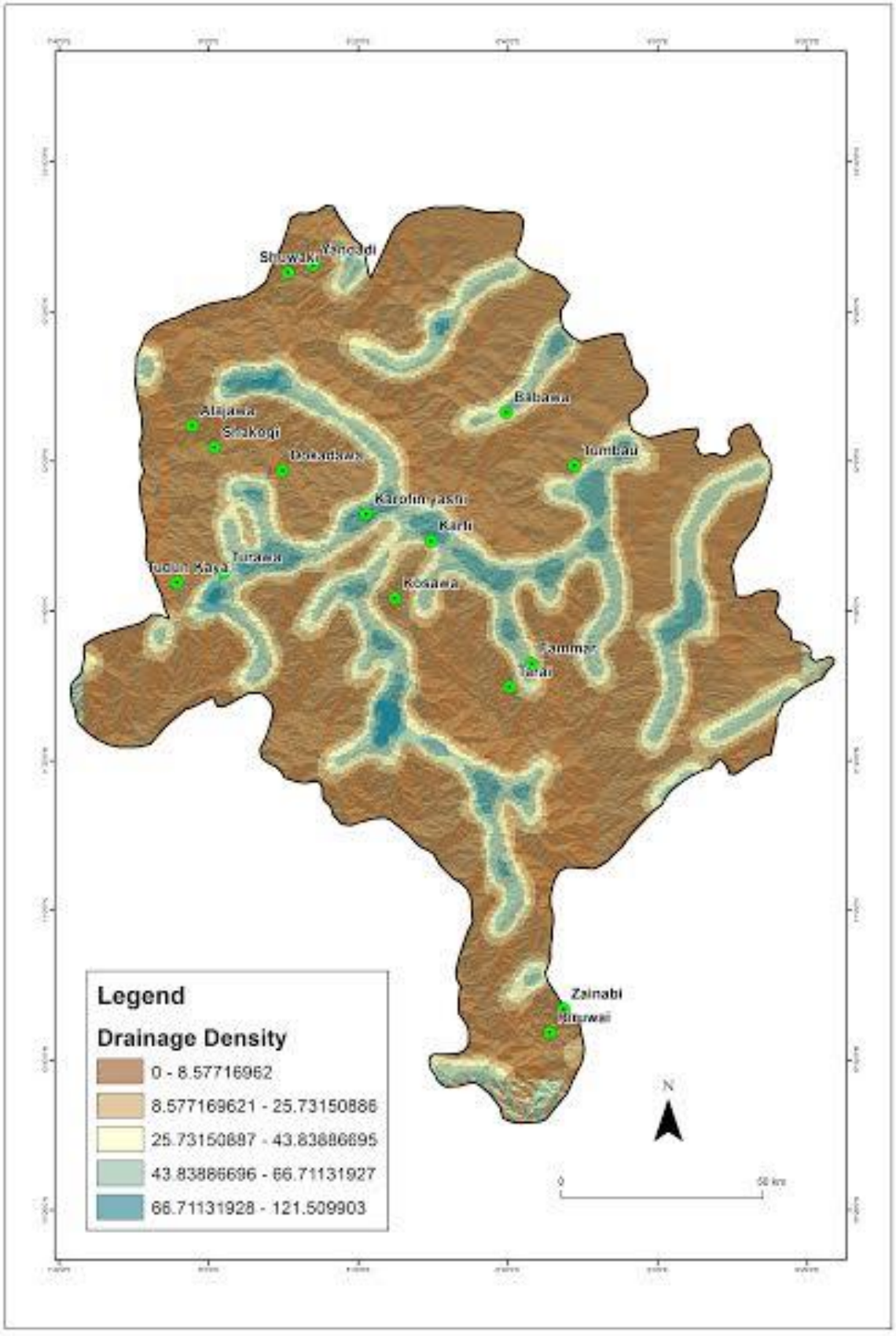


Figure 4.7 Drainage density classification of Kano State

Source: Data Analysis, 2013

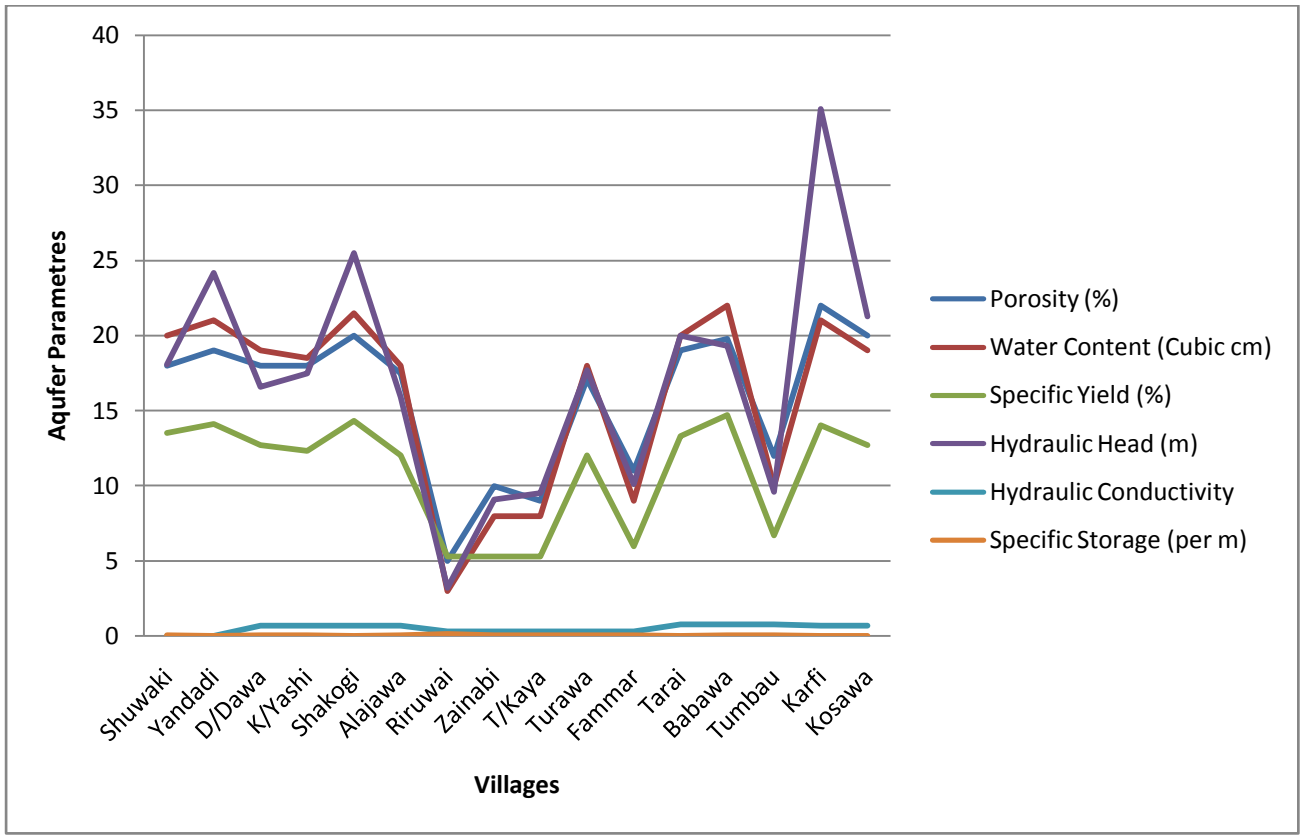


Figure 4.8 Variation of Aquifer parameter among the 16 rural Areas

Source: data Analysis, 2013

4.4 GROUNDWATER POTENTIAL ASSESSMENT

4.4.1 Results of VES Survey

The results for the resistivity measurements of both seasons of the sixteen rural villages were interpreted and presented as follows based on Achie law and standards of Grant and West (1965) which recommend a low resistivity area with high depth to be a promising aquifer and a high resistivity area with low depth to be a non promising aquifer in a hard rock terrain like this study area. Table 4.17 show the standard based on which the interpretation of VES data was used. Three to four layers were identified in this study (Appendix: 3a, 3b, 3c and 3d).

The VES results of the survey carried out in wet season July/August 2011 in Kano north senatorial district is presented in Table 4.12 and Figures 4.9, 4.10, 4.11, 4.12, 4.13 and 4.14. The results show that Shuwaki recoded apparent resistivity value of 132 ohm- m with depth of between 30- 35m is described as a promising aquifer suitable for drilling. Karofinyashi and Alajawa are described as high in terms of groundwater prospects with apparent resistivity of 79.17 ohm-m and 339.9 ohm-m respectively and the depths are 35- 40m, 30- 35m respectively. Rural areas with poor curves are Yandadi and Shakogi all with higher resistivity and low depth values. The Dokadawa curve is said to be moderate and that of Shakogi is described as low.

Table 4.12 VES survey results of the rural villages in the Kano north senatorial zone for the wet season

s/n	L.G.As	Rural villages	Location	Alt (m)	AR oms^{-m}	(m) depth	Avr depth (m)	Remark
1	Kunchi	Shuwaki	N12.42049^o					
			E008.17594^o	533	132.2	30-35	32.85	High
		Yandadi	N12.43751^o					
			E008.23260^o	499	321.3	10-15	12.70	Low
	Rimingado	Dokadawa	N11.97927^o					
2			E008.16412^o	539	307.4	25-30	26.74	Moderate
		Karofinyashi	N11.88268^o					
			E008.35069^o	458	79.17	35-40	39.90	High
3	Shanono	Shakogi	N12.03162^o					
			E008.0121273^o	566	919.0	10-15	12.65	Low
		Alajawa	N12.07925^o					
			E007.9628^o	560	339.9	30-35	31.99	High

Source: Field work 2011

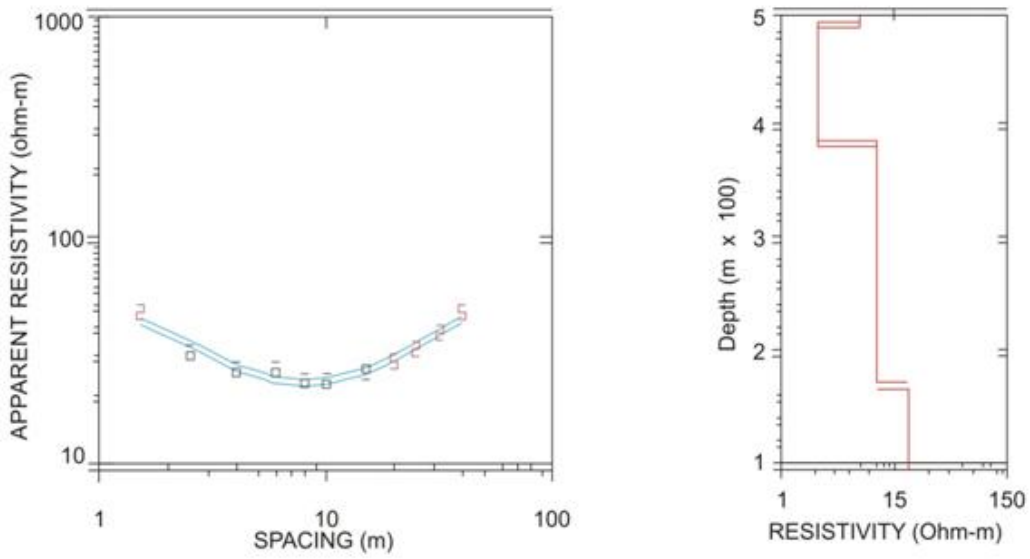


Figure 4.9 and VES curve of Shuwaki in wet season

Source: Data Analysis, 2013

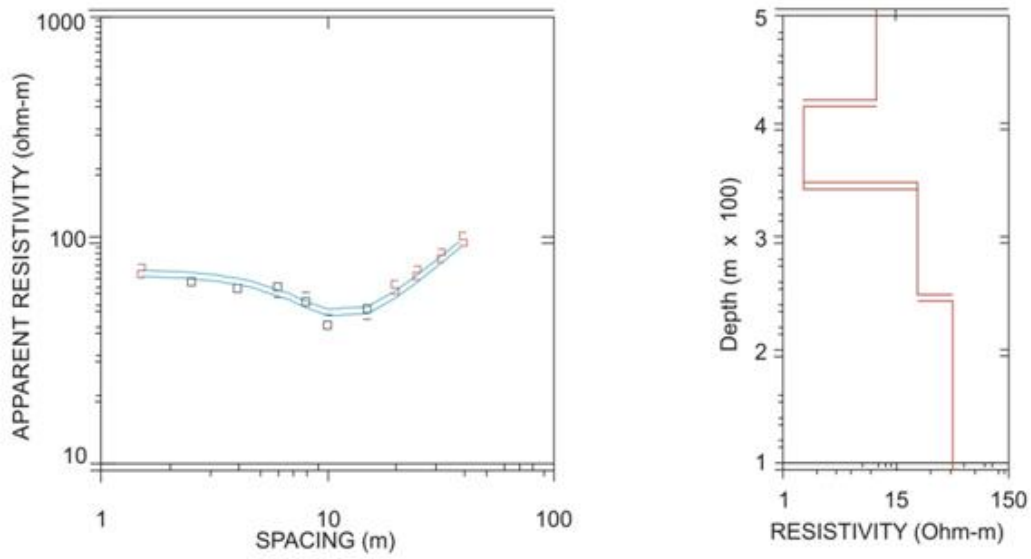


Figure 4.10 VES curve Yandadi in wet season

Source: Data Analysis, 2013

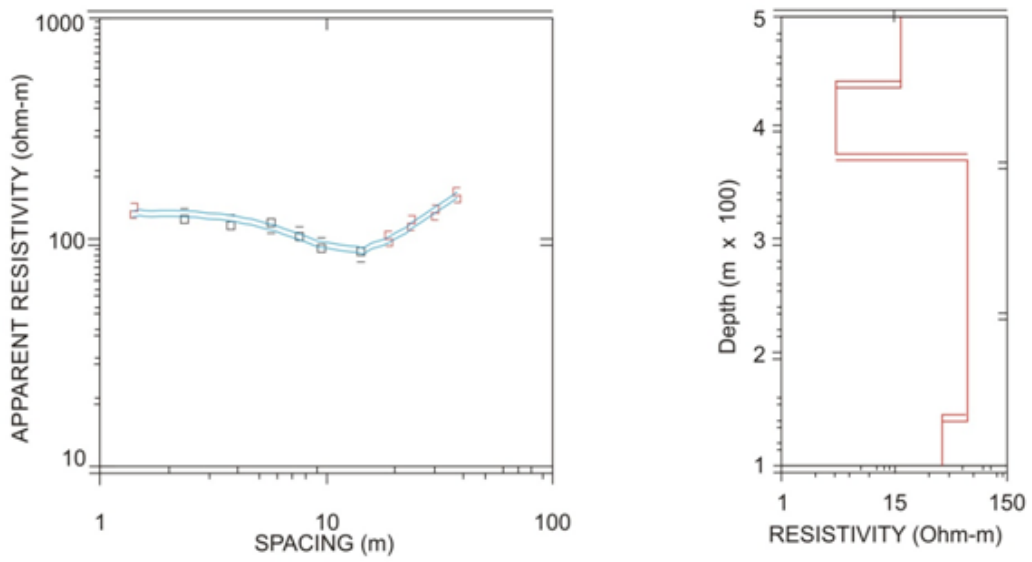


Figure 4.11 VES curve of D/Dawa in wet season

Source: Data Analysis, 2013

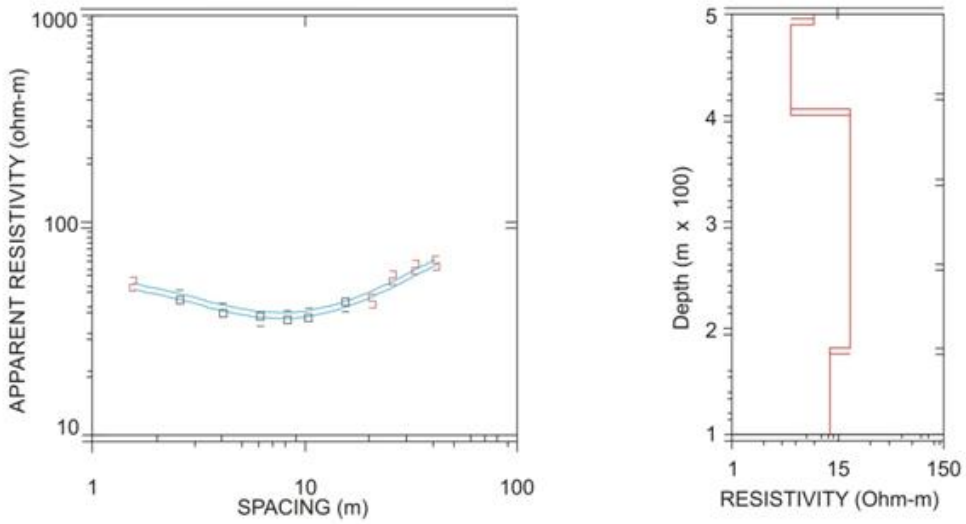


Figure 4.12 VES curve K/Yashi in wet season

Source: Data Analysis, 2013

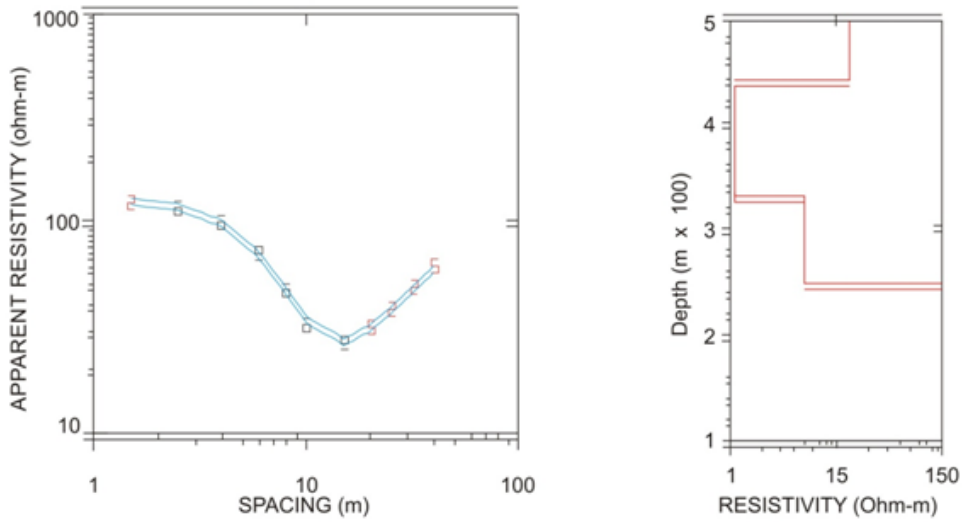


Figure 4.13 VES of S/Kogi in wet season

Source: Data Analysis, 2013

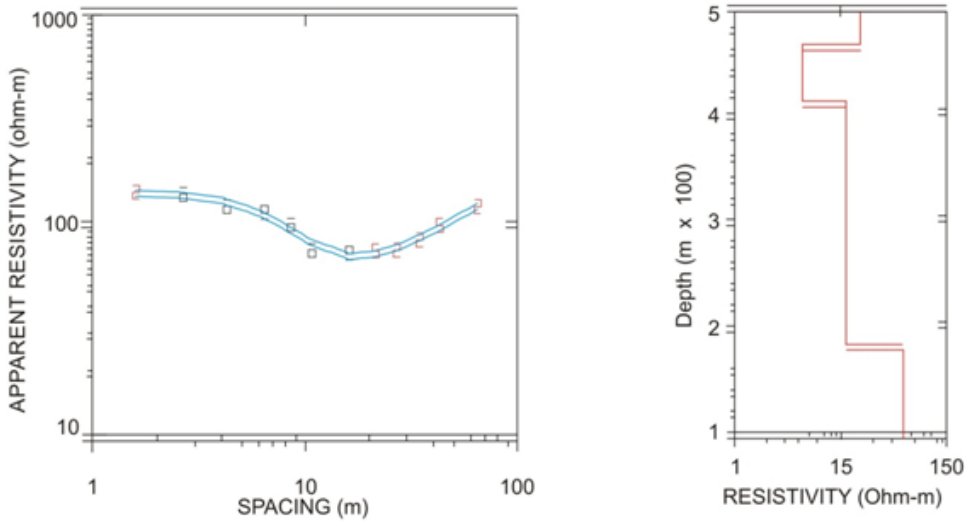


Figure 4.14 VES of Alajawa in wet season

Source: Data Analysis, 2013

Kano south senatorial district VES results of the wet season for the six rural villages are presented in Table 4.13 and Figures 4.15, 4.16, 4.17, 4.18, 4.19, 4.20. From the results It can be seen that Riruwai, Tudunkaya, Fammar and Tarai are areas found to be of low aquifer condition because the resistivity values are 44.5ohms-m 19992.2 ohms- m, 484 ohms- m and 2423.8 ohms- m respectively and depths of 15-25m, 15- 20m, 15- 20m and 20- 25m respectively. It can also be seen from the results and Figures (Figure; 4.16 and 4.18) that is Zainabi and Turawa are areas with promising aquifers based on the schuluberger array method results they are described to be high in terms of groundwater prospects. They are with low resistivities of 848.4 ohms-m and 97.72 ohm-m respectively and depths of 30-35m and 40-45m respectively.

