

Application of Remote Sensing and GIS for Groundwater Exploration, Abeokuta Southwestern Nigeria.

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Abstract

The manifestation and dissemination of groundwater in the basement complex rocks of Abeokuta, Ogun State, critically hinge on secondary porosities, through faults and fractures of the underlying lithology. The problem of scarcity of water in Federal University of Agriculture Abeokuta which is in Odeda Local Government area of Abeokuta can be effectively tackled by adopting the combined of Remote Sensing (RS) together with Geographical Information System (GIS) in generating a groundwater potential map of the region. Hence, this study was aimed at verifying the reliability of Geographical Information System (GIS) and Remotely Sensed data in carefully delineating groundwater potential zones in parts of Odeda Local Government Area, Abeokuta. The satellite imageries and topo – sheet was integrated using Arc GIS 10.1 software to generate thematic maps of geology, slope, normalized differential vegetation index (NDVI), land use/ land cover, lineaments density, drainage, and lithology of the study area. The weighting factor were assign to each layer of the thematic maps ranges between 1 - 4 in accordance to their relative importance to availability and distribution of groundwater. The results obtained from the analysis of integration of the data revealed that groundwater potential map the study area are classified into five zones; 9.2%, 44.9%, 33.7%, 10.2%, 1.9% of the study area falls under region of Very high, high, moderate, low and poor potentiality respectively. The study revealed that remote sensing and GIS provided competent tools for mapping auspicious sites for groundwater exploration.

Keyword: Basement, exploration, fracturing, freshwater, groundwater.

Introduction

Water is unique natural resources to man. It is disproportionately distributed across the planet earth. About 97.5% of the world global water is unsuitable for human and livestock consumption restricted to world's oceans (Shahid and Nath, 1999, Shahid *et al.*, 2000). Approximately 69.5% of the remaining 2.59% earth fresh water is coagulated glaciers and while 30.1% and

0.4% of the remaining earth water represent groundwater and atmospheric/surface water respectively (Fetter 2007, Finch, 1990, Egbai 2013). As a result of this, an assessment of earth fresh water resource is actually important for its sustainable management. However, in recent years, rapid increase in population, lack of advancement in exploration techniques and urbanization, the quest for freshwater have increased

exponentially. In order to address this problem, an urgent need for the efficient management and exploration of ground and surface water is required to put up with the interminably rising populace (Zhu and Ireland, 2012). The movement and occurrence of groundwater are majorly controlled by permeability and porosity of the underlying lithology of geology formation of the area (Aller et al., 1987, 1990; Tizo et al., 2009; Edet, 1993, Shahid *et al.*, 1999). Several geo-morphological and geological features affect recharge of groundwater in any geological region are faults and fracture. Areas underlain by the basement complex rocks are generally characterized by low groundwater prospect (Louis and Gambas, 2002). In a typical hardrock setting, the geological stratification normally encountered consists of hardrock basement overlain by variably thick unconsolidated materials referred to as the overburden or the regolith.

The overburden is further stratified into the vadose and phreatic zones, separated by the water table (Fetter, 1980; Hiscock, 2005). Fresh igneous and metamorphic bedrock which constitute the basement complex, occur at varying depths and mostly at low degree of decomposition, thus suggesting low porosity and permeability. This informed why groundwater prospects of aquifers within bedrocks are mostly rated low, or of minor hydro-geologic importance. Consequently, the major focus for groundwater development in hardrock terrain is the aquifer within the regolith material (Clark, 1985; Acworth, 1987; Das *et al.*, 2007).

However, a borehole anticipated to provide long term good yield is one which penetrates fairly thick overburden and additionally intersects available fracture(s) within the underlying bedrock (Carruthers and Smith, 1992).

Groundwater is majorly recharged by percolation of water through pores, faults and fractures of the underlying lithology (Gogoi, 2013; Nejad, 2009). The basement terrain of Abeokuta which falls within southwestern Basement Complex of Nigeria and the accessibility of groundwater are seasonal. Residents of Northern part Abeokuta, south-western Nigeria, rely on groundwater as a major source of water for domestic, livestock, farming and commercial uses. However, boreholes in the area experience low success yield at the peak of dry season. During the dry season, the quantity of water exploited from wells and bore-holes range from very little to nothing at times. Unfortunately, this remains the only source of water as most streams and rivers dry up. The culprit in this concern is the discontinuous nature of the basement aquifer system which limits the distribution and movement of groundwater. The prospect of groundwater in a particular region is affected by many factors such as drainage soil type, slope, recharge zones and lithology of the area. The privation of wide understanding on the distribution and occurrence of groundwater in the study area has led to the construction of boreholes and wells in unsuitable zones. Therefore, in order to effectively tackle this problem, extensive knowledge on the formation, storage and distribution of