Table 4.13 VES survey results of the rural villages in the Kano South senatorial zone for the wet season

s/n	L.G.As	Rural villages	Location	Alt (m)	AR oms^{-m}	(m) depth	Avr depth (m)	Remark
		Riruwai	N10.72851^o					
1	Doguwa		E008.75896^o	893	44.5	15-25	22.66	Low
		Zainabi	N10.78090^o					
			E008.7898^o	755	848.4	30-35	33.41	High
		TudunKaya	N11.73080^o					
2	Karaye		E007.92894^o	589	1992.2	15-20	18.67	Low
		Turawa	N11.75320^o					
			E008.03216^o	546	97.72	40-45	44.56	High
	Kibiya	Fammar	N11.55031^o					
3			E008.71932^o	486	571	15-20	13.72	Low
		Tarai	N11.49790^o E008.66964^o	493	2423.8	20-25	21.84	Moderate

Source: Field work 2011

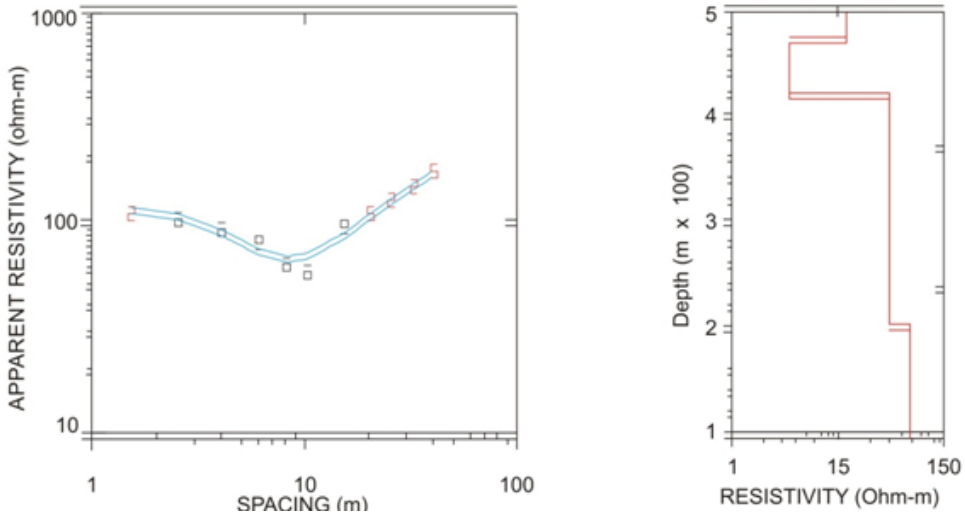


Figure 4.15 VES curve of Riruwai in wet season

Source: Data Analysis, 2013

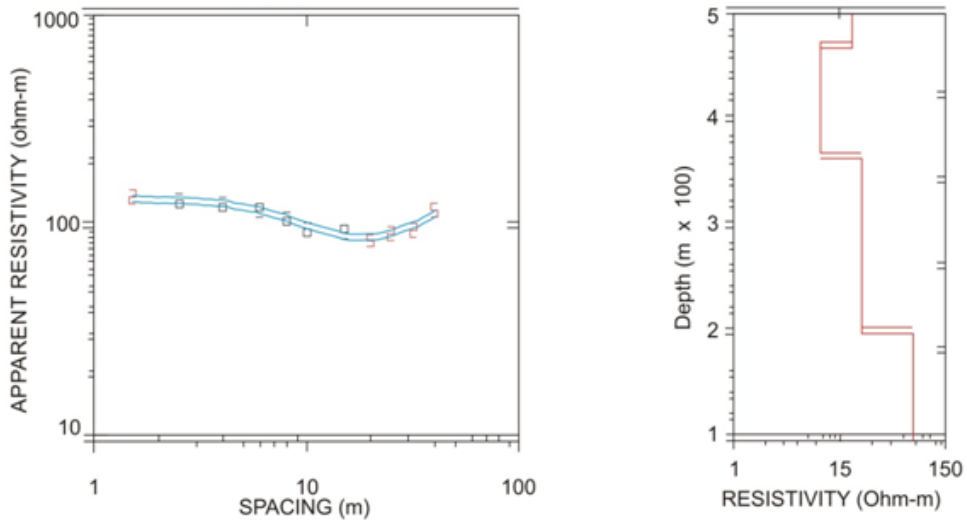


Figure 4.16 VES curve of Zainabi in wet season

Source: Data Analysis, 2011

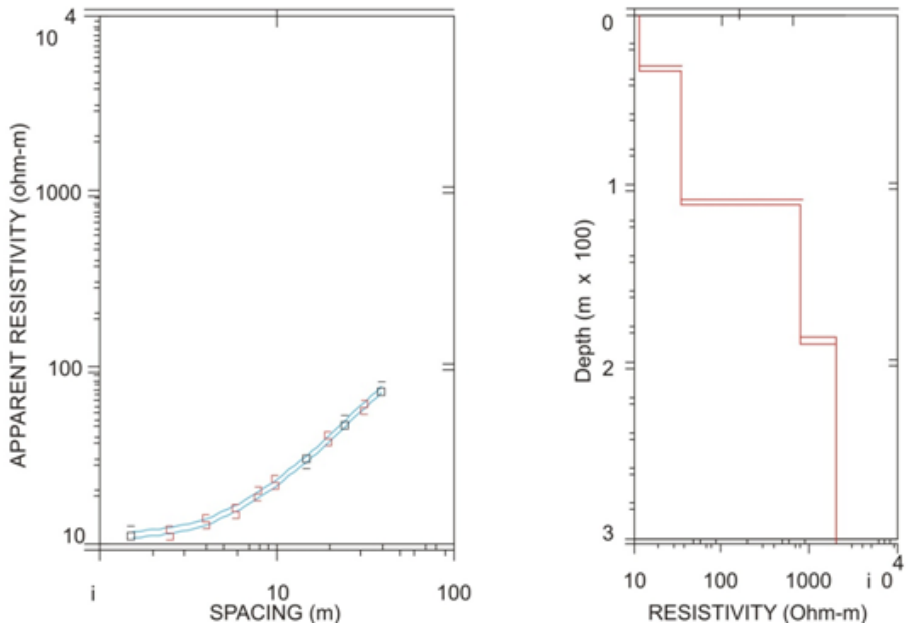


Figure 4.17 VES curve of T/Kaya in wet season

Source: Data Analysis, 2013

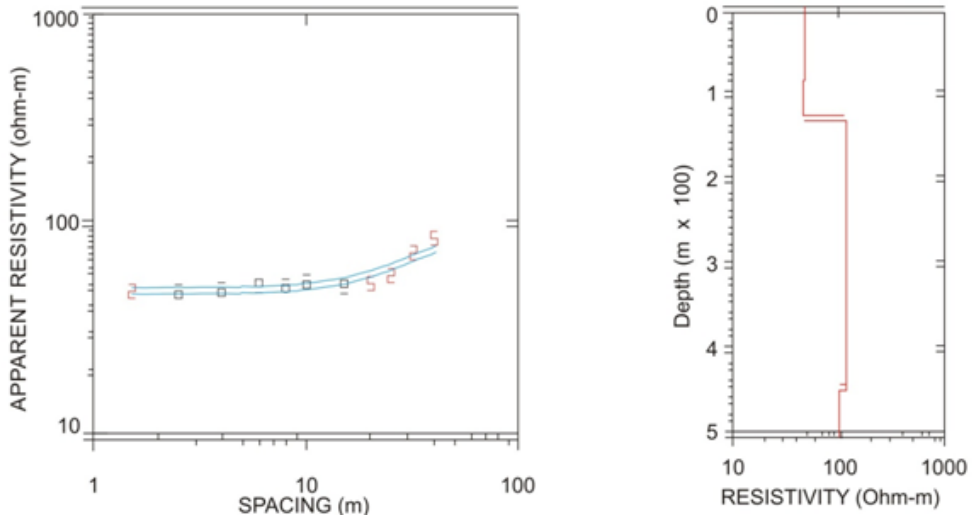


Figure 4.18 VES curve of Turawa in wet season

Source: Data Analysis, 2013

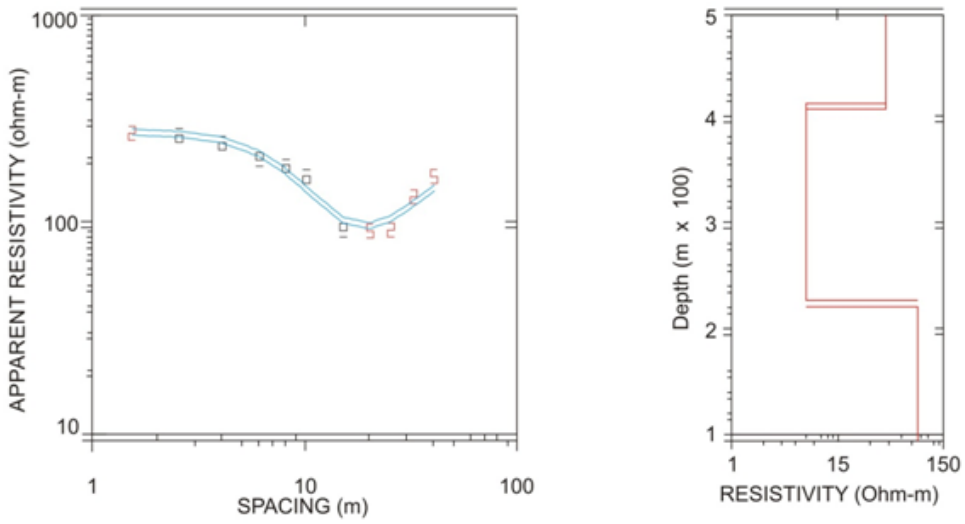


Figure 4.19 VES curve of Fammar in wet season

Source: Data Analysis, 2013

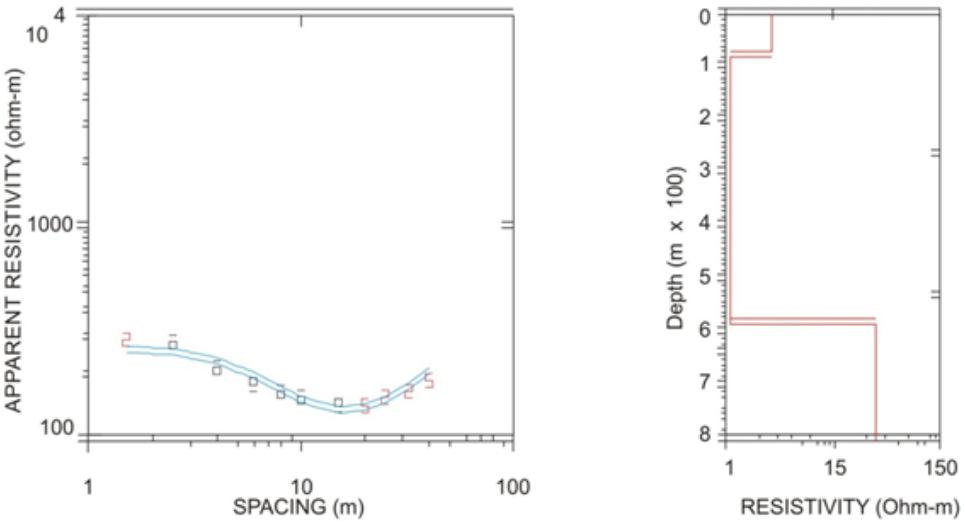


Figure 4.20 VES curve of Tarai in wet season

Source: Data Analysis, 2013

In Kano central senatorial district four villages were studied out of which three areas are high and one is low area in terms of groundwater prospect based on the schulumber array results taken in wet season July/August. The results are presented in table 4.14 and Figure 4.21, 4.22, 4.23 and 4.24. The result indicates that Babawa (figure:4.22), Tumbau(figure:4.21) and Kosawa(figure:4.24) are areas with high prospects because the curves are good with low resistivity of 242.9 ohms-m, 84.32

ohms-m and 170.3 ohms-m respectively and higher depths of 40-45m,35-40m and 40- 45m respectively. But in Karfi (figure: 4.23) VES results indicate a very high apparent resistivity of 363675.5 ohms-m with a lower depth of 10-15m this shows that the curve is a poor type and the area is not a promising one in terms of groundwater prospect it is described as low.

Table: 4.14 VES survey results of the rural villages in the Kano Central senatorial zone for the wet season

s/n	L.G.As	Rural villages	Location	Alt (m)	AR oms^{-m}	(m) depth	Avr depth (m)	Remark
1	Gezawa	Babawa	N12.06004^{o} E008.65827^{o}	456	242.9	40-45	42.84	High
		Tumbau	N11.99074^{o} E008.81459^{o}	426	84.32	35-40	37.17	High
2	Kura	Karfi	N11.82310^{o} E008.49462^{o}	440	363675.5	10-15	10.06	Low
		Kosawa	N11.77221229^{o} E008.45668^{o}	447	170.3	40-45	45.64	High

Source: Field work 2011

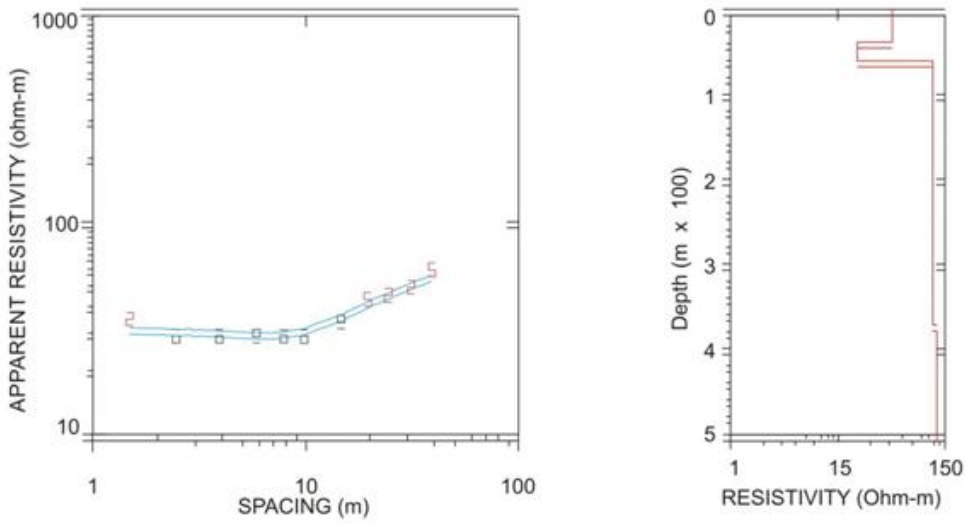


Figure 4.21 VES curve of Tumbau in wet season

Source: Data Analysis, 2013

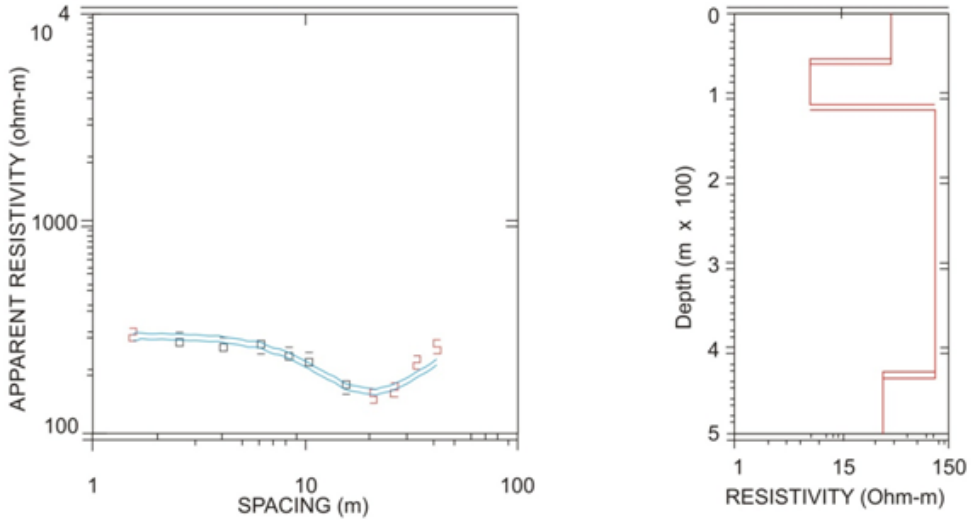


Figure 4.22 VES curve of Babawa in wet season

Source: Data Analysis, 2013

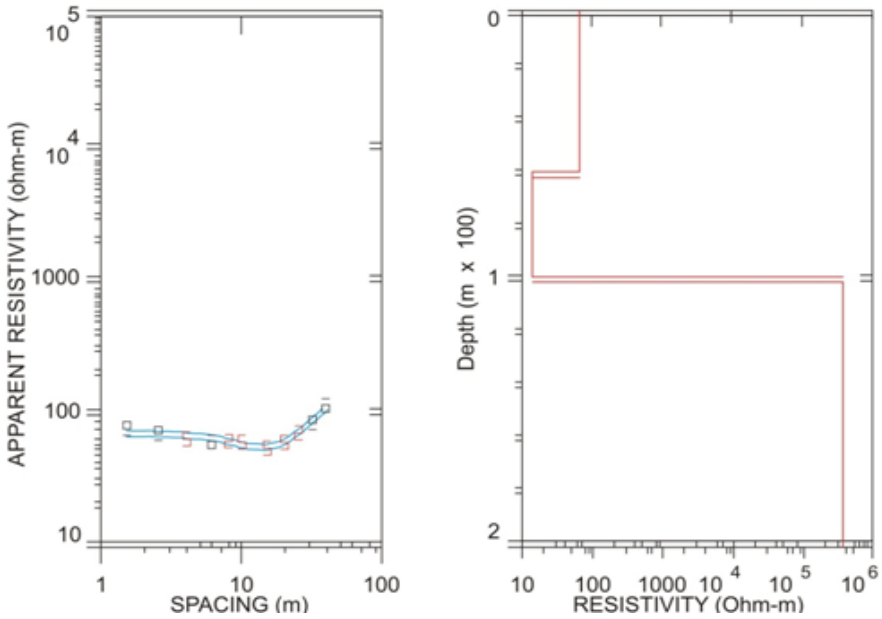


Figure 4.23 VES curve of Karfi in wet season

Source: Data Analysis, 2013

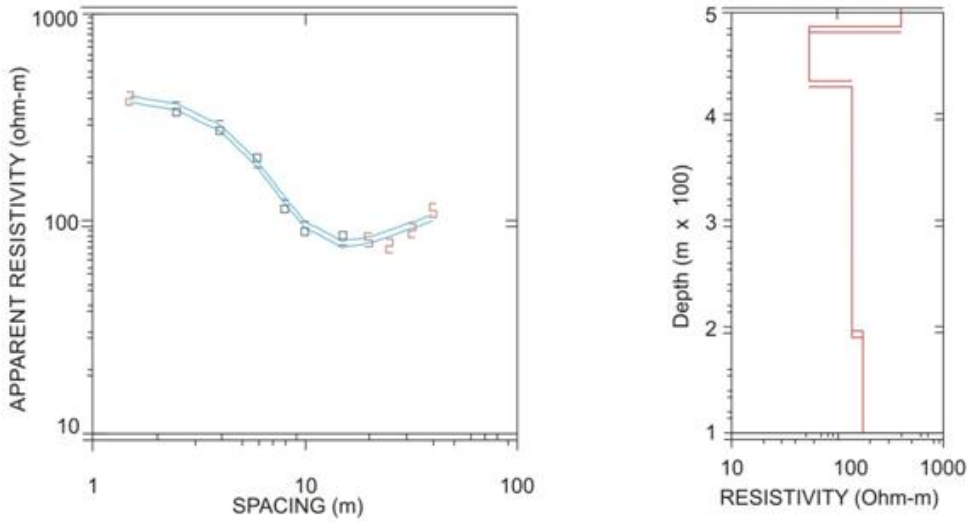


Figure 4.24 VES curve of Kosawa in wet season

Source: Data Analysis, 2011

The results for the VES survey of Kano north senatorial district conducted in dry season January/February, 2012 is presented in Table 4.15 and Figures 4.25, 4.26, 4.27, 4.28, 4.29 and 4.30. Sounding results shows that areas with high prospect are Shuwaki (Figure: 4.25) with apparent resistivity 36.63ohms-m and depth 35- 40m, Dokadawa

(Figure: 4.27) apparent resistivity 30.7 ohms-m and 35-40m depth, K/Yashi (Figure: 4.28) apparent resistivity 567 ohms-m and 25-30m depth and Alajawa (Figure: 4.30) with AR 323.4 ohms-m and depth of 35-40m. Areas with low prospects based on VES curves of dry season in Kano north are Yandadi (Figure: 4.26) and Shokogi (Figure:4.29) all with resistivity of 375.6 ohms-m, and 349.2 ohms-m with depth of 15-20m and 15-20m respectively.

Table 4.15 VES survey results of the rural villages in the Kano north senatorial zone for dry season

S/n	L.G.As	Rural villages	Location	Alt (m)	AR oms^{-m}	(m) depth	Avr depth (m)	Remark
		Shuwaki	N12.42049^{o}					
1	Kunchi		E008.17594^{o}	533	36.63	35-40	39.8	High
		Yandadi	N12.43751^{o}					
			E008.23260^{o}	499	375.6	15-20	14.34	Low
		Dokadawa	N11.97927^{o}					
2	Rimingado		E008.16412^{o}	539	30.7	35-40	48.39	High
		Karofinyashi	N11.88268^{o}					
			E008.35069^{o}	458	567.0	25-30	28.82	High
		Shakogi	N12.03162^{o}					
3	Shanono		E008.0121273^{o}	566	349.2	15-20	15.98	Low
		Alajawa	N12.07925^{o}					
			E007.9628^{o}	560	323.4	35-40	35.36	High

Source: Field work 2011

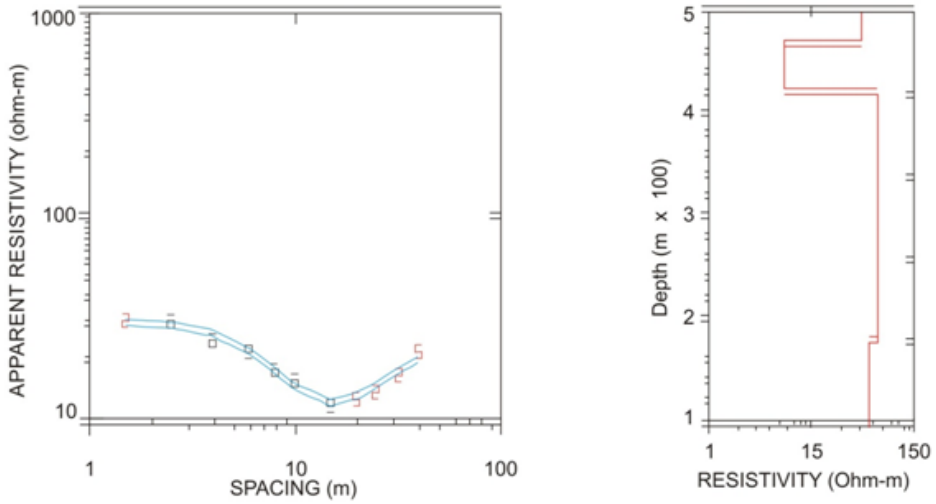


Figure 4.25 VES curve of Shuwaki in dry season

Source: Data Analysis, 2013

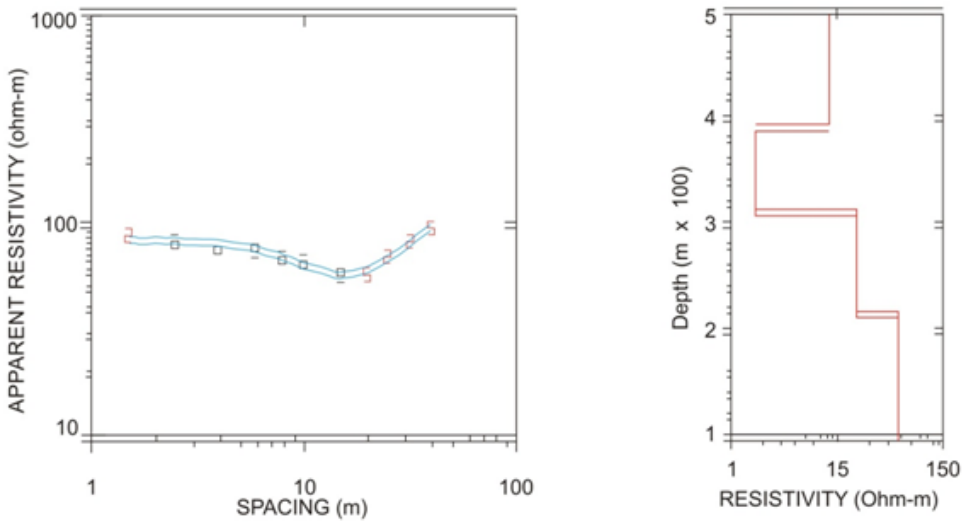


Figure 4.26 VES curve of Yandadi in dry season

Source: Data Analysis, 2013

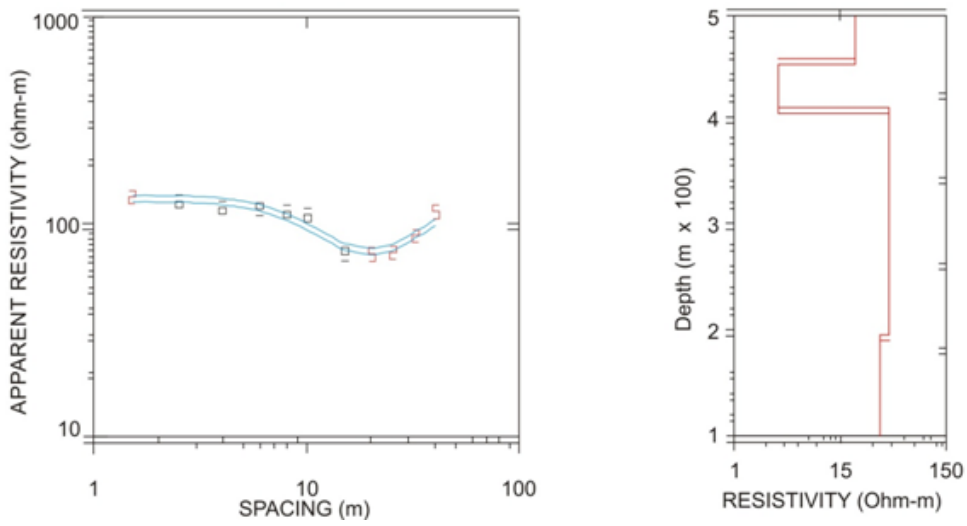


Figure 4.27 VES curve of D/Dawa of dry season

Source: Data Analysis, 2013

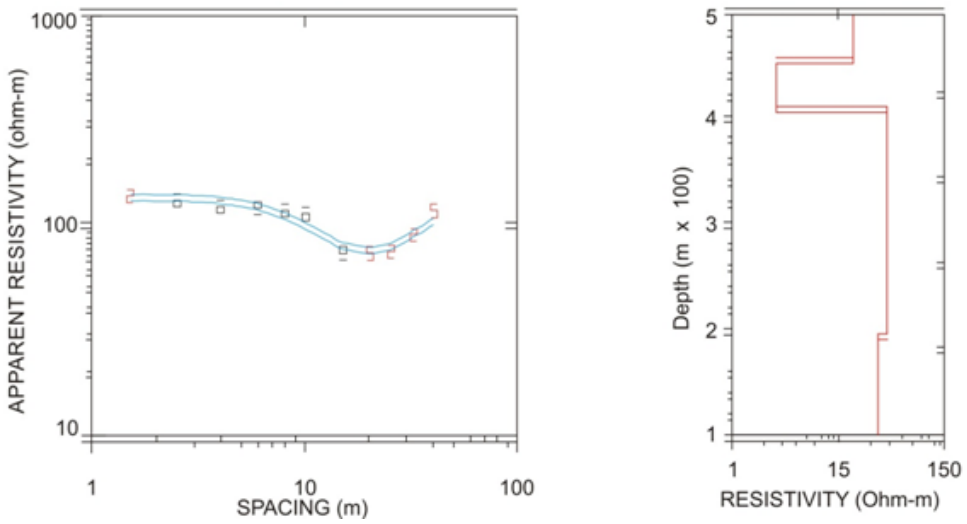


Figure 4.28 VES curve of K/Yashi for dry season

Source: Data Analysis, 2013

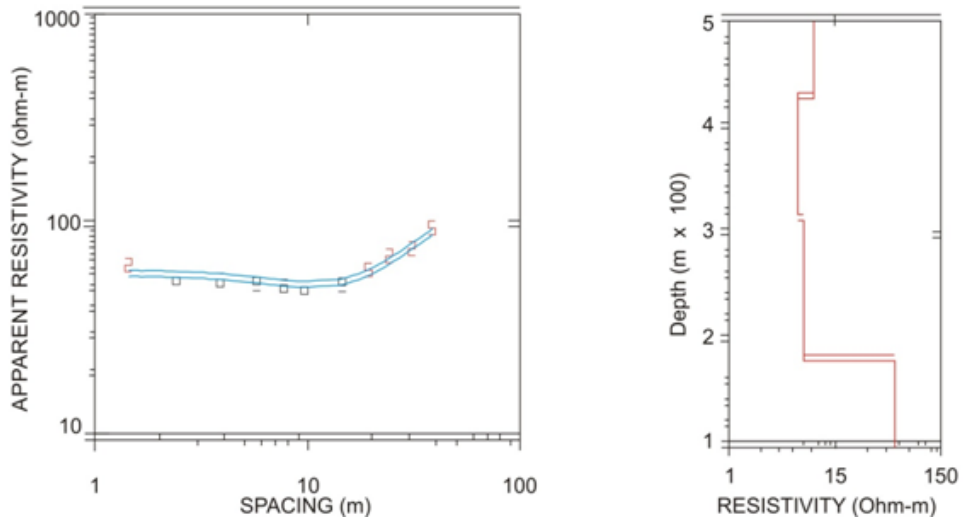


Figure 4.29 VES curve of S/Kogi in dry season

Source: Data Analysis, 2013

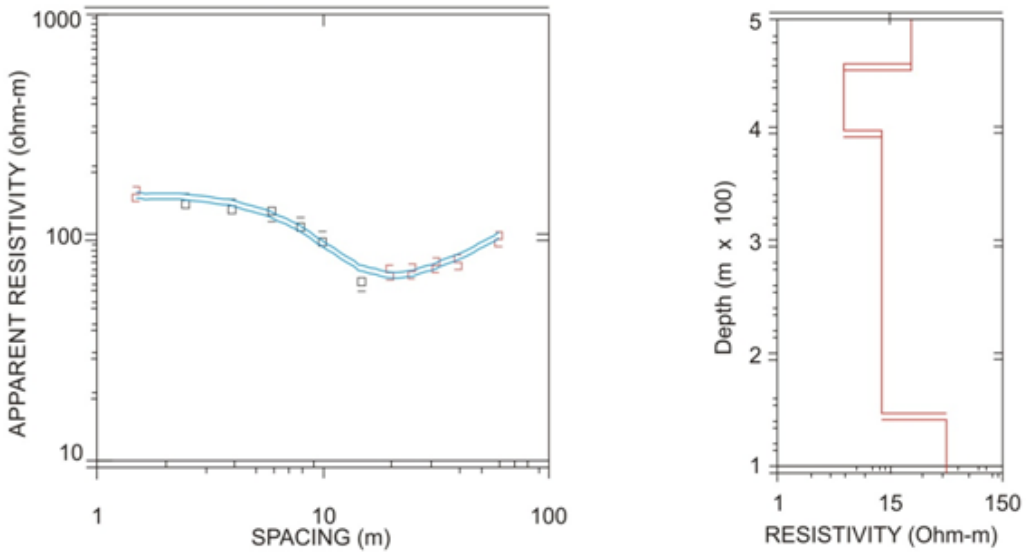


Figure 4.30 VES curve of Alajawa in dry season

Source: Data Analysis, 2013

In Kano south senatorial district dry season sounding results are presented as follows. Table 4.16 show the VES data of the six rural villages in the zone. The VES curves are presented in Figure: 4.31, 4.32, 4.33, 4.34, 4.35 and 4.36. Areas with good curves and described as areas of high groundwater

prospects are Zainabi (Figure: 4.32) with resistivity of 467.5 ohms- m and depth of 35-40m, Turawa (Figure: 4.34) with a resistivity of 85.95 ohms-m, depth 25-30m and Fammar (Figure: 4.35) with resistivity of 489.5 ohms-m and depth of 25-30m. The rest of the Villages are Riruwai (Figure: 4.31) resistivity is 361 ohms-m with a depth of 10-15m, Tudunkaya (Figure: 4.33) with resistivity of 329.7 ohms-m and a depth of 15-20m the last one Is Tarai (Figure: 4.36) resistivity in this area is very high 2536.4 ohms-m and a very low depth of 20-25m These areas are described as areas with poor curves and consequently of non Promising aquifers or areas with low groundwater prospects.

Table 4.16 VES survey results of the rural villages in the Kano South senatorial zone for dry season

s/n	L.G.As	Rural villages	Location	Alt (m)	AR oms^{-m}	(m) depth	Avr depth (m)	Remark
1	Riruwai	Riruwai	N10.72851^{o}					
			E008.75896^{o}	893	361.0	10-15	10.85	Low
		Zainabi	N10.78090^{o}					
			E008.7898^{o}	755	467.5	35-40	37.67	High
2	Karaye	TudunKaya	N11.73080^{o}					
			E007.92894^{o}	589	329.7	15-20	15.59	Low
		Turawa	N11.75320^{o}					
			E008.03216^{o}	546	85.95	25-30	21.91	High
3	Kibiya	Fammar	N11.55031^{o}					
			E008.71932^{o}	486	489.5	25-30	28.37	High
		Tarai	N11.49790^{o}					
			E008.66964^{o}	493	2536.4	20-25	20.44	Low

Source: Field work 2011

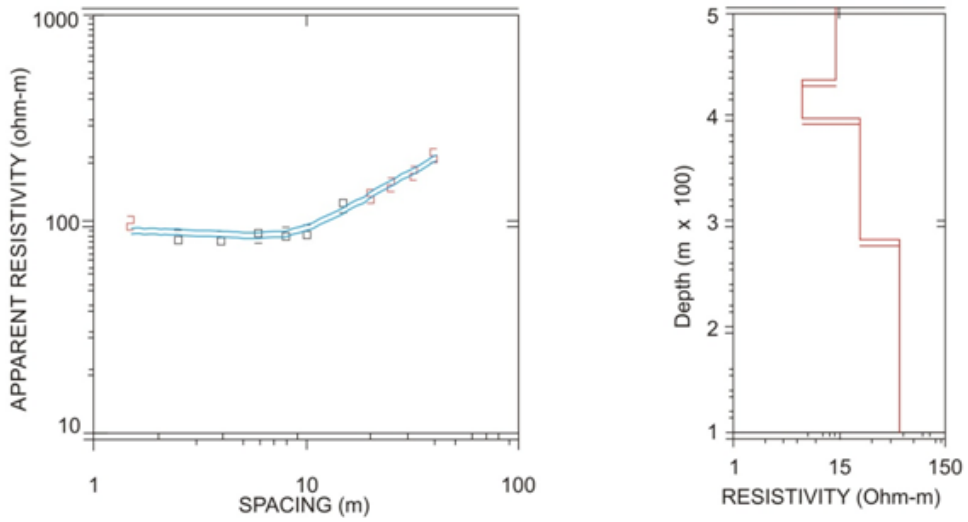


Figure 4.31 VES curve of Riruwai in dry season

Source: Data Analysis, 2013

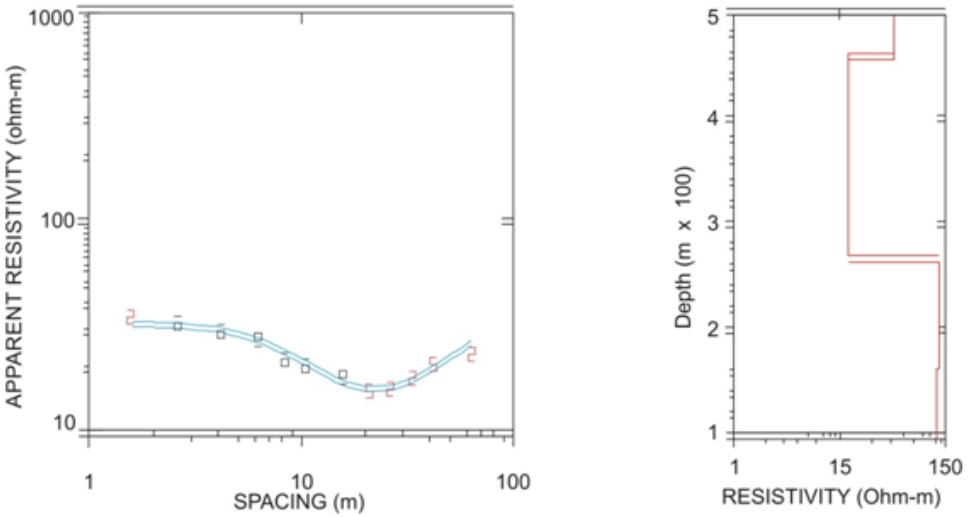


Figure 4.32 VES curve of Zainabi in dry season

Source: Data Analysis, 2013

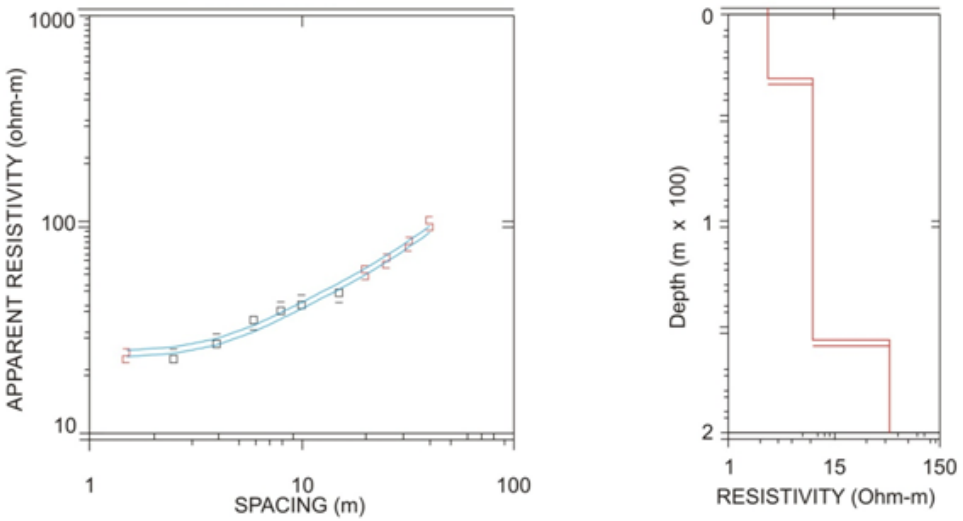


Figure 4.33 VES curve of T/Kaya in dry season

Source: Data Analysis, 2013

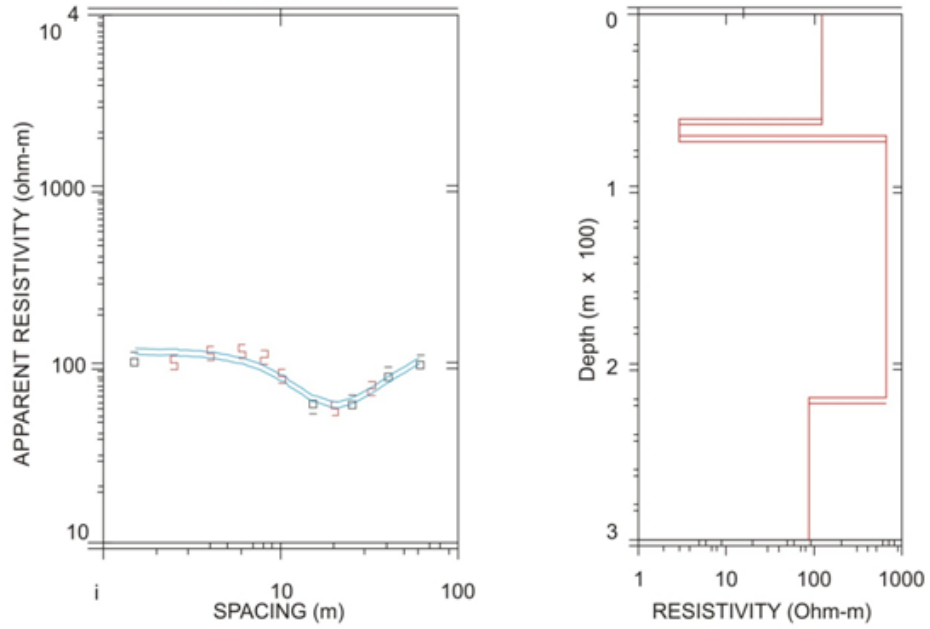


Figure 4.34 VES curve of Turawa in dry season

Source: Data Analysis, 2013

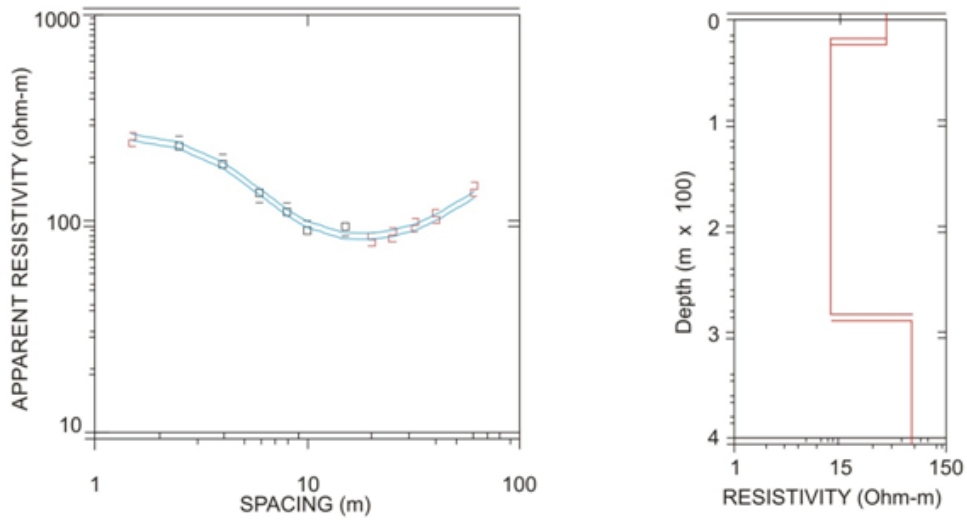


Figure 4.35 VES curve of Fammar in dry season

Source: Data Analysis, 2013

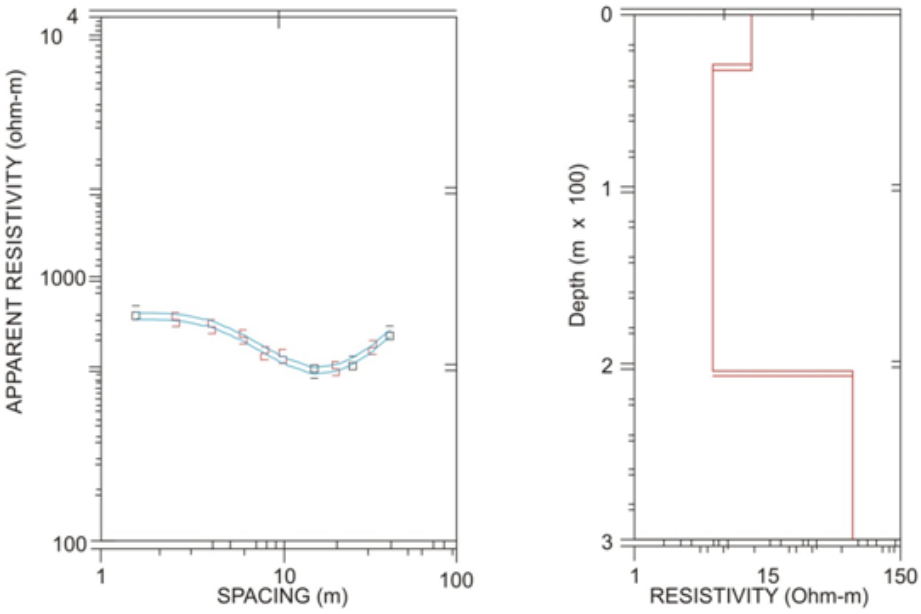


Figure 4.36 VES curve of Tarai in dry season

Source: Data Analysis, 2013

Table 4.17 and Figure 4.37, 4.38, 4.39 and 4.40 show the results of VES survey conducted in selected rural areas in Kano Central during dry season. Two of the areas produce promising curves with high prospects and the areas are Tumbau and Kosawa with low resistivity values of 116.1ohms and 211.1 ohms-m respectively and depth of 35-40m and 40-45m respectively.