groundwater must be acquired. The formation of groundwater occurs in two different zones namely; unsaturated and saturated zones. In crystalline basement complex area such as the area under consideration, the occurrence and movement of groundwater is determined by an extent of fracturing and weathering of the rocks (Oloruniwo and Olorunfemi 1987, Todd, 2004). Fracturing of rocks surfaces can be express lineaments which can be extracted from imagery of remotely sensed images. Consequently, this study is aimed to verify the reliability of integration of Remote Sensing (RS) and Geographical Information System GIS technologies mapping groundwater potential zones and the output will provide scientific facts to guide the siting of borehole and hand-dug well for active exploitation of groundwater in area under consideration.

Description of the Study Area

The study area covers part of Odeda and its environs. It is situated in the southwestern region of Nigeria. The study area covers an area of approximately 20km from the Abeokuta which is the state capital. It is bounded by latitude $7^{\circ}13'N$ to $7^{\circ}15'N$ and longitude $3^{\circ}24'E$ to $3^{\circ}26'E$ and its terrain varies with altitude. Odeda has a population of 109,449 (according to the 2006 population census figure) as shown in Figure 1.

Topography and Climatic Condition of the Study Area

Abeokuta is characterized by an undulating topography with elevation value ranging

from 100-400m above sea level (Akanni, 1992, Oloruntola and Adeyemi, 2014). The amount of rainfall varies between 750mm-1000mm in the rainy season and 250mm-500mm during the dry season (Akanni, 1992). The mean monthly temperature ranges between $25.7^{\circ}C$ in July to $30.2^{\circ}C$ in February with the mean annual temperature of $26.6^{\circ}C$. The study area falls within the basement complex formation of south western Nigeria.

Geology of the Study Area

The basement complex rock comprises of folded gneiss, schist quartzite, older granite and amphibolite/mica-schist (Jones and Hockes, 1964). Abeokuta belongs to the stable place which was not subjected to intense tectonics in the past (Ufoegbune et al., 2009). The northern side of Abeokuta is characterized by pegmatitic uncertain by granite while the southern part enters the transition zone with the sedimentary formation of the eastern Dahomey Basin as shown in Figure 2.

Hydrogeology of the study Area

The populaces in basement area depend mostly on surface water, which is supplied by the water corporations having their source from the River Ogun. This source of surface water can never meet the demand of populace due to logistic and effect of seasonal variation. This type of water source is major source of water intake in Abeokuta has a very low yield mainly for the duration of the dry season when the rate of evaporation is high precipitation is always lower than the average.

Generally, nearly all sachet water industries depend on the water from the state water corporations; this has amplified the problem of water shortage for this reason, the demand for the water turns into greater than the supply especially during dry season. Furthermore, people also use hand dug wells, on the other hand this stance difficult during dry season because the obligatory depth would not be gotten due to the terrain, because of these reasons, groundwater should have been a substitute source of water. But the problem about pinpointing high productive aquifers in several parts of Abeokuta is a great task because Abeokuta lies within the Basement Complex rocks of Southwestern Nigeria. These rocks are of Precambrian age to early Palaeozoic age and prolong from the north-eastern part of the Ogun state (which Abeokuta belongs) on the trot southwest ward and dipping towards the coast (Ako, 1979). The different rock has various hydrogeologic characteristics. The

underground faulting system is minimal and this has contributed to the problem of underground water occurrence in this area. The southern part of Abeokuta goes into the transition zone with the sedimentary basin, characterized by impartially satisfactory hydro-geological history. Also, western part of Abeokuta is regarded as by granitic gneiss which is fewer porous (Key, 1992). Thus, this area is greatly problematic and it is predisposed to low-slung yield groundwater supply. Abeokuta terrain was characterized to have two kinds of landforms.; knolls of granite, other rocks of the basement complex and nearly flat topography sparsely distributed low hills. Abeokuta is sapped by rivers, Ogun and Oyan which are the two major rivers and many small streams. The study area also has two climatic conditions mainly; the rainy season long-lasting for between seven and eight months between April and October with an interruption in August, and the dry season; running through November till February.