Babawa is having higher resistivity and higher depth of 491.3 ohms-m and 60-65m respective which represent a poor curve likewise in Karfi the resistivity is much higher with a very low depth of 10-15m at such it is also described as an area with low prospect.

Table 4.17 VES survey results of the rural villages in the Kano Central senatorial zone for dry season

s/n	L.G.As	Rural villages	Location	Alt (m)	AR oms^{-m}	(m) depth	Avr depth (m)	Remark
1	Gezawa	Babawa	N12.06004^{o}					
			E008.65827^{o}	456	491.3	60-65	66.14	Low
		Tumbau	N11.99074^{o}					
			E008.81459^{o}	426	116.1	35-40	38.15	High
2	Kura	Karfi	N11.82310^{o}					
			E008.49462^{o}	440	5199809	10-15	6.99	Low
		Kosawa	N11.77221229^{o}					
			E008.45668^{o}	447	211.1	40-45	45.34	High

Source: Field work, 2011

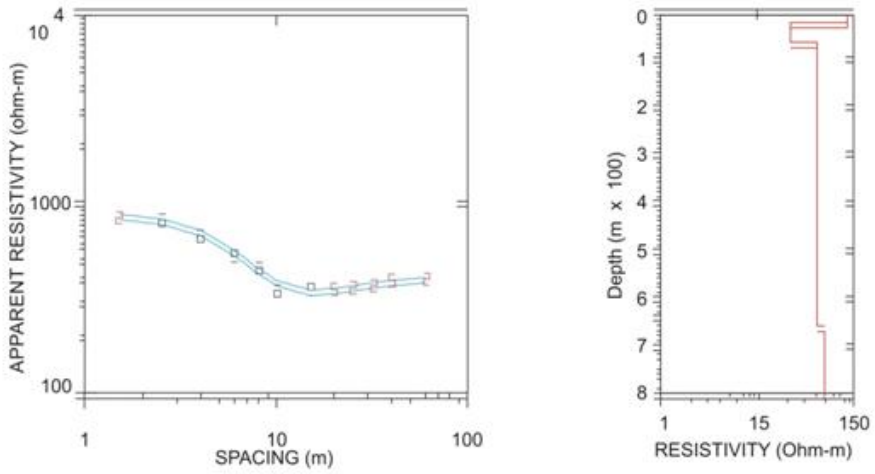


Figure 4.37 VES curve of Babawa in dry season
Source: Data Analysis, 2013

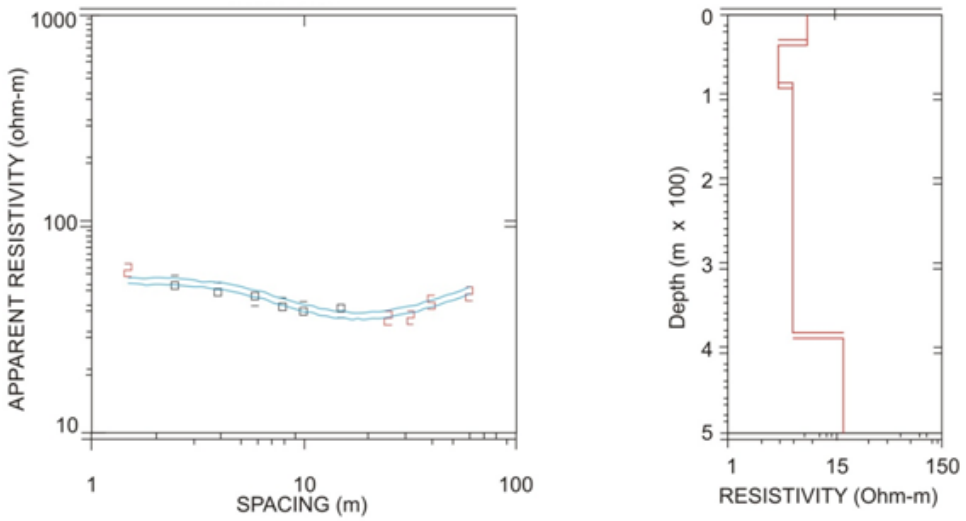


Figure 4.38 VES curve of Tumbau in dry season

Source: Data Analysis, 2013

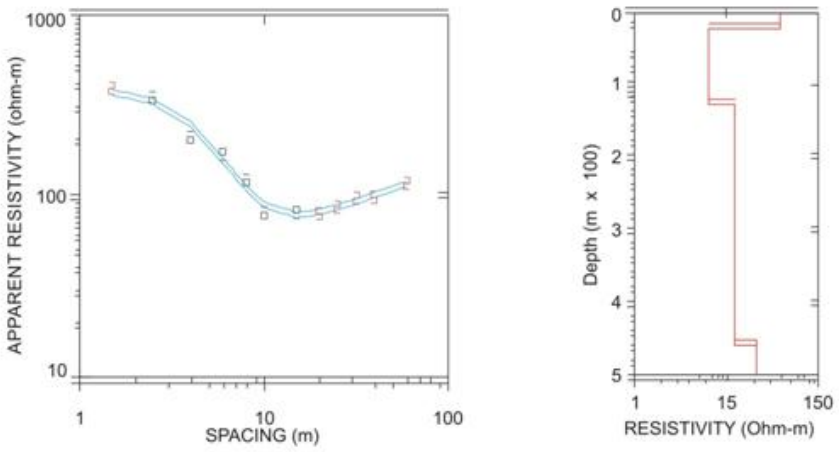


Figure 4.39 VES curve of Kosawa in dry season
Source: Data Analysis, 2013

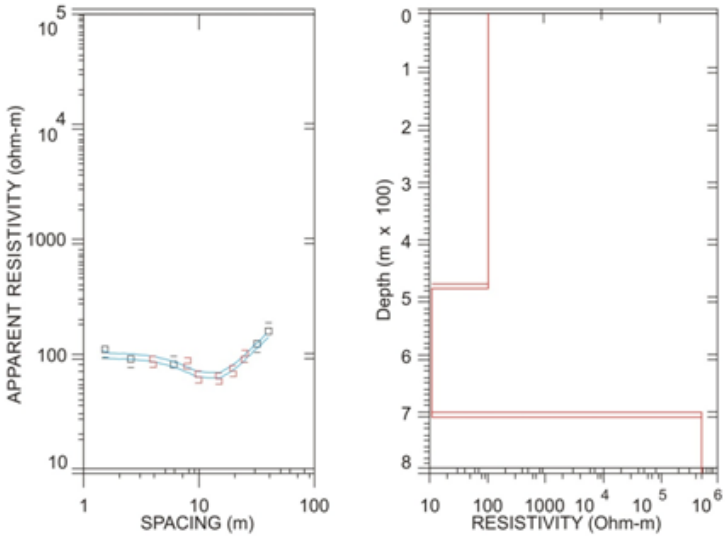


Figure 4.40 VES curve of Karfi in dry season

Source: Data Analysis, 2013

4.4.2 Occurrence of Groundwater in Rural areas of Kano State

Table 4.18 indicate results of water levels and water table in metres obtained from pumping test in the sixteen villages. The result indicated that areas with higher water table values such as Riruwai with 873m and 874m in both 2011 and 2012 are areas of low groundwater prospects. Areas such as Shuwaki with 519.8 and Tumbau 402.19 they are among high groundwater prospect areas. Table 4.19 A and B show ‘t’ test result were it indicated that calculated ‘t’ is greater than the table ‘t’ therefore null hypothesis is rejected at 0.05 level of significant and the alternative hypothesis is accepted. Based on this it is established that there is abundant occurrence of groundwater in Kano state that can be used to supply water to the rural dwellers.

Table 4.18 Water table condition in metres in 2011 and 2012

S/N	Villages	Water Level (M) 2011	Altitude (M)	Water Level (M) 2012	Water table (M) 2011	Water Table (M) 2012
1	Shuwaki	13.20	533	13.10	519.8	519.9
2	Yandadi	14.98	499	14.90	484.02	484.1
3	Dokadawa	12.13	539	13.12	526.87	525.88
4	Karofinyashi	16.12	458	15.12	441.88	442.88
5	Shakogi	13.81	566	13.71	552.19	552.29
6	Alajawa	13.22	560	13.30	546.78	546.7
7	Riruwai	18.31	893	19.31	874.69	873.69
8	Zainabi	17.81	755	17.80	737.19	737.2
9	TudunKaya	17.19	589	14.20	571.81	574.8
10	Turawa	13.30	546	12.80	532.7	533.2
11	Fammar	16.70	486	16.90	469.3	469.1
12	Tarai	14.98	493	13.20	478.02	479.8
13	Babawa	12.20	456	13.81	443.8	442.19
14	Tumbau	17.81	420	16.70	402.19	407.3
15	Karfi	13.30	440	13.29	426.7	426.71
16	Kosawa	12.48	447	12.40	434.52	434.6

Source: Data Analysis, 2013

Table 4.19 A Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	Water table 2011 and 2012	-1.203	15	.248

Source: Data Analysis, 2013

Table 4.19 B Paired Samples Test

		Mean	Bootstrap[a]				
			Bias	Std. Error	Sig. (2-tailed)	95% Confidence Interval	
						Lower	Upper
Pair 1	Water table 2011 and 2012	-.49250	-.00109	.38847	.258	-1.33904	.19687

Source: Data Analysis, 2013

4.4.3 Identification of groundwater potential zones using weighted overlay

The result in Figure 4.41 indicates that the study area is classified into Very High, High, Moderate, Low and Very Low in terms of groundwater potentials. Table 4.20 indicates result for the weighted overlay of the six factors of groundwater occurrence in the study area as follows with consistency ratio of 0.04. Lineament density among all factors is having the highest weight of 0.46 or 46% this indicate that it is the most important factor in the study area in terms of groundwater occurrence followed by drainage density with 0.024 or 24%, geology 0.11 or 11%, soil 0.05 or 5% and lastly vegetation recorded the lowest value of weight which indicated that among the six factors vegetation is the one with lesser importance in terms of groundwater potential assessment in the study area.

Table 4.20 weighting of the all factors

	Lineament	D/D	Geol	Hydrogeology	Lithology	Vegetation	Weight	%
Lineament	**1**	3	5	5	7	**9**	0.46	46
D/ Density	1/3	**1**	3	3	5	7	0.24	24
Geology	1/5	1/3	**1**	1	3	5	**0.11**	11
Hydrogeol.	1/5	1/3	1	**1**	3	1	0.11	11
Lihology	1/7	1/5	1/3	1/3	**1**	1/7	0.05	5
Vegetation	**1/9**	1/7	1/5	1/5	1	**1**	0.03	3

Consistency ratio-0.04

Source: Data Analysis, 2013

Table: 4.21 and Figure: 4.41 and 4.42 shows the condition of the selected rural villages in terms of groundwater prospects as follows: Three villages fall within the Very High zone and are Yandadi, Shuwaki from Kano north and Karfi from Kano central. Babawa and Kosawa from Kano central and Tarai from Kano south are classified as High. Areas classified as Moderate are Shuwaki, Alajawa, Dokadawa and K/yashi from Kano north and Turawa from Kano south. Rural areas that fall within a zone classified as Low are Fammar, Zainabi and Tudunkaya from Kano south and Tumbau from Kano central. Riruwai located at the extreme southern part of the study area is classified as zone of Very Low groundwater potential.

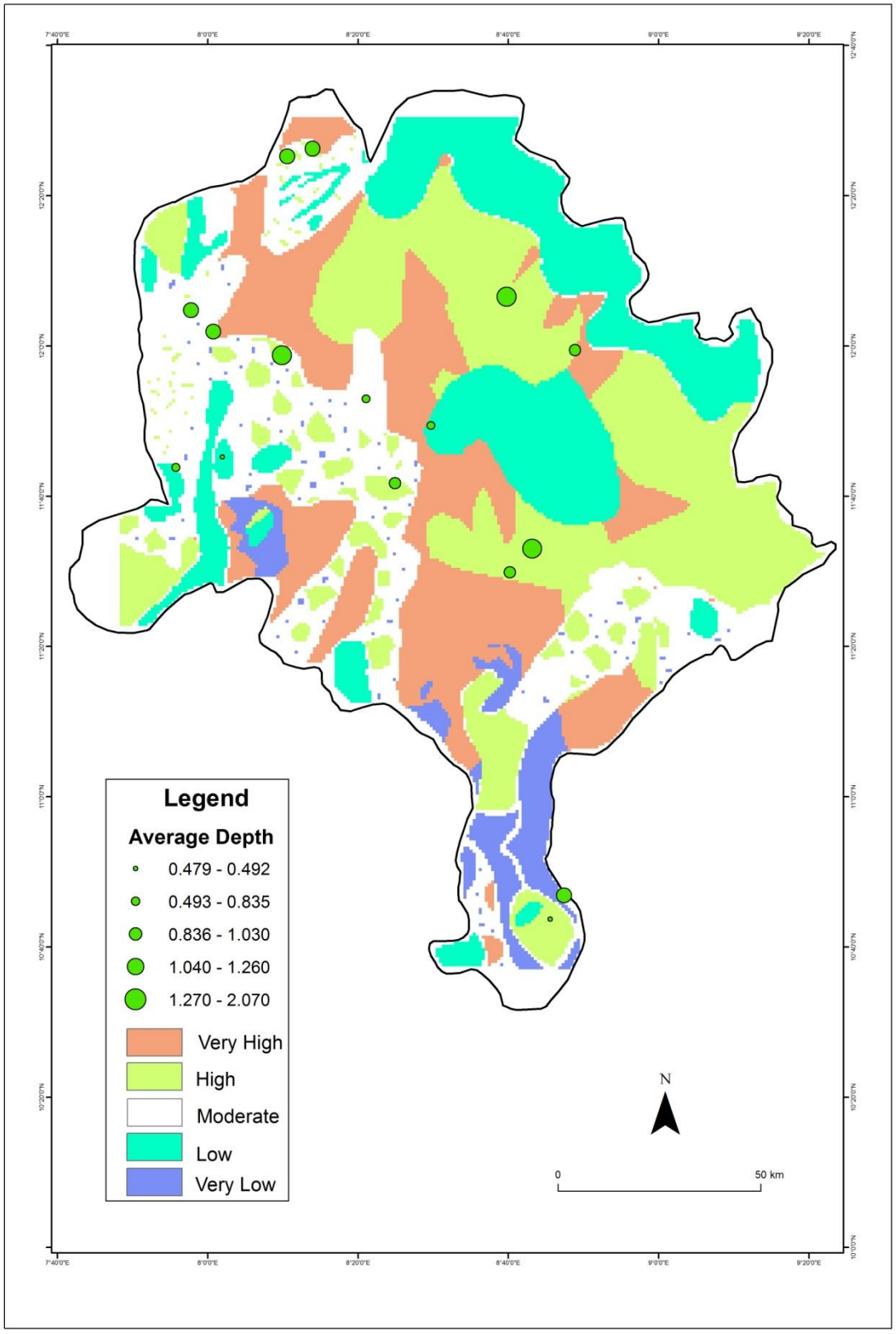


Figure 4.41 Groundwater potential zones map

Source: Data analysis, 2013

Table 4.21 Groundwater potential of the sixteen rural villages

S/N	Name of Rural Villages	Latitudes	Longitudes	Groundwater potential
1	Shuwaki	N12.42049^{o}	E008.17594^{o}	Moderate
2	Yandadi	N12.43751^{o}	E008.23260^{o}	Very High
3	Dokadawa	N11.97927^{o}	E008.16412^{o}	Moderate
4	Karofinyashi	N11.88268^{o}	E008.35069^{o}	Moderate
5	Shakogi	N12.03162^{o}	E008.0121273^{o}	Very High
6	Alajawa	N12.07925^{o}	E007.9628^{o}	Moderate
7	Riruwai	N10.72851^{o}	E008.75896^{o}	Very Low
8	Zainabi	N10.78090^{o}	E008.7898^{o}	Low
9	TudunKaya	N11.73080^{o}	E007.92894^{o}	Low
10	Turawa	N11.75320^{o}	E008.03216^{o}	Moderate
11	Fammar	N11.55031^{o}	E008.71932^{o}	Low
12	Tarai	N11.49790^{o}	E008.66964^{o}	High
13	Babawa	N12.06004^{o}	E008.65827^{o}	High
14	Tumbau	N11.99074^{o}	E008.81459^{o}	Low
15	Karfi	N11.82310^{o}	E008.49462^{o}	Very High
16	Kosawa	N11.77221229^{o}	E008.45668^{o}	High

Source: Data Analysis, 2013

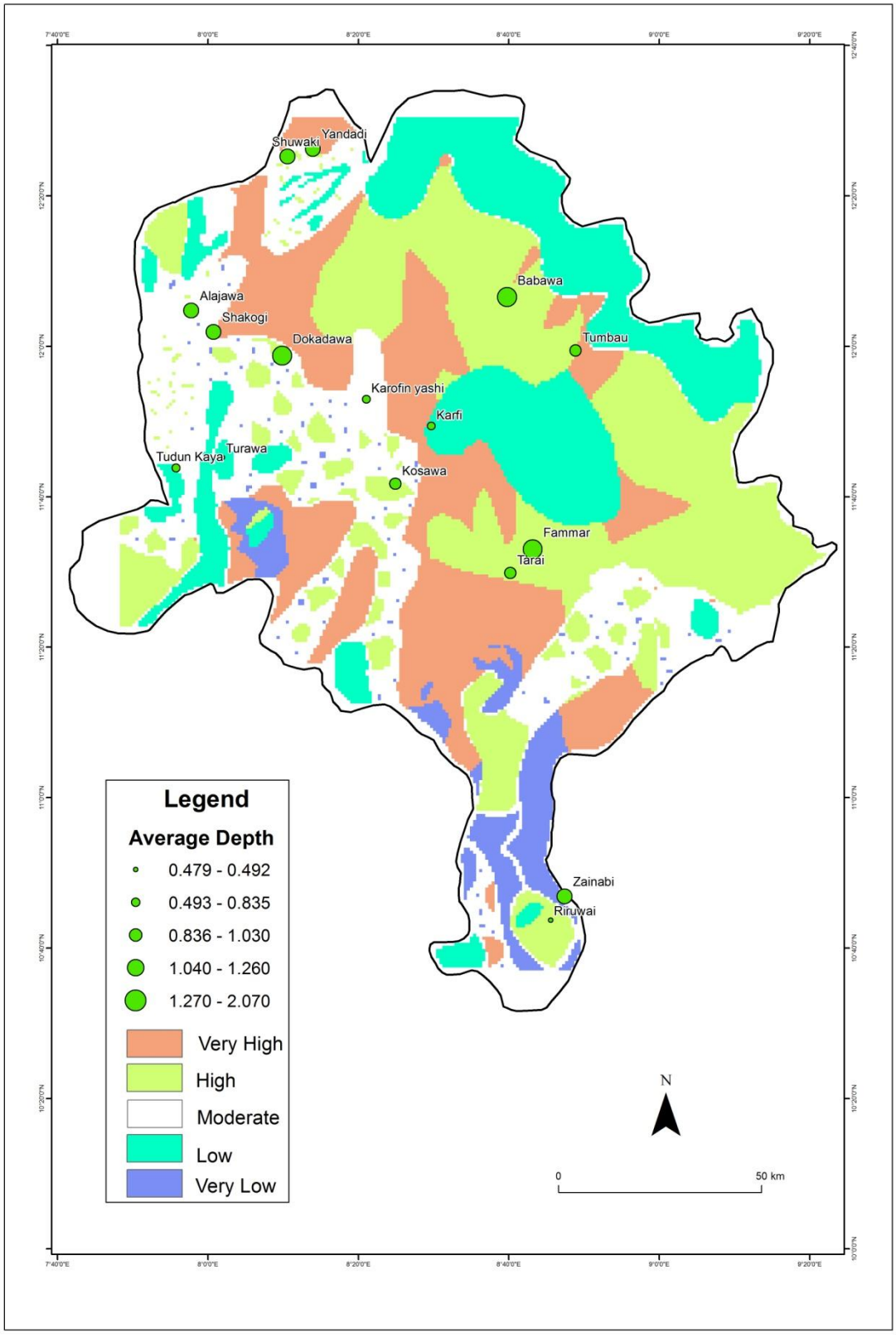


Figure 4.42 Groundwater potentials map with the villages

Source: Data Analysis, 2013

4.4.4 Relationship between groundwater potential and the factors

Groundwater prospective zones were analysed on the basis of Lineament density, Drainage density, Geology, Hydrogeology, Soil/Lithology and Vegetation. The parameters in each factor were given weight and are related to groundwater potential as adopted from Goyal *et al.,* (2009) Tesfaye (2010) and Oluwatola *et al.,* (2013).

4.4.4.1 Lineament density

The results of lineament density are presented in Table 4.22 and Figure 4.43 and 4.44. It can be seen from the result that the higher the lineament density in an area the more the groundwater potential. Areas with highest lineament density of between 22.5- 28.11 Km/Km^2 are having weight of 0.48 and 48% weight while areas with lowest lineament density of between 0- 5.5 Km/Km^2 are having weight of 0.05 and 5% weight. It is deduced that lineament orientations in the study area are N-S, NNE-SSW, NE-SW and NW-SE. The dominant ones are NW-SE, NE-SW and N-S. The lineament density map shows that the lineament density is high around Yandadi, Babawa, Kosawa, Karofinyashi, Turawa, and Dokadawa. It can also be seen that most of these areas are areas with Very High to moderate groundwater potential. This is because lineament is an expression of fractures, joints, faults and or other lines of weaknesses usually found on basement crystalline rocks and other hard rock like in this study area. Areas with lower lineament densities coincides with areas of Low to Very groundwater potentials, these areas include Zainabi, Tumbau, Riruwai, Fammar and Tudunkaya

Table 4.22 Lineament densities in Km/Km^2

	22.5-28.11	**16.8-22.5**	**11.2-16.8**	**5.6-11.2**	**0-5.6**	**Weight**	**Percentage**
22.5-28.11	1	3	3	7	7	0.48	48
16.8-22.5	1/3	1	1	5	5	0.22	22
11.2-16.8	1/3	1	1	3	5	0.20	20
5.6-11.2	1/7	1/5	1/3	1	1	0.06	6
0-5.6	1/7	1/5	1/5	1	1	0.05	5

Consistency ratio: 0.02

Source: Data Analysis, 2013



Figure 4.43 Lineament line map of the study area

Source: Data Analysis, 2013

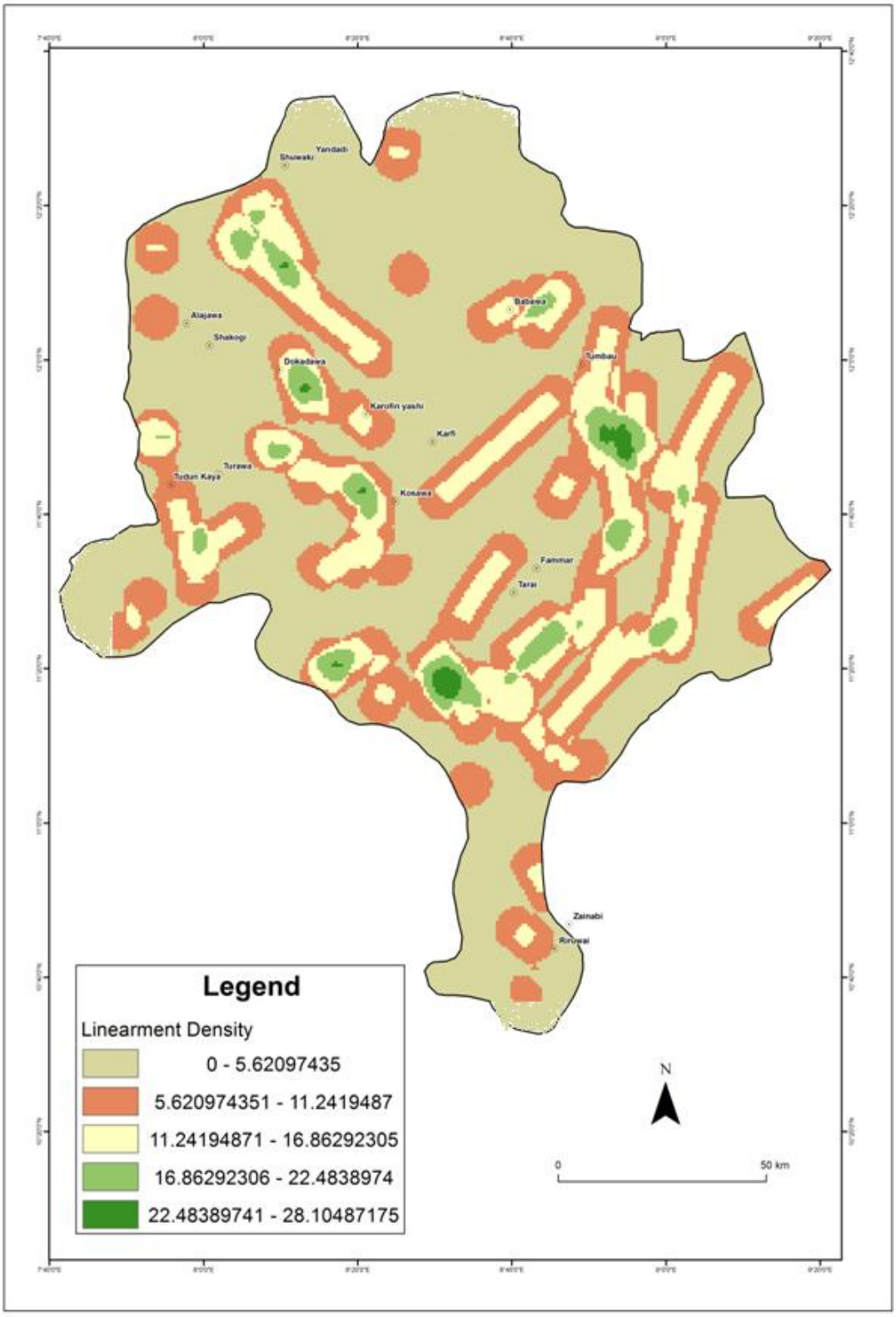


Figure 4.44 Reclassified Lineament Density Map of the study area

Source: Data Analysis, 2013.

4.4.4.2 Drainage Density

The results of drainage density weighting in Table: 4.23 and Figure 4.45 shows that areas with higher drainage densities are those areas with high groundwater potentials; this can be proved from the weighting where high drainage density is having a higher weight. A drainage density of 97-121.5Km/Km^2 is having the highest weight of 0.37 or 37% weight while the lowest value of drainage density recorded the lower value of weight in weighted overlay analysis of 0-24.3Km/Km^2. In the results areas with high drainage densities and at the same time with High groundwater prospects are Turawa, K/Yashi, Babawa, Yandadi, Kosawa and Tarai while areas with lower drainage densities and low Groundwater potentials are Tumbau, Shuwaki, Riruwai Zainabi, Tudunkaya, Shakogi, Dokadawa and Tarai. It is also observed from the result that the drainage pattern in the study area is most likely structurally controlled.

Table 4.23 Drainage Density Weighting

	97.2-121.5	**72.9-97.2**	**48.6-72.9**	**24.3-48.6**	**0-24.3**	**Weight**	**Percentage**
97.2-121.5	**1**	1	3	3	5	0.37	37
72.9-97.2	1	**1**	1	3	3	0.27	27
48.6-72.9	1/3	1	**1**	1	3	0.17	17
24.3-48.6	1/3	1/3	1	**1**	1	0.11	11
0-24.3	1/5	1/3	1/3	1	**1**	0.08	8

CR: 0.05

Source: Data Analysis, 2013

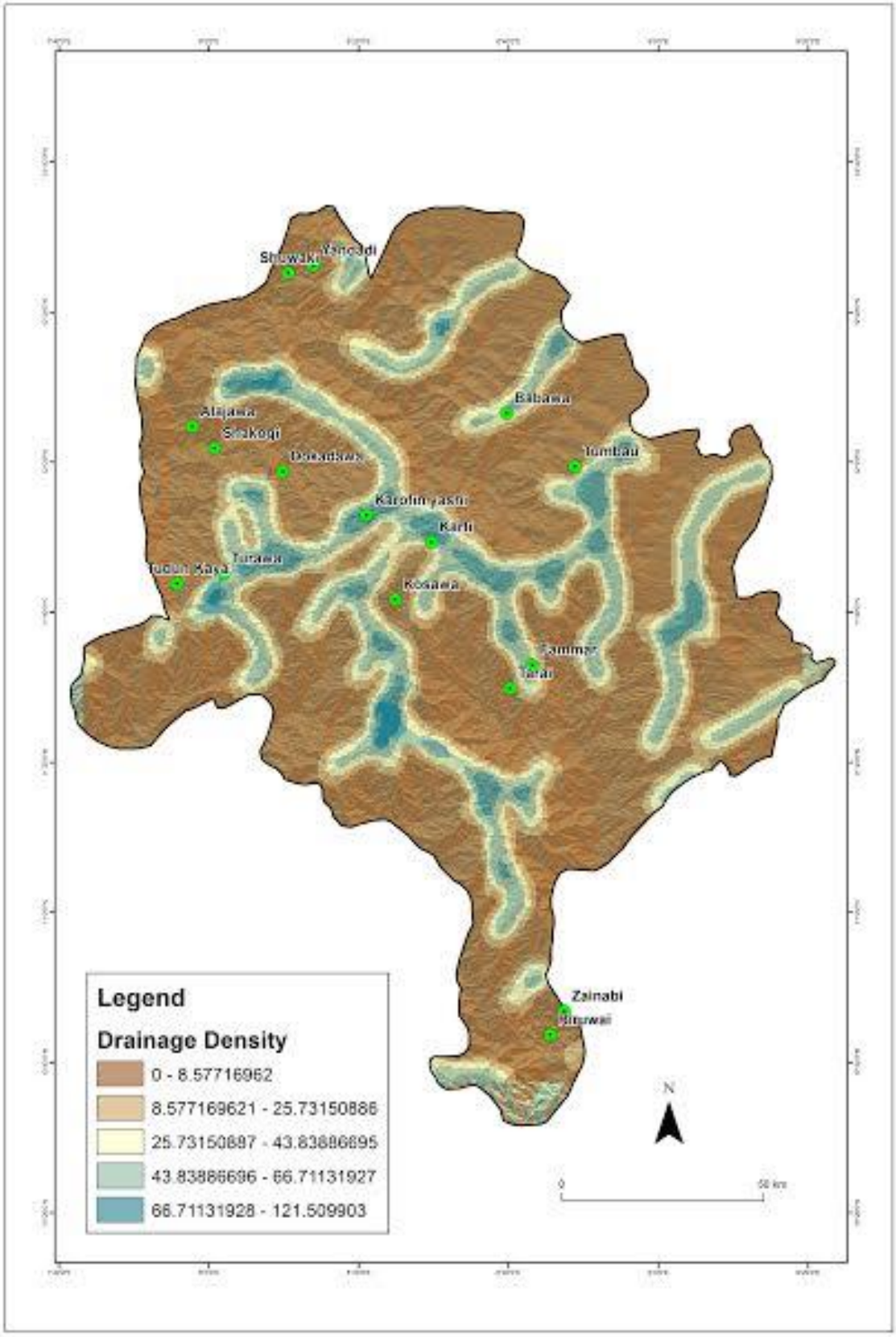


Figure 4.45 Reclassified drainage density map of the study area

Source: Data Analysis, 2013

4.4.4.3 Geology weighting

The result for weighting of Geology is presented in Table 4.24 and Figure 4.46. It shows that among the Geologic formations in the study area homblende granite, migmatite, medium biotite and biotite gneiss are having more weight in relation to groundwater potential. The weights are 0.25 or 25%, 0.17 or 17%, 0.16 or 16% respectively. Areas with High to moderate groundwater potential are Karfi, K/Yashi and Kosawa while areas with Low groundwater potential are Riruwai, Zainabi and Fammar with low weight of 0.02 or 2%. Those areas are underlain by quartz porphyry and quartzite massive schist which were believed to have originated from younger granites of Jurassic period.

Table 4.24 Geological map Weighting

	H	**M**	**IG**	**MG**	**BG**	**GG**	**FGB**	**MB**	**Q**	**QM**	**Weight**	**Percentage**
H	**1**	1	5	5	7	7	9	9	1	1	0.25	25
M	1	**1**	1	3	3	5	7	9	1	1	0.17	17
IG	1/5	1	**1**	3	5	7	9	9	1	1	0.16	16
MB	1/5	1/3	1/3	**1**	1	3	5	7	1	1	0.08	8
BG	1/7	1/3	1/5	1	**1**	3	5	7	1	1	0.08	8
GG	1/7	1/5	1/7	1/3	1/3	**1**	3	5	1	1	0.08	8
FGB	1/9	1/7	1/9	1/5	1/5	1/3	**1**	3	1	1	0.08	8
MB	1/9	1/9	1/9	1/7	1/7	1/5	1/3	**1**	1	1	0.05	5
Q	1	1	1	1	1	1	1	1	**1**	1	0.03	3
QM	1	1	1	1	1	1	1	1	1	**1**	0.02	2

Consistency ratio= 0.08

Source: Data Analysis, 2013

KEY

H- Homblend Granite

M- Migmatite

IG- Ignimbrite

MG- Medium biotite gneiss

BG- Biotite Granite

GG- Granite Gneiss

FGB- Fined Grained biotite Granite

MB- Medium Biotite Granite

Q- Quartz Porphyry

QM- Quartzite massive chist and quartz chist

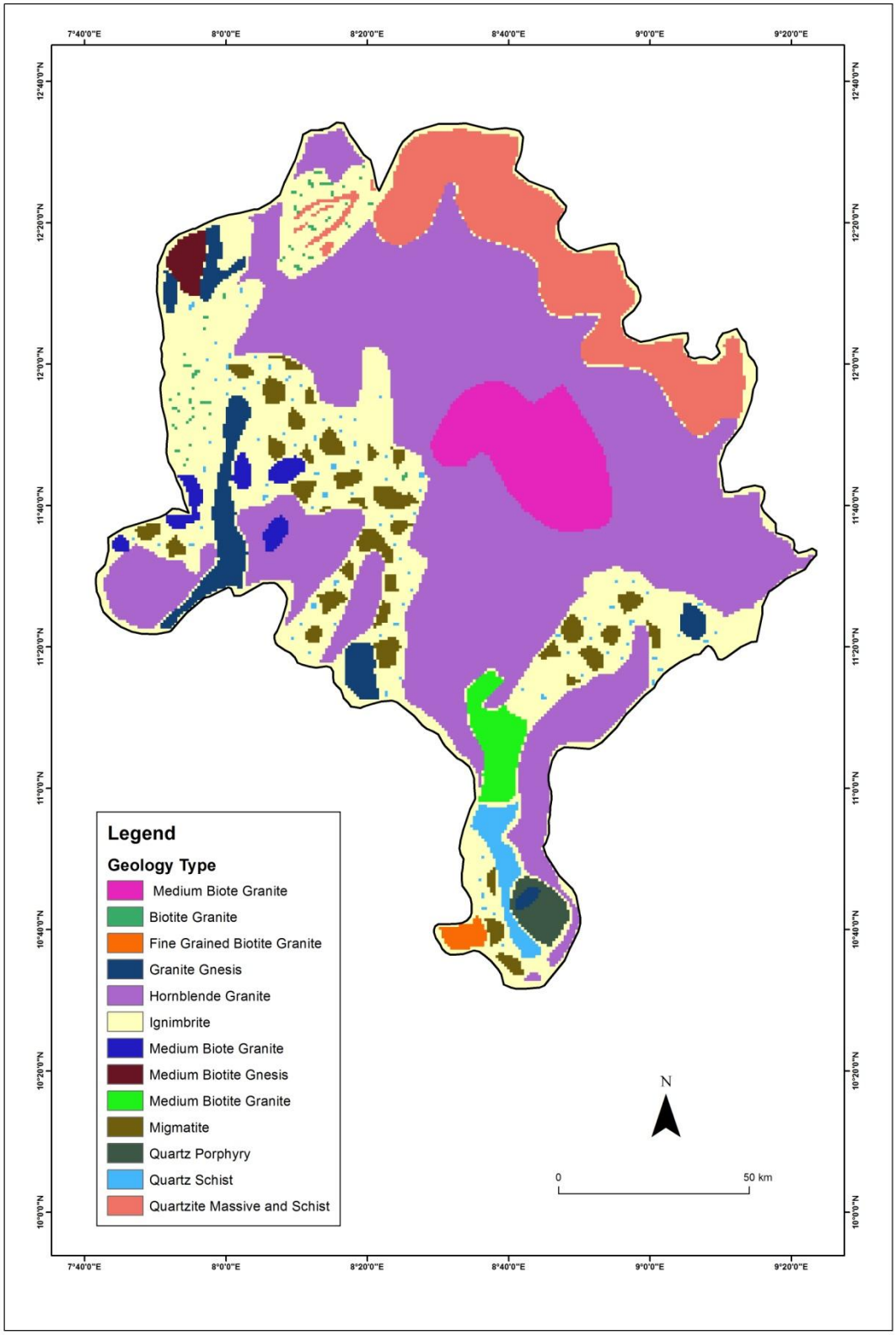


Figure 4.46 Reclassified Geological map of the study area

Source: Data Analysis, 2013

4.4.4.4 Hydrogeology and groundwater potential

It can be seen from Table 4.25 and Figure 4.47 that areas characterized with pink white granite, metamorphic coarse, coarse pink black granite and quaternary formations are classified as areas associated with Very High to High groundwater potential. These areas have higher weight of 0.32 or 32%, 0.18 or 18%, 0.16 or 16%, 0.11 or 11% respectively and low values of water table that ranges from 402m to 666m. Such areas comprises of Karofinyashi, Yandadi, Babawa and Karfi. Areas associated with younger granite with weight of 0.02 or 2%, black and white granite with weight 0.03 or 3%, metamorphic suits with weight 0.05 or 5% and Dior granite 0.05 or 5% are areas with higher water table values from 717m to 875m and are areas with low groundwater potentials. Such areas include Riruwai Zainabi and their adjoining areas.