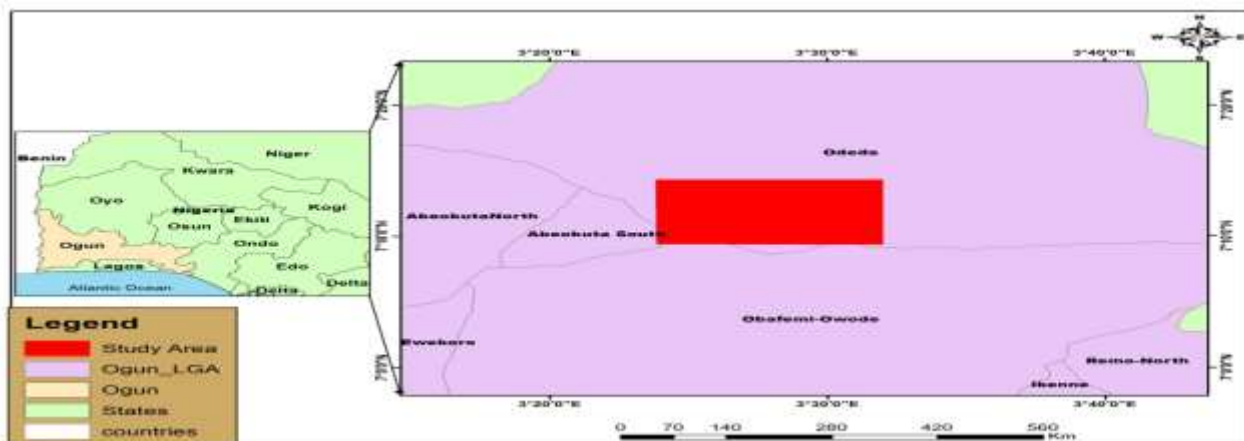


Figure 1: Location Map of the Study Area

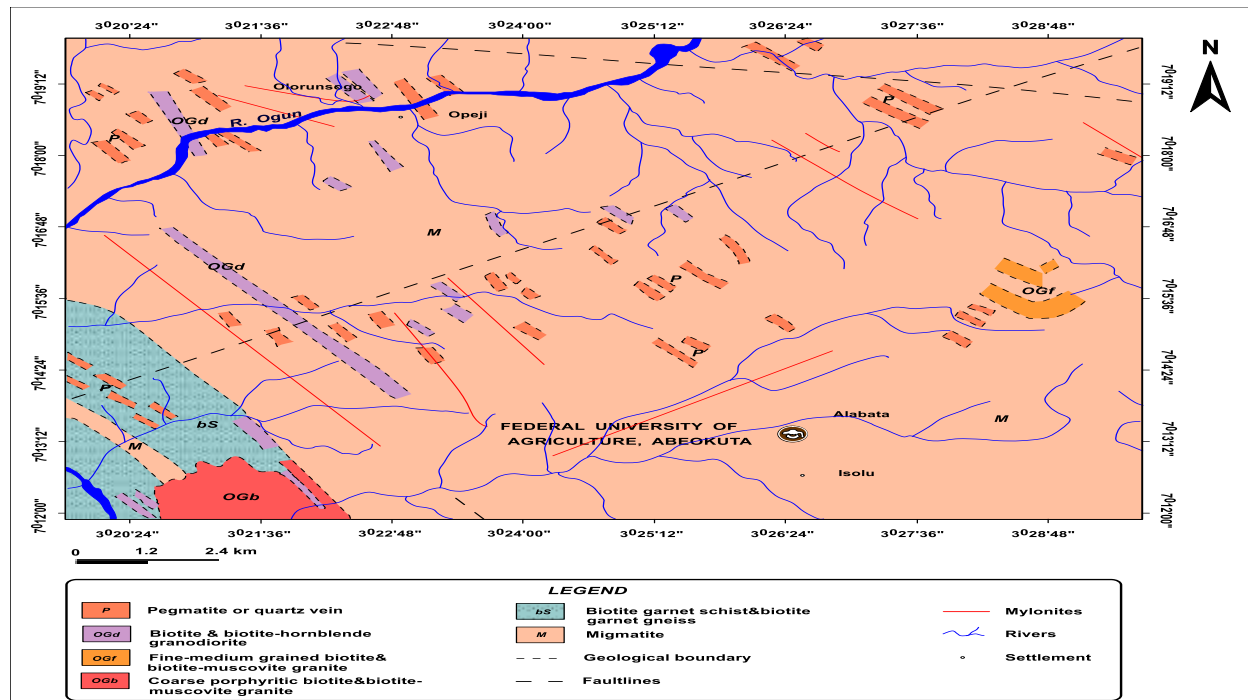


Figure 2: Geological Map of Abeokuta Showing the Study Area

Materials and Methods

In evaluating the study area, the groundwater prospective zone mapping is carried out by integrating satellite derived multi thematic maps using GIS technique and Digital Image Processing (DIP) of remote sensing data to identify the spectral class where layers of lithology, drainage patterns and lineaments were used to derive the most promising sites for groundwater exploration (Ibrahim and Ahmed, 2016, Waters et al., 1990, Goval et al., 2003). The GIS approach is based on the hypothesis that lineaments and drainage patterns important factors for evaluating the potential concentration of water in the fracture zone aquifer, while the second approach was proposed as a rapid method with minimum inputs for groundwater exploration.

Toposheets and high resolution satellite images acquired from Nigeria Geological

Survey Agency and Google Earth respectively which were used for preparation of thematic maps. Seasonal Landsat Eight (8) images were used to prepare the thematic map as shown in the Table 1. All data used in this study were geo-referenced and projected to Geographic Coordinate System-World Geodetic System 1984 (GCS WGS) and Universal Transverse Mercator (UTM) zone 32 North for the easy handling in a GIS environment (Ibrahim and Ahmed, 2016, Jenson and Domingue, 1988). Satellites data were enhanced and processed for the better visualization. The toposheets were used as allusion maps for the preparation of thematic maps. Goggle Earth was used to update the individual maps from the current existing images in Google Earth over and done with the colour pattern and their look in the image. Also, weight was assigned to each thematic map

according to their characteristics and interrelationships with groundwater as presented in Table 2.

Table 1: Data Acquisition

Sensor	Date of Acquisition	Spatial Resolution	Pathway	Source
Land sat TM	Dec 1984	30	191/055	Global land cover
Land sat ETM+	08 Nov 2000	30	191/055	United States Geological survey
Land sat OLI	19 Dec 2015	30	191/055	Global land cover facilities.
STRM (DEM)		30		Unites States Geological Survey