Table 4.25 Hyrogeological map Weighting

	PWG	MC	CPBG	QF	QZ	DG	MS	BWG	YG	Weight	Percentage
PWG	1	3	5	5	7	7	9	9	1	0.32	32
MC	1/3	1	1	3	5	7	7	7	1	0.18	18
CPBG	1/5	1	1	3	5	5	5	7	1	0.16	16
QF	1/5	1/3	1/3	1	3	5	7	9	1	0.11	11
QZ	1/7	1/5	1/5	1/3	1	1	3	5	1	0.08	8
DG	1/7	1/7	1/5	1/5	1	1	3	5	1	0.05	5
MS	1/9	1/7	1/5	1/7	1/3	1/3	1	3	1	0.05	5
BWG	1/9	1/7	1/7	1/9	1/5	1/5	1/3	1	1	0.03	3
YG	1	1	1	1	1	1	1	1	1	0.02	2

Consistency ratio= 0.07

Source: Data Analysis, 2013

Key

PWB- Pink white granite

MC- Metamorphic course

CPBG- Coarse pink black granite

QF- Quaternary formation

QZ- Quazite

DG- Dior granite

MS- Metamorphic suit

BWG- Black and white granite

YG- Younger granites

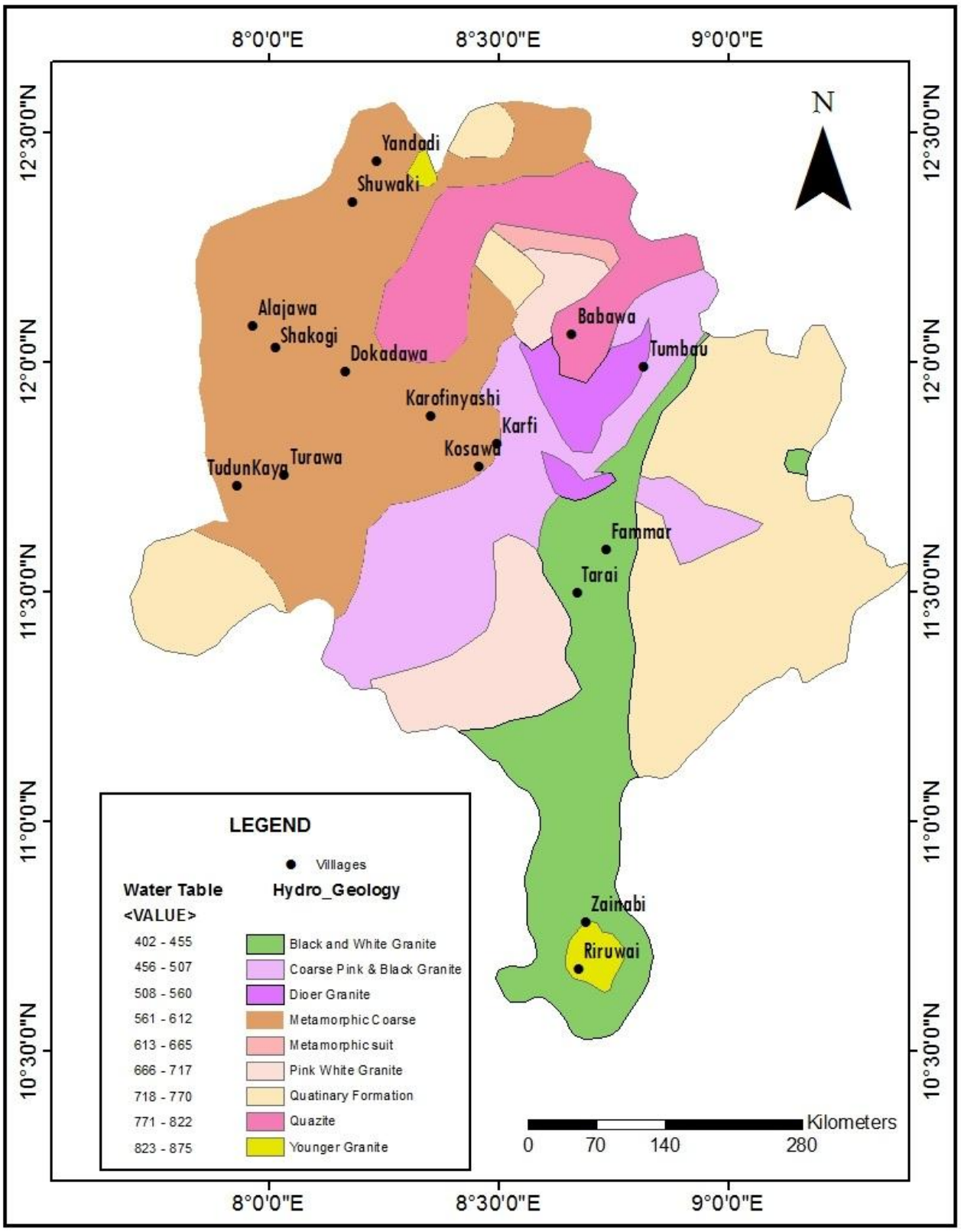


Figure 4.47 Reclassified Hyrogeological Map of the study area

Source: Data Analysis, 2013

4.4.4.5 Soil and groundwater potential

The result for soil weighting in relation to groundwater potential in the study area is presented in Table 4.26 and Figure 4.48. The result shows that soil is one of the important factors in groundwater identification. Areas with hydromorphic soils and ferruginous tropical soils are more important in terms of groundwater potential because they have higher weights of 0.41 or 41% and 0.38 or 38%, such areas include Shakogi, Alajawa, Yandadi, Karfi, Babawa, K/ yashi and Turawa. Areas dominated with lithosols are areas with moderate groundwater potential with a weight of 0.15 or 15% while areas associated with brown and reddish brown, these areas include Riruwai, Zainabi, Tudunkaya and Fammar soils are classified as areas of low groundwater potential with a weight of 0.06 or 6%.

Table 4.26 Soil map weighting

	Hydromorphic soil	**Ferruginous tropical soil**	**Lithosols reddish brown**	**Brown and reddish brown**	**Weigh**	**Percentage**
Hydromorphic soil	1	1	3	7	0.41	41
Ferruginous tropical soil	1	1	3	5	0.38	38
Lithosols reddish brown	1/3	1/3	1	3	0.15	15
Brown and reddish brown	1/7	1/5	1/3	1	0.06	6

Consistency ratio= 0.01

Source: Data Analysis, 2013

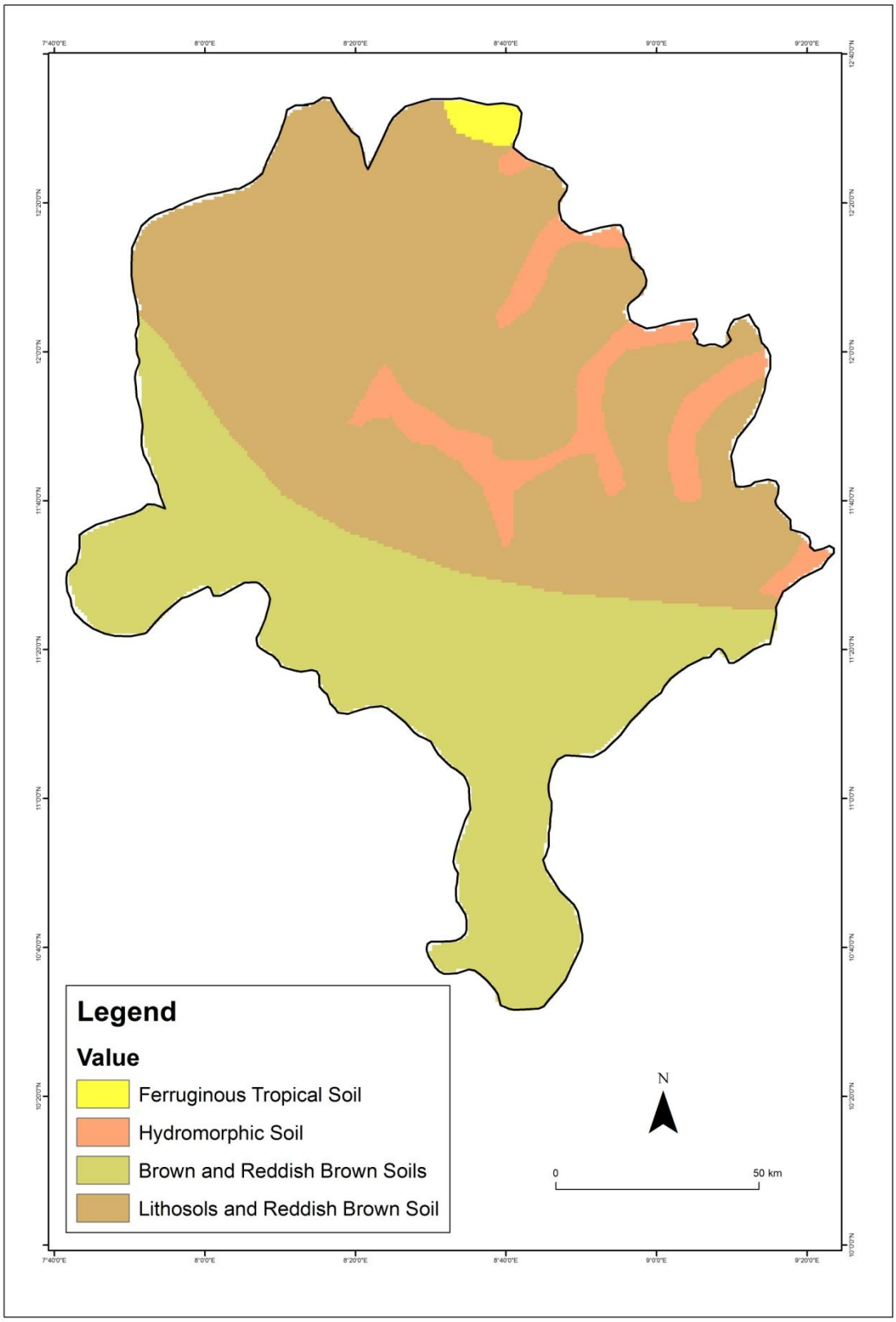


Figure 4.48 Reclassified Soil Map of the study area

Source: Data Analysis, 2013

4.4.4.6 Vegetation and groundwater potential

The result of vegetation weighting in relation to groundwater potential is presented in Table 4.27 and Figure 4.49. The result shows that among the major types of vegetation in the study area areas under Sudan savanna >60% is having more influence on groundwater potential and are within Very High to High groundwater potential zones with a weight of 0.56 or 56% followed by Sudan savanna 30- 60% with a weight of 0.26 or 26%. These areas include Karfi, K/Yashi, Babawa, Yandadi and Turawa. Shrub savanna and savanna wood land recorded low weight and low groundwater potential with weight of 0.13 or 13% and 0.05 or 5% respectively. These areas include Riruwai, Zainabi and some patches at extreme northern and southern parts of the study area.

Table 4.27 Vegetation weighting

	SS >60% I	**SS 30-60%**	**Shrubs SV**	**S/ wl**	**Weight**	**Percentage**
SS >60%	**1**	3	5	7	0.56	56
SS 30-60%	1/3	**1**	3	5	0.26	26
Shrubs SV	1/5	1/3	**1**	5	0.13	13
SV WL	1/7	1/5	1/5	**1**	0.05	5

CR: 0.02

Source: Data Analysis, 2013

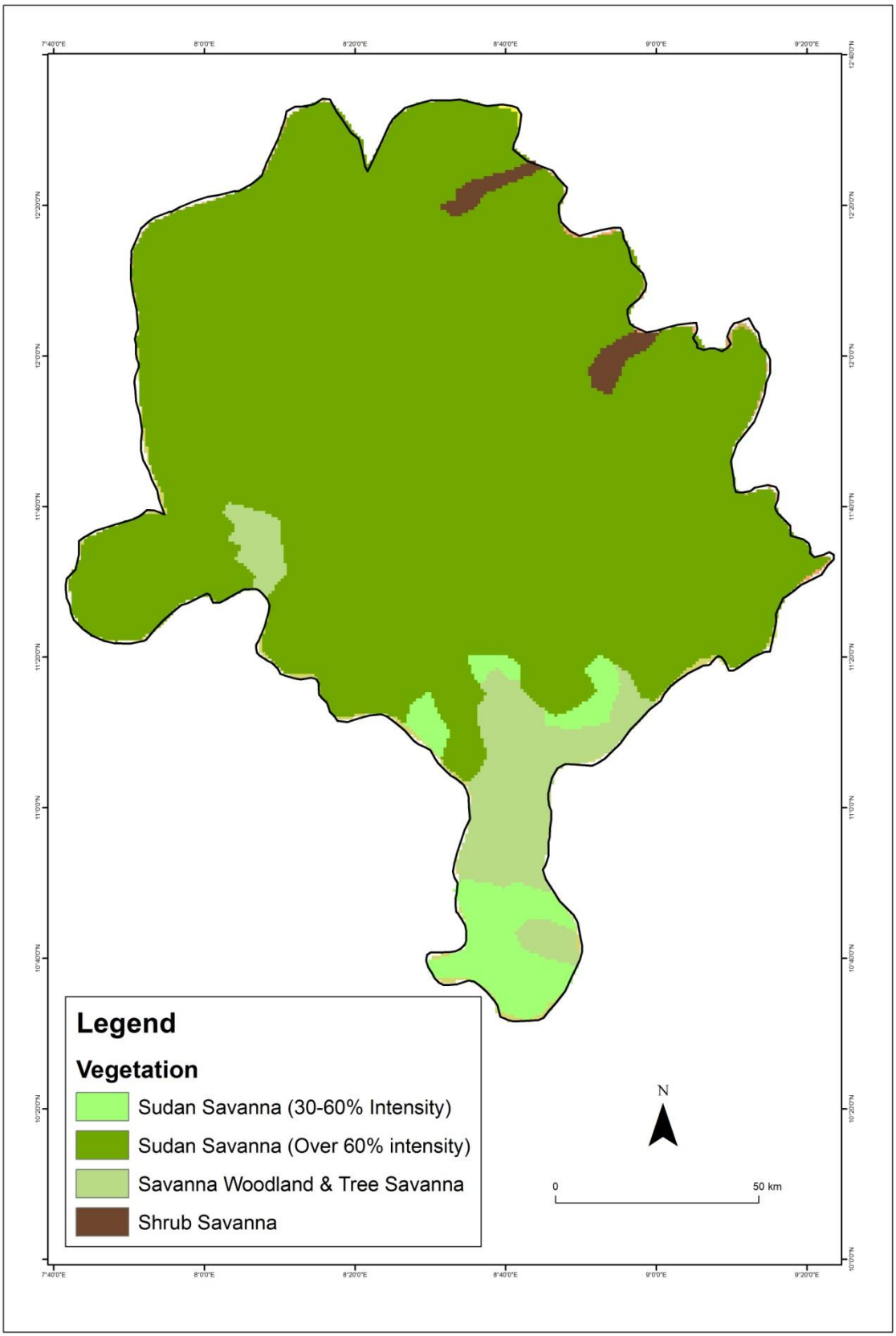


Figure 4.49 Reclassified Vegetation Map of the study area

Source: Data Analysis, 2013

4.5 CHARACTERISATION OF GROUNDWATER POTENTIAL ZONES

4.5.1 Aerial Extent of the GWPZS

Table 4.28 presented the result of the areal coverage of each of the groundwater potential zone in the final groundwater potential Zones map of Kano state. The result indicates that the whole state is categorised into five zones of groundwater potential zones as follows Very High 5,676 km^2 with 27.3%, High 7,400km^2 with 35.7%, Moderate 1,284km^2 with 6.2%, Low 5,375km^2 with 25.9% and Very Low with 1,025km^2 with 4.9%. These show that High Potential zone is having the largest areal coverage and Low potential zone is the least in terms of aerial coverage.

It is observed that High potential occupied areas in the north central, east central and pockets in south western part of the state. Very High groundwater potential dominates in the north central, central and south central parts of the study area. Moderate groundwater potential zone spread as pockets in north central, North West, south east and extreme southern end. Low groundwater potential zone concentrate in north-north east, central areas and pockets in south east, south central and south. Lastly Very Low groundwater potential zone occur as pockets in the south west, southern parts of the state such areas include parts of Tudunwada, Doguwa, Fammar, Burumburum and Falgore.

Table 4.28 Percentage Areal Coverage of groundwater potential Zones

S/N	Groundwater potential zones	Areal coverage (KM^2)	Percentage (%)
1	Very High	5,676 km^2	27.3%
2	High	7,400 km^2	35.7%
3	Moderate	1,284 km^2	6.2%
4	Low	5,375 km^2	25.9%
5	Very Low	1,025 km^2	4.9%
	Total	20,760 km^2	100%

Source: Data Analysis, 2013

4.5.2 Characteristics of the groundwater potential zones

Table 4.33 and 4.34 Indicates results of pumping tests which were used in characterization of the identified GWPZS. It can be seen that Shuwaki, Yandadi, Dokadawa, K/Yashi, Shakogi, Alajawa, Turawa, Tarai, Babawa, Karfi and Kosawa are areas with lower draw down of 7.81m to 9.70m at 30 minutes and are areas with higher discharge rates at 30 minutes of between 0.65L/m to 1.11 L/m. It can also be seen that these villages fall within Very High, High and Moderate Groundwater potential zones (GWPZS). It can be observed that Riruwai, Zainabi, Tumbau, Tudunkaya, Fammar and Tumbau recorded higher draw down of 13.80m to 15.40m at 30 minutes. In these same areas discharge was found to be 0.5 to 0.7L/m. It was determined that these areas fall within either low or Very Low groundwater potential zones (GWPZS).

The result of the general characteristics of the Groundwater potential zones was presented in Table 4.29, 4.30, 4.31 and 4.32. The result shows that Very High, High and moderate groundwater potential zones are characterised by alluvial soil, hydromorphic soils, and ferruginous soils. In terms of geology and landforms they are associated with pink and white granite, quartzite suits

fractured valley fills and older granitic formations of various types. These three (3) zones are characterised by high lineament density, high drainage density, high runoff high vegetation cover and low relief or low slope values. It can be observe that Low and Very Low groundwater potential zones are characterised by lithosols and reddish to reddish brown soils. They are younger granite areas characterised by metamorphic suits fine granites to medium biotite and Quartz chist. These areas are characterised by low lineament lines density, low drainage density, low vegetation cover, low runoff concentration and high slope values.

Table 4.29 Characterising Groundwater Potential Zones Based on Slope

S/N	Slope	Explanation	Relationship with groundwater	Groundwater PZ
1	**0^o - 2^o**	Level or almost level	No much runoff, water percolates	Very High
2	**2^o - 3^o**	Gentle	Infiltration reduces runoff increases	High
3	**3^o - 5^o**	Moderate	Much run off Low infiltration	Moderate
4	**5^o - 18^o**	Moderately Steep	Very much Runoff	Low
5	**>18^o**	Very Steep	Total Runoff no infiltration	Very Low

Source: Data Analysis, 2003

Table 4.30 Pumping test results and groundwater potential of the 16 villages

S/N	Bore hole Location/Village	Discharge at 30 mint.(L/M)	Water level (M)	Draw Down (M) at 30mnt.	Remark	GWP of the area
1	Shuwaki	0.70	13.20	9.70	PBH, M	Moderate
2	Yandadi	0.75	14.98	8.98	PBH,M	Very High
3	Dokadawa	0.71	12.13	10.20	PBH,M	Moderate
4	K/Yashi	0.8	16.12	8.25	PBH,M	Moderate
5	Shakogi	0.65	13.81	7.81	PBH,M	Very High
6	Alajawa	0.71	13.22	9.20	PBH,M	Moderate
7	Riruwai	0.5	18.31	15.40	HP	Very Low
8	Zainabi	0.6	17.81	14.81	HP	Low
9	T/Kaya	0.7	17.19	13.80	HP	Low
10	Turawa	1.11	13.30	9.30	PBH,M	Moderate
11	Fammar	0.6	16.70	14.70	HP	low
12	Tarai	0.75	14.98	8.98	PBH,M	High
13	Babawa	0.70	12.20	8.50	PBH,M	High
14	Tumbau	0.65	17.81	14.82	PBH,M	Low
15	Karfi	0.76	13.30	8.95	PBH,M	Very High
16	Kosawa	0.78	12.48	9.48	PBH,M	High

KEY: PBH, H =Productive Borehole Mechanical
H= only hand pump

Source: Field work, 2013

Table 4.31 Characterization of the groundwater potential zones using Pumping test results

S/N	Groundwater potential Zones (GWPZ)	Characteristics based on pumping test data
1	**Very High**	It is characterised by a discharge of 0.70- 0.76 L/M at 30m and a very low drawdown of 7.81- 8.98m at 30minuts
2	**High**	Areas with discharge of 12.20- 14.98L/M and Drawdown of 8.98- 9.48m
3	**Moderate**	Having a discharge of about 12.3- 13.30L/M and Drawdown of 8.25- 10.20m
4	**Low**	Discharge of about 16.70- 17.81 and Drawdown of 14.70- 14.82
5	**Very Low**	Discharge of 18.31L/M and Drawdown of 15.40m and above

Source: Data Analysis, 2013

Table 4.32 Characteristics of the five (5) identified GWPZS based on factors

S/N	Groundwater potential Zones (GWPZ)	Characteristics
1	**Very High**	Alluvial plains, pink and white granite, metamorphic coarse, black and white granite, fractured valley fills, high lineament density, very low slope values and high runoff areas.
2	**High**	Hydromorphic soils, Ferruginous soils, Quaternary formations, Quazite areas, fractured valley fills, high lineament density, low slope values and high runoff areas.
3	**Moderate**	Hydromorphic soils, Ferruginous soils Dior granite areas, medium biotite gneiss areas granite gneiss, migmatite, high lineament density, moderate slope values, and moderate high runoff areas.
4	**Low**	Lithosols areas, metamorphic suits, fine grained biotite granite, medium biotite, moderate low runoff, low lineament density areas, moderately high slope values, fairly vegetated areas.
5	**Very Low**	Mountain peaks, escarpments with steep cliffs, younger granite areas, Quartz porphyry, Quartzite massive chist and quartz chist, black and white granite, brown and reddish brown soils and shrub savannah and wood lands with high slope values.

Source: Data Analysis, 2013

4.6 GROUND WATER POTENTIAL AND VES SURVEY RESULTS

The results for the VES survey results and Groundwater potential zones are compared and presented in Table 4.33. It was observed that the techniques are in close agreement with little variations in some area.

Table 4.33 Ground water potential of the rural villages and VES survey results

S/N	Rural Villages	Latitudes	Longitudes	VES WET. S	VES DRY. S	Final GWPZs
1	Shuwaki	N12.42049^{o}	E008.17594^{o}	High	High	Moderate
2	Yandadi	N12.43751^{o}	E008.23260^{o}	Low	Low	Very High
3	Dokadawa	N11.97927^{o}	E008.16412^{o}	High	High	Moderate
4	Karofin yashi	N11.88268^{o}	E008.35069^{o}	High	High	Moderate
5	Shakogi	N12.03162^{o}	E008.01212^{o}	Low	Low	Very High
6	Alajawa	N12.07925^{o}	E007.9628^{o}	High	High	Moderate
7	Riruwai	N10.72851^{o}	E008.75896^{o}	Low	Low	Very Low
8	Zainabi	N10.78090^{o}	E008.7898^{o}	High	High	Low
9	Tudun Kaya	N11.73080^{o}	E007.92894^{o}	Low	Low	Low
10	Turawa	N11.75320^{o}	E008.03216^{o}	High	High	Moderate
11	Fammar	N11.55031^{o}	E008.71932^{o}	Low	High	Low
12	Tarai	N11.49790^{o}	E008.66964^{o}	Moderate	Moderate	High
13	Babawa	N12.06004^{o}	E008.65827^{o}	High	Moderate	High
14	Tumbau	N11.99074^{o}	E008.81459^{o}	High	High	Low
15	Karfi	N11.82310^{o}	E008.49462^{o}	Low	Low	Very High
16	Kosawa	N11.77229^{o}	E008.45668^{o}	High	High	High

Source: Data Analysis, 2013

CHAPTER FIVE: DISCUSSION OF RESULTS

The study identified the major sources of water supply in the rural areas of Kano. It is established that the major sources of drinking water in the study area are from surface water sources and open wells. The result of the interview indicated that rural areas in Kano north rely more on surface water sources because larger percentage of the people interviewed stated that they depend on either river or reservoirs for their drinking water. Rural villages in Kano central and Kano south depend on open wells. It was determined from the interview result that the major source of drinking water in Kano north is surface water; Kano central and Kano south have their major source as groundwater. Surface water is found to be the major available source of drinking water in Kano north senatorial district (Sara and Charles, 1988). This finding is also in line with that of Chris (2005) in Kakamega District in Kenya where 85% of the respondents stated that their major water sources are surface water and spring.