Soil map		1:7,945,418		FAO/ UNESCO

Table 2: Weighting of Each Thematic Layer

No	Parameter	Weight	Rating	Description	Remarks
1	Slope	4	4	Nearly flat	Good
			3	Gentle	Moderate
			2	Steep	Poor
2	Drainage density	3	4	Low	Poor
			3	Moderate	Fair
			1	High	Good
3	Land use/Land cover	1	1	Building	
			3	Outcrops	
			3	Vegetation	
			4	Wetlands	
4	Lineament density	5	4	Present	This is rather vague
			1	Absent	
5	Vegetation index	2	4	Dense	Good
			3	Moderate	Moderate
			2	Sparce	Poor
6	Lithology	5	1	Gneiss/Granite	Very poor
			2	Pink&Gray Granite	Very Poor – Poor
			3	Quartzite	Poor – Moderate
			4	Charnockitte	Good

Slope Map

Slope is an elevated geological formation of the earth's surface, and it is one of the most important features for the classification of groundwater potential zones. The higher the degree of slope, the higher the rate of surface runoff and erosion leading to a decrease in the recharge potential, whereas, plain slope or gently slope are favorable zones for groundwater due to the increase in the recharge rate, and low surface runoff (Du Wencai and Ye Deliao, 1993, Anon, 1990). The slope map was generated by importing processed Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) into Arc GIS 10.1 software using the spatial analysis tools. The generated slope map was then reclassified using its layers into appropriate class for the formation of groundwater prospect zones.

Lithology Map

The lithology map of the study area was acquired from the archive of Nigeria Geological Survey Agency (NGSA). The acquired map was extracted. Thereafter extracted map was geo-referenced and digitized using Arc GIS 10.1 software. The study area is covered by Abeokuta formation, coarse porphyritic biotite, biotite muscovite granite and prophyroblastic gneiss.

Lineament Map

The lineament map was generated from Land sat 8 and was expressed in lineament per unit area using the Arc GIS line density tool. In order to generate the lineament

density of the area under consideration, the generated lineament from Land Sat 8 along with lineaments gotten from Normalized Differential Vegetation Index (NDVI) and Digital Elevation Model (DEM) were overlaid, after which appropriate weightings were allocated to each layer of both the lithology and the lineament map of the study area.