The interview result also established that most of the respondents obtained their water at less than 500 meters from their residents. It was observed that distance covered to get water in Kano north is greater than that of villages in Kano central and Kano south because of its scarcity and overdependence on surface water sources. Emmanual (2012) attributed that a distance of 500meters to water points is equivalent to normal access to water.

In terms of usage of the water sources in the rural areas responses indicates that in most of the villages it was discovered that reservoirs, rivers and open wells are highly used. Ponds are the least in terms of usage while tap and borehole are fairly used because they are not adequate. This finding is in close agreement with that of Jansz (2011) where 70% of the respondents have no access to tap water and 85% of the respondents collect water from their domestic water sources.

The research findings through interview identified that in the sixteen villages studied most of the water sources are constructed and owned by individuals. This is supported by 39.3% of the responses. The next in terms of control is government with 31.2% of the total responses, this shows that government effort is inadequate in areas of rural water supply. This is in line with the assertion of Wardrop (1990) that most of the water sources in the villages around Kano are controlled by individual members of the community. This finding is similar to that of Waller (1982) in some rural areas in U.S.A where 44% of the population in Maina use their own open wells, 1% in Puerto and 14% as National average in US. It is also in line with findings of TNDA (2010) in Tanzania that community owned water supply is the leading in rural areas said by about 80% of respondents. WUP (2001) states that various traditional means of obtaining water have been developed by individuals and communities for many centuries, the commonest and oldest is the use of hand-dug well and collection of water direct from streams and ponds.

It was deduced from the interview result that in most of the rural areas of Kano State water supply is inadequate as stated by 62.9% of the total respondents. The study also established that villages in Kano south suffer more in terms of water shortage followed by village of Kano north and then villages in Kano central. This finding is in line with that of Sara and Charles (1988) that areas at the southern part of Kano suffer more from water shortage, this is directly linked with nature of hydrogeology of the areas. This is also supported by Macdonald (2005). Who established that water supply is grossly inadequate in most of the rural community of Kano. The result is supported by findings of Jansz (2011) in Niassa Province, Mozambique where 70% of the respondents are of the opinion that water supply is inadequate. This finding is contrary to that of Emmanuel in rural areas of Ghana were over 70% or respondents are of the opinion that water supply is adequate. Shortage of drinking water in the study areas is increasing; this can be proving from appendix: 2a and 2b.

The study revealed that majority of the households in the rural areas bought drinking water from water vendors this is because 60.7% of the respondents said they buy water. The study also

established that households of the rural areas in Kano south buy water more than those of Kano north and Kano central. The survey result also identified that in most of the rural areas of the state households are spending N100 to N200 daily on drinking water. This is an indication of water scarcity in villages of Kano. This result is supported by findings of Chris (2005) in Kakamega District, Kenya where 89% of the respondents said they buy drinking water every day.

The research results indicate the nature of hydrogeology of the study area through digitization of contour map, drainage map, drainage density map of the study area and aquifer parameters determination. The findings of the research work established that rural areas with highest contour values of > 580m AMSL and lower values of porosity water content, hydraulic head hydraulic conductivity, specific storage and specific capacity, such as Riruwai and zainabi are ascribed to have low groundwater potential from both VES survey result and RS and GIS analysis and are areas with inadequate water supply. while areas with low contour values of 340m to <340m including Kosawa, Karfi, K/Yashi, Babawa and Tumbau are within zones of moderate to High groundwater potential and at the same time are areas with higher values of aquifer parameters because of high percolation and high groundwater concentration. This result coincided with the finding of Munhong (1998), Tesfaye (2010), and Goyal *et al.,* (2009) that areas of lower terrain are areas most likely to have more groundwater potential than highland areas in a hard rock terrain regions. It was also discovered in Jordan by Nezar *et al.,* (2012) that areas of higher relief are of low potential and lower areas are of higher potential.

The research findings determine that slope value is one of the significant hydro geological factors in assessing groundwater potential in the study area. It indicates that areas of higher slope values of $>9^{o}$ are around Riruwai and are described as areas of Very Low groundwater potential, areas with slope values of between 6^{o} - $< 9^{o}$ fall within areas of Low groundwater potential such areas include Tudunkaya, Alajawa, Kosawa and Yandadi. Areas with low slope values of between 0^{o} -3^{o} and 3^{o}-6^{o} such as K/yashi, Shakogi, Shuwaki, Alajawa and Karfi were found be within zones of Moderate,

high and very high groundwater potentials, this is because low slope areas attracts more surface water concentration and infiltration as groundwater and the lower the slope values the more drainage concentration, more infiltration and more groundwater. This result is supported by findings of Tesfaye (2010) Who reported that a slope 0-2^{o} is said to be gentle and shows the presence of good groundwater potential while >13^{o} shows the presence of poor groundwater potential. This result is also substantiated by Shahid et al (2000), Sultan et al (2009), Goyal *et al.*, (2009), Venkatesan *et al.,* (2010), Okoro *et al.,* (2010), Sitender (2011), Abel *et al.,* (2011), Emmanuel *et al.*, (2011), Anudu *et al.*, (2011) and Oluwatola et al., (2013) that low slope values in an area indicates high drainage concentration, more rivers and more groundwater potential and vice-versa.

Beside this Hisin-Fu *et al.,* (2009) pointed out that rainfall is the main source of ground recharge in tropic and sub tropic regions. The slope gradient directly influences the infiltration of rainfall. Larger slopes produce a smaller recharge because water runs rapidly off the surface of a steep slope during rainfall, not having sufficient time to infiltrate the surface and recharge the saturated zone. Also Magesh *et al.,* (2011) in Nadu India discovered that a slope of 0-6 ^{o} is of very good potential, 6-16 ^{o} is of good potential, 16-27 ^{o} is of poor potential and above >27 ^{o} is of very poor potential groundwater zone.

The result revealed that areas of higher drainage densities are areas of very high, high and moderate groundwater potential and such areas consist of K/yashi, Turawa, Karfi and Kosawa while areas with low drainage lines densities are around Riruwai, Zainabi, Fammar Tarai and TudunKaya and are areas of low to very low groundwater potential. This is because the more the drainage the higher the rate of percolation through lineaments and soil pore spaces. This result is in agreement with that of Hsin-Fu *et al.,* (2009) whom conducted a similar research in Taiwan and concluded that a zone with a high drainage length density has a high level of groundwater recharge. The result is also in line with that of Anudu *et al.,* (2011) who conducted a similar work in Wamba and its adjoining

areas in Nassarawa State. The results obtained are however, contrary to that obtained by Subash *et al.,* (2008), Venkatesan *et al.,* (2010), and Subin *et al.,* (2012) They stated that drainage density is the prime indicator of identification of potential groundwater zones and the higher the drainage density the lesser the infiltration capacity as well as groundwater because much of water coming as rainfall goes as run off.

The drainage density result is also contrary to the findings of Abel *et al.,* (2011) in Ekiti area south western Nigeria Chandra *et al.,* (2008) and Sitender (2011). Their result indicates that high drainage density equals to low groundwater potential. The reason for the differences of this finding with the findings of the research work is based on differences in geologic formation and soil.

The results of aquifer parameters analysis indicates that areas with higher porosity, higher water content, higher specific yield, higher hydraulic conductivity, hydraulic head and specific storage are areas of higher drainage densities and older granites and these are areas with higher groundwater potential. While areas with lower values of these aquifer parameters are areas associated with low drainage density and younger granites and consequently low groundwater potential. This result is supported by several scholars (Kolja, 2007; Tesfaye, 2010; Kandri *et a l.,* 2008; Fetter, 1994; Timothy, 2006 and Munhong, 1998).

VES survey results using Schlumberger array method indicate that most of the curves plotted for the sixteen rural areas are 'A' types (P1<P2<P3) and shape of the curves depend on the layers thickness, number of layers in the subsurface and ratio of resistivity of the layers. It can be observed from appendix I in some of the curves four layers were identified as top soil, sandy clay, weathered fracture and partly weathered rock. In some curves three layers can be observed which are top soil, clayey/sandy cay/laterite and weathered fresh basement. This result agreed with that of Mosuro *et al.,* (2012) in Imopo Ogun state where three and four layers were also identified. Olorunfemi and Fasuyi (1993) states that groundwater yield in basement complex terrain is generally low for clay

bearing/low permeability weathered aquifer and high for weathered and fracture aquifer with enhance permeability through secondary porosity. Areas around Yandadi, Shakogi, Dokadawa, Shuwaki and Karofin yashi are good curves all with low resistivities and high depth. This result is supported by that of Nwankwo *et al.,* (2013) in Akobo Area in Ibadan that a low resistivity (<200 ohm/m) coupled with high thickness (>20m) is described as a promising aquifer area. It is contrary with findings of Yanet (2012) in Kaura Kaduna state where 5 layers were identified with a resistivity values ranging from 132 to 7082 ohm/m, It is also contrary to the findings of Gada (2006) in Sokoto were 5 layers were identified because Sokoto is underlain by sedimentary formations. It is established from the VES result that northern and central senatorial districts have more promising aquifers than Kano south senatorial district. Base on this it is established that groundwater occur in weathered basement. The aquifer of the basement complex area of Kano state are the weathered and fractured rocks in which groundwater exist under water table condition (Mohammad, 1984). The study established that there is abundant occurrence of groundwater in Kano State that can be used to supply water to the rural dwellers. This finding is similar to that of Abubakar and Auwal (2012) who undertakes VES survey in DawakinTofa, L.G.A of part of Kano State.

Groundwater potential zones of the study area were identified to be five classes based on VES survey result and GIS and RS analysis as Very High, High, moderate, Low and Very Low. This is in line with findings of Srinivasa and Juggran (2003) in India where five classes were identified as Very high potential, high potential, moderate potential, low potential and very low potential. Goyal *et al.,* (2009) also identified five classes of groundwater potential. This is contrary to the result of Abel *et al.,* (2011) where four classes were identified as Very good potential, Good potential, Moderately Good potential and poor potential. Oluwatola *et al.,* (2013) identified three classes in SW Nigeria as low, moderate and high.

It can be seen that relationship was established between factors and groundwater potential. Among the factors it was discovered that lineament line density is the most important with highest weight of 0.46 or 0.46% and the major lineament trends were observed to be NW-SE, NE-SW and N-S. It is established that areas with high lineament density are those areas of high to moderate groundwater prospects. Such areas include Yandadi, Kosawa, K/Yashi Turawa and Dokadawa. This is attributed to the fact that more lineament lines allow more water to sinks down as groundwater. This finding corresponds to that of Anudu *et al.,* (2011) in Wamba, Nassarawa State. They stated that areas having high lineament density represent areas with relatively high groundwater potential. This result also coincided with that of Abel *et al.,* (2011) in Ekiti area and discovered that the lineament dominant directions are NW-SE and NE-SW and areas with high lineament density are areas with high groundwater potential. Also Arun *et al.,* (2009), Chandra et al (2010) and Tesfaye (2010) supported this. Also Sitender (2011) discovered that areas with lineament density of 0.00 – 0.54 are nil in terms of groundwater potential and areas of 2.73 – 3.28 are having very high groundwater potential.

It was discovered in the weighted overlay analysis that drainage density is the second in priority of groundwater potential after lineament with a weight of 0.024 (24%). Based on this it was determined that areas with high drainage densities are areas with moderate to high groundwater potentials and are Turawa, K/Yashi, Babawa, Yandadi, Kosawa and Tarai while areas with lower drainage densities and low to very low Groundwater potentials are Tumbau, Shuwaki, Riruwai Zainabi, Tudunkaya, Shakogi, Dokadawa and Tarai. This result is supported by that of Goyal *et al.,* (2009), Anudu *et al.,* (2011), Girish *et al.,* (2009), Sultan (2009) and Hsin-Fu *et al.,* (2009). Findings of all these studies agreed that a high drainage density area corresponds to high groundwater potential. Also Magesh *et al.,* (2011) confirmed that the suitability of groundwater potential zones is indirectly related to drainage density because of its relation to surface runoff and permeability. Their study established that a drainage density of 1.00-1.93 Km/Km^2 is a very good

potential and 0-0.34 Km/Km^2 is a very poor potential. The results of Subin *et al.,* (2012), Shahid (2000), Tesfaye (2010), Oluwatola *et al.,* (2013) and that of Abel *et al.,* (2011) are contrary to these findings, according to their findings the higher the drainage density the lower the groundwater potential of an area. The difference is due to the fact that their study areas are different with this study area in terms of geology, lithology and lineament density that control surface runoff and groundwater relationship. In their studies more drainage concentration means more surface runoff and in this study more drainage density means more percolation and more ground water due to the presence of high lineament density, weathered and fractured basements.

Relationship between Geology and groundwater indicates that geology is also important in the weighted overlay analysis with weight of 0.11 (11%). It was observed that areas underlain by homblende granite, migmatite, medium biotite and biotite gneiss are within very high, high and to moderate groundwater potential such as Karfi, K/Yashi and Kosawa while areas with low to very low groundwater potential such as Riruwai, Zainabi and Fammar are underlain by quartz porphyry and quartz schist which were believed to have originated from younger granites of Jurassic period. This is because such areas are having low infiltration or percolation that resulted into low groundwater concentration. This result is in accordance with that of Abel *et al.,* (2011) those areas underlain by charnockitic rocks, quartz porphyry and porphritic granites in the study area were found to be of limited groundwater potential due to the presence of higher slopes, low infiltration and low lineament. This finding is also in line with saying that Riruwai complex provides one of the finest examples in the Nigerian province of the complex cycle of younger granite magnetic activity (Jacobson and Macleod, 1977). It is also in agreement with findings of Alkali *et al.,* (2011) in Gwoza and Sitender (2011) in Haryana India that sand silt and clay formation have highest weight of 6, coarse to fine alluvial sand 4, quartzite phyllite and slate 3 and Quartzite Chist is the least with 1.

The study also looked at the nature of hydrogeology and groundwater potential of the rural areas of Kano state. The result showed that areas associated with Pink and white granite, metamorphic coarse, coarse pink black granite and quaternary formations are areas associated with more rivers, streams and dams. Such areas are also discovered to have more drainage densities and lineament densities which are all structurally controlled by the nature of geology and recorded higher values of aquifer characteristics such as porosity, water content, and specific storage, at the same time such areas are characterised by low values of water table. These are areas ascribed to have more groundwater potential and are within very high, high and moderate groundwater potential zones because of high percolation of the surface water that resulted into more groundwater. The areas include K/yashi, Yandadi, Babawa, and Karfi. This is in association with the findings of Mandal (2011) that the accumulation and movement of groundwater is controlled by hydrogeology which is divided into consolidated rock structure, semi consolidated and unconsolidated. The unconsolidated areas are areas of moderate groundwater potential. It was determined that areas associated with younger granites, black and white granites, metamorphic suits, Dior granites and quazites are areas dominated by high contour values, higher slopes and less river higher water table values. Such areas are areas of low to very low groundwater prospects. They include Riruwai and Zainabi in Southern Kano. This result is in conformity which that of Gouri *et al.,* (2012) in New Guinea who discovered that low potential zones include rocky areas and volcanic structures with low porosity, which acts as runoff, zones as well as low water yield. Also Yalet (2012) in Kaura Southern Kaduna discovered that poorest areas in terms of borehole yield are younger granites terrains with thin overburden aquifer of maximum thickness of 10m.

It was observed that groundwater potential varies with soil types. Shaban *et al.,* (2006) stated that the type of rock exposed to the surface significantly affects groundwater recharge. Lithology affects the groundwater recharge by controlling the percolation of water flow and aquifer characteristics (El- Baz and Hamida, 1995). From the findings it can be seen that areas with hydromorphic soils

and ferruginous tropical soils are more important in terms of groundwater potential such areas include Shakogi, Alajawa, Yandadi, Karfi, Babawa, K/ yashi and Turawa. Areas dominated with lithosols are areas with moderate groundwater potential while areas associated with brown and reddish brown soils or laterite, these areas include Riruwai, Zainabi, Tudunkaya and Fammar and are classified as areas of low to very low groundwater potential because of low percolation. This result is similar to the findings of Hsin-Fu *et al.,* (2009) that alluvial soils, hydromorphic soils and coarse soils in the downstream areas are the areas classified as very high zones of groundwater potential because such soils allow percolation and groundwater concentration. Similarly it is in agreement with the findings of El-Baz and Hamida (1995), Goyal *et al.,* (2009) and Magesh *et al.*, (2011). It is also reported that coarse grained sediment and alluvial soil zones are suitable for groundwater potential while lateritic soil zones produce poor groundwater potential (Gouri *et al.*, 2012). Also Shahid *et al.,* (2000) discovered in Bengal India that sandy loam is the one with high weight of 9, sandy clay loam 8, clayey loam 5 and silt clay 2. Also Oluwatola *et al.,* (2013) in south western Nigeria reported that sandy soil is having weight of 3 followed by loam with 2 and clay with 1 in terms of groundwater potential.

It was discovered that vegetation is the least among the factors in terms of groundwater potential in the study areas but even among the vegetation types there are variations with regards to groundwater potential. In the study area Sudan savannah >60% is having more influence on groundwater potential followed by Sudan savanna 30- 60% these areas include Karfi, K/Yashi, Babawa, Yandadi and Turawa. Shrub savannah and savanna wood land are areas of low to very low groundwater potential; these areas include Riruwai, Zainabi and some patches at extreme northern and southern parts of the study area. This coincided with the findings of Gouri *et al.*, (2012) that presence of high dense vegetation in areas indicates possibility of acting as major conduits for subsurface movement and for the storage of groundwater. Also Hsin-Fu *et al.,* (2009) reported that forested areas covered by vegetation are areas of good groundwater potential. It was also reported

that woodlands associated with volcanic activities and hills are of low groundwater potential (Magesh *et al.,* 2011).

Among these zones high potential is the largest, followed by very high, low, moderate and lastly very low. This finding is in close agreement to that of Oluwatola *et al.,* (2013) where moderate potential has 79.5%, high 17.24% and 3.23% is low. Groundwater potentials characteristic indicated that areas that fall under promising groundwater potential zones are characterised by high discharge, low draw down and good aquifer and physical characteristics. This finding is in agreement with that of Tesfaye (2010), Goyal *et al.,* (2009), Okoro *et al.,* (2010) and Alkali *et al.,* (2011) in Gwoza.

It was observed from result validation that weighted overlay result obtained from GIS and RS analysis is more effective, more detailed and more general than that of VES survey result since some of the areas described as low under VES are described as moderate or low in the integrated analysis. But the result of the two techniques is similar in majority of the rural areas studied. From the result it can be seen that Shuwaki, Dokadawa, K/yashi, Alajawa, Turawa, Tarai, Tumbau, Babawa and Kosawa are described as areas of high to moderate groundwater potential by the two techniques. Yandadi, Shakogi and Karfi are described as areas of moderate potential by GIS and RS method and low from the VES results. Areas like Tudunkaya, Zainabi and Fammar are of low potential in the weighted overlay analysis and very low in the VES survey. Riruwai fall under very low category in the both methods.

CHAPTER SIX: SUMMARY, CONCLUTION AND RECOMMENDATIONS

6.1 SUMMARY

The study identified groundwater potential of rural areas of Kano state. The investigation was achieved through assessing water supply situation and nature of hydrogeology of the study area. This is with intention of improving rural water supply condition in Kano State. Multicriterian methods were adopted in the study. These include questionnaire survey through interview, VES survey, determination of aquifer characteristics through laboratory analysis and weighted overlay analysis i.e. analytical hierarchy process (AHP) through GIS and remote sensing.

It was determined that there is overdependence on surface water in the study area as a major source of drinking water more especially in the rural areas of Kano north and Kano south due to its scarcity. It is established that northern and central senatorial districts have more promising aquifers than Kano south. Groundwater occurs in weathered basement. Groundwater potential zones identified were divided into very high, high, moderate, low and very low based on factors. It was proved that areas of promising groundwater potential dominated areas of low to very low potential. Goyal et al (2009) and Tesfaye (2010) identified 5 groundwater potential zones in their studies. This can be attributed with the variation in factors determining groundwater potential and methods adopted in the study.

The study like other studies of different authors established that groundwater potential in the study area is attributed to the following:-

► Nature of hydrogeology and geology in the study area affect aquifer characteristics. It was established that areas of high porosity, water content, specific storage and water head are areas of probably promising aquifers.

► Areas with low resistivity values and high depth are areas with high curves, good aquifer characteristics and consequently high groundwater potential.

► Among the six factors lineament line density is the most important in terms of groundwater occurrence in the study area followed by drainage density, geology Lithology and vegetation was found to be the least.

► The study revealed that areas of high lineament density and drainage density are areas of potential groundwater.

► Slope also determine groundwater potential of an area because it was proved that low slope value areas have high groundwater potential and high slope low groundwater potential.

► Variation in terms of geologic formation in the study area also determines groundwater potential of the areas. Areas with consolidated younger granites have low groundwater potential while areas of older granites, weathered basements and unconsolidated materials have high groundwater potential.

►It is established from the water table results that there is abundant occurrence of groundwater in Kano State that can be used to supply water to the rural dwellers.

►The study attributed that pumping test results in the 16 rural areas are directly related to groundwater potential classes. This is because very high, high and moderate areas are described as productive and can take mechanical boreholes while areas of low and very low groundwater potential can only take hand pump or non.

► Both VES results, GIS overlay analysis, laboratory test results and pumping test results are in close agreement in terms of groundwater potential.

6.2 CONCLUSION

Remote sensing and GIS have proving their credibility beyond reasonable doubt in natural resources assessment. From the findings of this study it is concluded that water scarcity is more pronounced in rural areas of Kano north and Kano south. It is also concluded that large percentage of people in these rural areas depends largely on surface water than groundwater sources. From the result of this study, it is concluded that nature of hydrogeology of the study area contributes in the groundwater potential distribution. It is concluded that high groundwater potential areas are associated with homlendgranite, migmatite, medium biotite and biotite gneiss. It is also proved that rural areas of Kano state with these geologic and hydrogeology formations are ascribed to have high porosity, water content, hydraulic head, specific storage, hydraulic conductivity and specific yield among others and these areas are believed to have weathered basements and unconsolidated materials which attracts more groundwater in a basement complex area of this type.

It is also concluded that the study area fall under five groundwater potential zones which are very high, high, moderate, low and very low. The five groundwater potential zones are directly controlled by six factors which are lineament density, drainage density, geology, hydrogeology, soil and vegetation arranged according to their relative importance to groundwater potential. Based on the findings of the research it is concluded that rural areas in Kano sate with high lineament lines density, high drainage density, low slope values, older granite basement complex, alluvial, hydromorphic and ferruginous soils and high percentage of savanna vegetation are areas with high groundwater potential. From findings of the research it is concluded that promising groundwater potential areas are characterised by low draw down from bore hole pumping test results.

The outcomes of this study identifies that the groundwater potential zones identified through integrated weighted overlay method was in close agreement with VES survey results, aquifer parameters data and interview results. It is therefore concluded that integrated GIS, RS and other

conventional methods are useful, very efficient, time and cost effective tools for identification and delineation of groundwater potential zones for rural water supply.

6.3 RECOMMENDATIONS

In relation to the findings obtained from the research work and conclusion reached the following recommendations are forwarded.

- The groundwater potential map and thematic maps produced are sources of vital information and data base which can be updated from time to time by adding new information for development.
- Government, nongovernmental organisations, wealthy individuals and community should provide more bore holes and hand pumps in the study area to arrest drinking of untreated water. More especially in the rural areas of Kano south and north where water shortage is more pronounced and taken of river and reservoir water is very common.
- Since lineament, Drainage Density, Geology, Hydrogeology, Soil, Vegetation and slope are the major factors controlling groundwater occurrence in the study area analysis of these parameters should be supported by more high resolution terrain data like radar images.
- Since larger percentage of the study area is within very high, high to moderate groundwater potential zones Governments at all levels should do everything possible to assist in successfully exploiting and managing this important resource through drilling and providing constant power supply and adequate fuel for generators in the rural areas of Kano state.
- Rural areas in the extreme southern part of the study area should be given special treatment regarding water supply since most of them are within the younger granites region

characterised by low to very low groundwater potential and over dependence on surface water sources like in Riruwai People depend on a pond called Green water developed from previous mining activities (plate: 1.3)

- It is also recommended that high-yielding boreholes should not be developed in areas of moderate to low groundwater potential but alternatively hand pumps are likely to be successful and the best alternatives. While in areas with good aquifer characteristics and higher groundwater potential mechanical borehole are the best options.

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LIST OF APPENDICES

Appendix 1: Questionnaire on Sources of Rural Water Supply Situation in Kano State

Location ref. latitude---------- longitude ----------

Height (m) ASL----------Senatorial District ---------- LGA ----------

Village/Rural area ----------

Personal data

Sex---------- Age ---------- Occupation ----------

1. What are your common sources of water? ----------

   ----

2. How long do you trek to get water? ----------
3. (a) Do you buy water?

   (i)Yes ( ) (ii) No ( )

   (b) If yes how much do you spend par day?

   ----

4. Fill the following boxes to state how you use the water source

S/N	Water sources	Highly use	Moderately use	Fairly use
1.	Pond			
2.	Reservoirs/Dam			
3.	River			
4.	Open well			
5.	Hand Pump			
6.	Bore hole (Engine)			
7.	Bore hole (Solar)			
8.	Tap			

5. Our water supply is controlled by?

(i) Nature ( )

(ii) Individuals ( )

(iii) Community ( )

(iv)Entrepreneurship ( )

(v) Government ( )

6. (a) Is water supply adequate in your area?

(i) Yes ( ) (ii) No ( )

(b) If yes state the source----------

---

7. The major source of my portable water is

(a) Groundwater ( )

(b) Surface water ( )

(c) Tap water ( )

(d) Bottle/ pure water ( )

Thank you very much for spending your time in answering these questions

Appendix 2a: amount of raw and treated water in Kano in 2002- 2003

Year	**2002**		**2003**	
Month	**Raw**	**Treated**	**Raw**	**Treated**
January			4,689,355,000.00	2,829,973,952.00
February			4,577,344,000.00	2,738,865,000.00
March	4,345,140,000.00	3,850,531,000.00	3,887,465,000.00	2,664,776,234.00
April	3,260,660,000.00	2,895,426,000.00	4,500,355,000.00	2,829,973,956.00
May	3,499,320,000.00	3,017,258,000.00	3,588,344,000.00	1,976,865,921.00
June	3,821,124,000.00	3,180,301,000.00	4,722,255,000.00	2,887,776,822.00
July	4,003,995,000.00	3,941,652,000.00	4,676,366,000.00	2,786,667,726.00
August	5,100,258,000.00	4,145,950,000.00	4,722,255,000.00	2,887,767,822.00
September	5,111,249,000.00	4,094,085,000.00	4,470,002,000.00	3,647,025,021.00
October	5,129,304,000.00	4,136,085,000.00	4,687,355,000.00	2,829,973,952.00
November	3,943,698,000.00	3,351,447,000.00	4,517,962,000.00	2,895,089,177.00
December	4,865,581,000.00	4,009,036,000.00	5,164,060,000.00	3,942,221,852.00
Total	43,080,329,000.00	36,621,771,000.00	54,201,118,000.00	34,916,977,435.00
Mean	7,832,787,090.91	6,658,503,818.18	8,338,633,538.46	5,371,842,682.31
S.D	11164476527	9485820843	13244735771	8540682666
C.V	142.5351717	142.4617467	158.8358058	158.9898136

Source: Statistical Year Book, 2006

Appendix 2b: amount of raw and treated water in Kano in 2004- 2005

Year	**2004**		**2005**	
Month	**Raw**	**Treated**	**Raw**	**Treated**
January	4,210,603,399.00	3,864,239,621.32	3,864,239,621.32	
February	4,062,997,306.00	3,205,964,452.00	3,205,964,452.00	3,996,871,960.00
March	3,315,266,964.00	2,829,973,952.00	2,829,973,952.00	4,841,050,000.00
April	4,535,638,785.00	4,518,197,517.00	4,518,197,517.00	5,632,804,315.00
May	5,032,866,000.00	4,372,244,905.00	4,372,244,905.00	6,099,805,315.00
June	4,192,740,000.00	3,188,772,801.00	3,188,772,801.00	3,424,056,750.00
July	4,709,212,000.00	3,817,009,395.00	3,817,009,395.00	4,636,225,779.00
August	4,628,674,400.00	3,114,657,556.00	3,114,657,556.00	5,033,246,555.00
September	5,926,843,176.00	3,161,248,564.00	3,161,248,564.00	2,943,348,116.00
October	4,073,487,423.00	3,880,512,473.00	3,880,512,473.00	2,644,609,994.00
November	3,607,779,400.00	3,031,882,928.00	3,031,882,928.00	5,245,738,941.00
December	4,480,836,165.00	2,771,794,624.00	2,771,794,624.00	5,245,738,941.00
Total	52,776,945,018.00	41,756,498,788.32	41,756,498,788.32	49,743,496,666.00
Mean	8,119,530,002.77	6,424,076,736.66	6,424,076,736.66	8,290,582,777.67
S.D	12906417422	10213969252	10213969252	12540608392
C.V	158.9552279	158.9951314	158.9951314	151.2632915

Source: Statistical Year Book, 2006

Appendix 3a: typical layers of Schulumberger Configurations at Kosawa

DATA SET: KSW

CLIENT: TASI'U RILWAN YALWA DATE: 30-07-2011
LOCATION: KOSAWA VILLAGE SOUNDING: 03
COUNTY: KURA L.G.A.,KANO STATE AZIMUTH: E-W
PROJECT: Phd thesis(Phd/scie/08857/08-9 EQUIPMENT: OHMEGA
ELEVATION: 0.00
SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

Schlumberger Configuration

FITTING ERROR: 7.252 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			0.0		
1	393.6	2.20	2.20	0.00560	867.7
2	64.80	10.29	12.50	0.158	667.1
3	123.9	32.84	45.34	0.264	4072.2
4	211.1				

ALL PARAMETERS ARE FREE

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	1.50	391.0	376.4	3.71
2	2.50	348.0	333.3	4.20
3	4.00	210.0	247.3	-17.80
4	6.00	169.0	157.6	6.74
5	8.00	122.0	110.6	9.29
6	10.00	81.00	89.91	-11.00
7	15.00	81.00	78.76	2.75
8	20.00	80.00	81.63	-2.03
9	25.00	87.00	86.65	0.398
10	32.00	97.00	93.82	3.27
11	40.00	98.00	101.1	-3.25
12	60.00	117.0	116.2	0.652

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER
P 1 1.00
P 2 0.00 1.00
P 3 0.00 0.00 0.97

Appendix 3b: typical layers of Schulumberger Configurations at Tarai

DATA SET: TARAI

CLIENT: TASI'U RILWAN YALWA DATE: 04-08-2011
LOCATION: TARAI VILLAGE SOUNDING: 03
COUNTY: KIBIYA L.G.A.,KANO STATE AZIMUTH: N-S
PROJECT: Phd thesis(Phd/scie/08857/08-9 EQUIPMENT: OHMEGA
ELEVATION: 0.00
SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

Schlumberger Configuration

FITTING ERROR: 2.741 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES (Ohm-m^2)
			0.0		
1	204.5	3.17	3.17	0.0155	648.5
2	75.23	17.27	20.44	0.229	1299.5
3	2536.4				

ALL PARAMETERS ARE FREE

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	1.50	210.0	202.3	3.63
2	2.50	191.0	195.8	-2.56
3	4.00	173.0	178.4	-3.12
4	6.00	151.0	150.3	0.441
5	8.00	122.0	127.1	-4.18
6	10.00	117.0	111.6	4.60
7	15.00	96.00	97.17	-1.22
8	20.00	99.00	99.92	-0.935
9	25.00	107.0	109.8	-2.68
10	32.00	131.0	129.4	1.16
11	40.00	157.0	155.5	0.940

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	1.00				
P 2	0.00	0.99			
P 3	0.00	-0.01	0.02		
T 1	0.01	0.02	0.01	0.97	
T 2	0.00	-0.02	-0.09	0.03	0.95

Appendix 3c: typical layers of Schulumberger Configurations at Turawa

DATA SET: TRW

CLIENT: TASI'U RILWAN YALWA DATE: 15-08-2011
LOCATION: TURAWA VILLAGE SOUNDING: 03
COUNTY: KARAYE L.G.A..KANO STATE AZIMUTH: N-S
PROJECT: Phd thesis(Phd/scie/08857/08-9 EQUIPMENT: OHMEGA
ELEVATION: 0.00
SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

Schlumberger Configuration

FITTING ERROR: 6.731 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES (Ohm-m^2)
			0.0		
1	48.53	8.75	8.75	0.180	425.0
2	46.48	4.09	12.85	0.0881	190.5
3	114.4	31.70	44.56	0.276	3630.0
4	97.72				

ALL PARAMETERS ARE FREE

No.	SPACING (m)	RHO-A (ohm-m) DATA	RHO-A (ohm-m) SYNTHETIC	DIFFERENCE (percent)
1	1.50	48.00	48.53	-1.11
2	2.50	48.00	48.56	-1.16
3	4.00	49.00	48.66	0.693
4	6.00	51.00	48.95	4.00
5	8.00	51.00	49.50	2.93
6	10.00	53.00	50.31	5.06
7	15.00	50.00	53.49	-6.98
8	20.00	52.00	57.77	-11.11
9	25.00	57.00	62.44	-9.55
10	32.00	73.00	68.69	5.89
11	40.00	84.00	74.80	10.94

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER
P 1 0.97
P 2 0.03 0.18
P 3 0.01 0.20 0.45
P 4 0.00 0.01 0.06 0.01

Appendix 3d: typical layers of Schulumberger Configurations at Karfi

DATA SET: KARFI

CLIENT: TASI'U RILWAN YALWA
LOCATION: KARFI TOWN
COUNTY: KURA L.G.A.,KANO STATE
PROJECT: PHD.THESIS-Phd/scie/08857/08-9
ELEVATION: 0.00
SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

DATE: 30-07-2011
SOUNDING: 01
AZIMUTH: N-S
EQUIPMENT: OHMEGA

Schlumberger Configuration

FITTING ERROR: 7.931 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			0.0		
1	103.7	4.76	4.76	0.0459	493.8
2	10.83	2.23	6.99	0.206	24.22
3	519980.9				

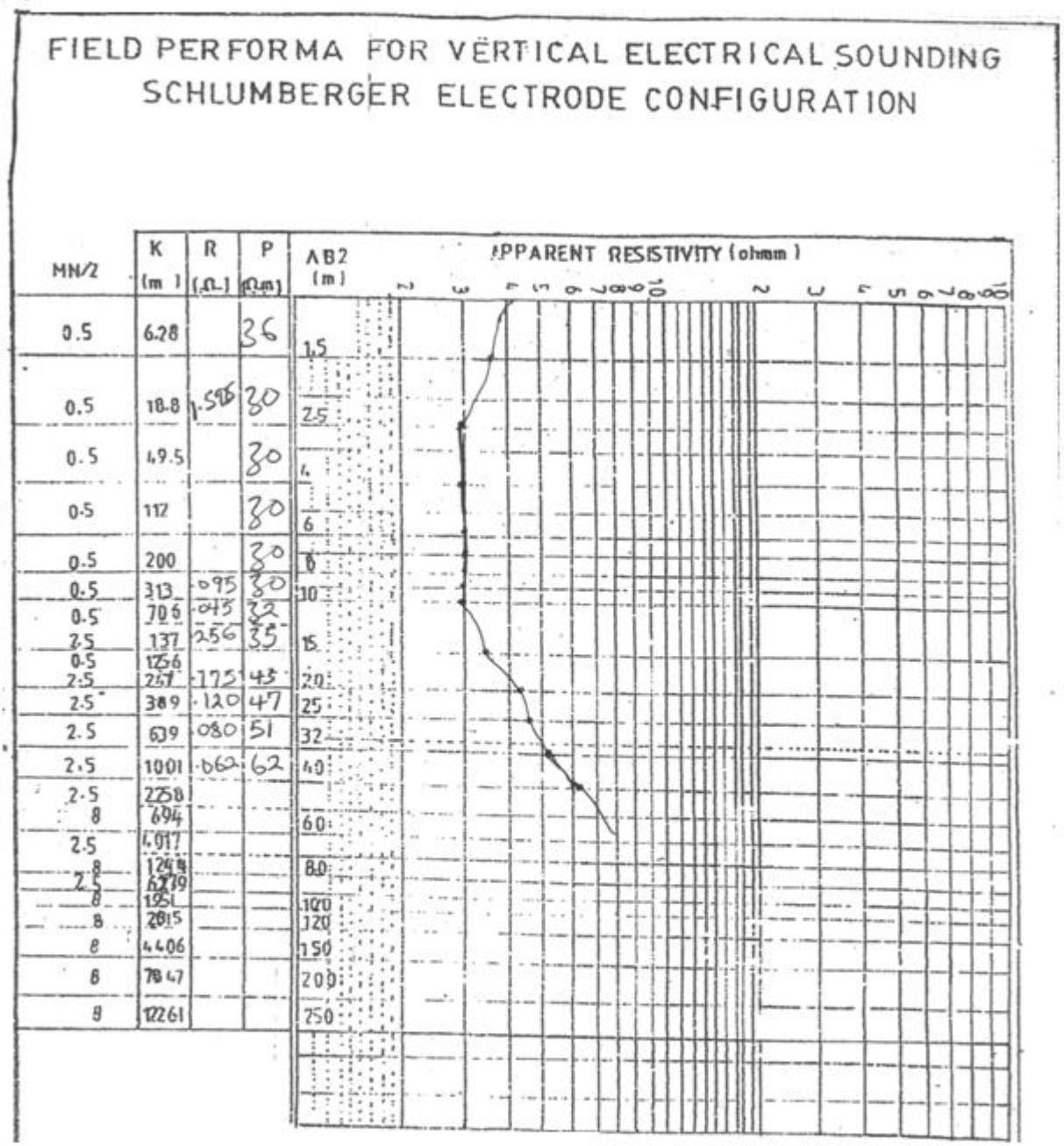
ALL PARAMETERS ARE FREE

No.	SPACING (m)	RHO-A (ohm-m) DATA	RHO-A (ohm-m) SYNTHETIC	DIFFERENCE (percent)
1	1.50	112.0	103.6	7.46
2	2.50	92.00	101.8	-10.65
3	4.00	91.00	96.93	-6.52
4	6.00	90.00	87.26	3.04
5	8.00	88.00	77.48	11.95
6	10.00	67.00	70.54	-5.28
7	15.00	65.00	68.90	-6.00
8	20.00	76.00	81.45	-7.17
9	25.00	102.0	99.14	2.79
10	32.00	125.0	126.1	-0.903
11	40.00	178 .0	157.5	11.48

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	1.00				
P 2	0.00	0.52			
P 3	0.00	0.01	0.05		
T 1	0.00	0.04	0.00	1.00	
T 2	0.00	-0.48	0.01	0.04	0.52

Appendix 4: Log-Log Graphs for recording VES Data at the Field



FIELD PERFORMA FOR VERTICAL ELECTRICAL SOUNDING
SCHLUMBERGER ELECTRODE CONFIGURATION

MN/2	K (m)	R (Ω)	P (Ωm)
0.5	6.28		36
0.5	18.8	1.595	30
0.5	49.5		30
0.5	117		30
0.5	200		30
0.5	313	.095	30
0.5	706	.045	32
2.5	137	.256	35
0.5	1256		
2.5	257	.175	45
2.5	389	.120	47
2.5	639	.080	51
2.5	1001	.062	62
2.5	2258		
8	694		
2.5	4917		
8	1244		
2.5	6279		
8	1951		
8	2815		
8	4406		
8	7847		
8	12261		

AB2 (m)

APPARENT RESISTIVITY (ohmm)

FIELD PERFORMA FOR VERTICAL ELECTRICAL SOUNDING
SCHLUMBERGER ELECTRODE CONFIGURATION

MN/2	K (m)	R (Ω)	P (Ωm)	AB2 (m)
0.5	6.28		135	1.5
0.5	18.8	6.92	130	2.5
0.5	49.5		124	4
0.5	112		117	6
0.5	200		106	8
0.5	313	302	95	10
0.5	706	134	95	
2.5	137	675	92	15
0.5	1256			
2.5	257	349	84	20
2.5	389	232	90	25
2.5	639	145	93	32
2.5	1001	125	125	40
2.5	2258			
8	694			60
2.5	4917			
8	1254			80
2.5	6279			
8	1951			100
8	2815			120
8	4406			150
8	7847			200
8	12261			250

APPARENT RESISTIVITY (ohmm)

Appendix 5: Pumping test report of one of the promising areas (station: Shanono)

CONSTANT DISCHARGE					RECOVERY PERIOD			
TIME (MIN)	TIME SINCE PUMPING BEGIN (MIN)	DISCHERGE RATE/ MIN	WATER LEVEL BELOEW DATUM (M)	DRAW DOWN (M)	TIME (MIN)	THE SINCE PUMPING STOPED (MIN)	WATER LEVEL BELOW DATUM (M)	RESIDUAL DRAW DOWN (M)
12:00am	1	1.36	6.00	0.00	120	0	24.95	8.98
	2	1.21	7.84	1.84	121	1	23.42	7.42
	3	1.02	8.96	2.96	122	2	12.38	6.38
	4	1.00	9.72	3.72	123	3	11.79	5.79
	5	0.98	10.84	4.84	124	4	10.84	4.84
	10	0.94	11.49	5.49	125	5	9.96	3.96
	15	0.92	12.84	6.84	126	6	8.99	2.99
	20	0.84	13.56	7.56	127	7	8.22	2.22
	30	0.75	14.98	8.98	128	8	7.98	1.98

Yield: 0.7 L/S => 74L/MM => 44.4 L/M => 2664 L/H

REMARK: A PRODUCTIVE BOREHOLE WITH STABLE YIELD AND STABLE DYNAMIC, WATER LEVEL IT CAN SUSTAINED MOTORIZED WITHOUT THE EXISTENCE OF GROUNDWATER REPLATION OR DROUGHT IN THE FEATURE.

Source: field Work, 2013