Land Use/Land Cover Map

Land use /land cover map were generated by using high resolution imagery of consecutive three (3) years which are 1984, 2000 and 2015 to ascertain several changes that have occurred in the area under consideration. Four features were taken into consideration in analysis of land use and land cover map; building, wetlands (recharge zones), vegetation and outcrop. The thematic map was later reclassified and weighting of each training samples was based on their uses and how they influence the movement and occurrence of groundwater. Also, kind of land use provides necessary information on soil moisture, infiltration, surface water and groundwater. Regions having high groundwater potentiality encourage settlement, urbanization and agriculture while those having low potentiality discourage settlement, urbanization and agriculture.

Soil Map

Soil type of any expanse of area is an essential feature to be considered in determining the rate of infiltration and aquifer depth of that specific region. The prerequisite in determining the irrigation

system is the rate of infiltration in given area. Therefore, for this study, soil map of the study area was cropped from soil unit FAO/UNESCO/IS-RIC map of Nigeria. The study area is covered majorly by two soil association Egbeda and Ondo, and each having schist and fine grained Biotite gneisses, medium grained granites and gneisses as parent rocks.

Normalized Differential Vegetation Index Map

Normalized Differential Vegetation Index (NDVI) displays pixels (areas) with vegetation which was generated by using Band 4 that is Red (RED) and Band 5 that is Near Infrared (NIR) band of Land sat 8 given as Equation 1 using Arc GIS model builder. The result which ranges from -1 to +1 were adopted to reclassify various vegetation densities in the study area.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad \dots 1$$

Drainage Density Map

Drainage density is a measure of the length of stream channel per unit area of the drainage watershed and also reflects subsurface formation as well as characteristics of the surface (Magesh *et al.*, 2012, Krishnamurthy *et al.*, 1996, Batelaan *et al.*, 1993). Low drainage density leads to decreases in rate of surface runoff subsequently give rise to a high recharge potential while high drainage density is promising for surface runoff thereby, resulting in low recharge potential. This clearly implies that drainage density is the reciprocal of permeability. Drainage

map of the study area was generated by using the spatial analyst tool box in ArcGIS10.1 platform. Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) was processed to generate flow accumulation, flow direction, aspect, and stream order. The drainage density map of the study area was generated from stream network using focal statistics of the spatial analyst tool box in Arc GIS 10.1. Finally, the drainage density was reclassified and ranked according to its influence on groundwater.

Subsequently, all the above generated thematic maps were converted to Raster format and then assigned suitable weights in accordance to their relation to the occurrence and distribution of groundwater. All weighted thematic maps were integrated and processed in Arc GIS 10.1 to delineate the potential zones in the study area. The weighting adopted for this work was graphically presented in Figure 10.

Weighting

The various thematic maps used were assigned with a weighting value ranges from 1-4, depending on how they influence the movement, occurrence and distribution of groundwater. The weighting factor 1 represents very poor, 2 represents poor, 3 implies good, and lastly 4 denotes very good groundwater potentiality. The weighting value employed in this work was based on the respective importance of the various thematic maps to the occurrence and movement of groundwater following the approach of some selected research works done by (Mukherjee *et al.*, 2012;

Singh *et al.*, 2013; Saraf and Choudhary, 1998).

Data Integration

The seven thematic maps; Slope, Soil type, Lineament, Lithology, Drainage density, Normalized Differential Vegetation Index, Land Use/Land Cover were integrated using Arc GIS 10.1 software to generate groundwater potential index for the area under consideration. Hence, a complex groundwater potential index (GWPI) for the study area was produced using the Fuzzy overlay tool in Arc GIS software where the final potential map showing the prospect zones of the study area was acquired.

Result and Discussion

After the integration of seven thematic maps and extracted relevant information in the course of this study, it was discovered

that several factors such as slope, drainage, soil, lithology and lineament affects the movement, distribution, storage and availability of groundwater in the study area.

Slope Map

From the analysis of the slope, the slope degree ranges from 0.0 to 10.7579298. The study area was divided into nine slope classes, with the areas having 0 – 1.0125-degree slope classified as very good because of its nearly flat terrain, which promotes relatively high infiltration because slope of any terrain is one of the factors allowing the infiltration of groundwater into subsurface or in other words groundwater recharge. The areas having a slope >7.299 degrees were considered as poor for groundwater storage due to their low infiltration and high surface runoff features as shown in Figure 3 (the thematic slope map of the study area).

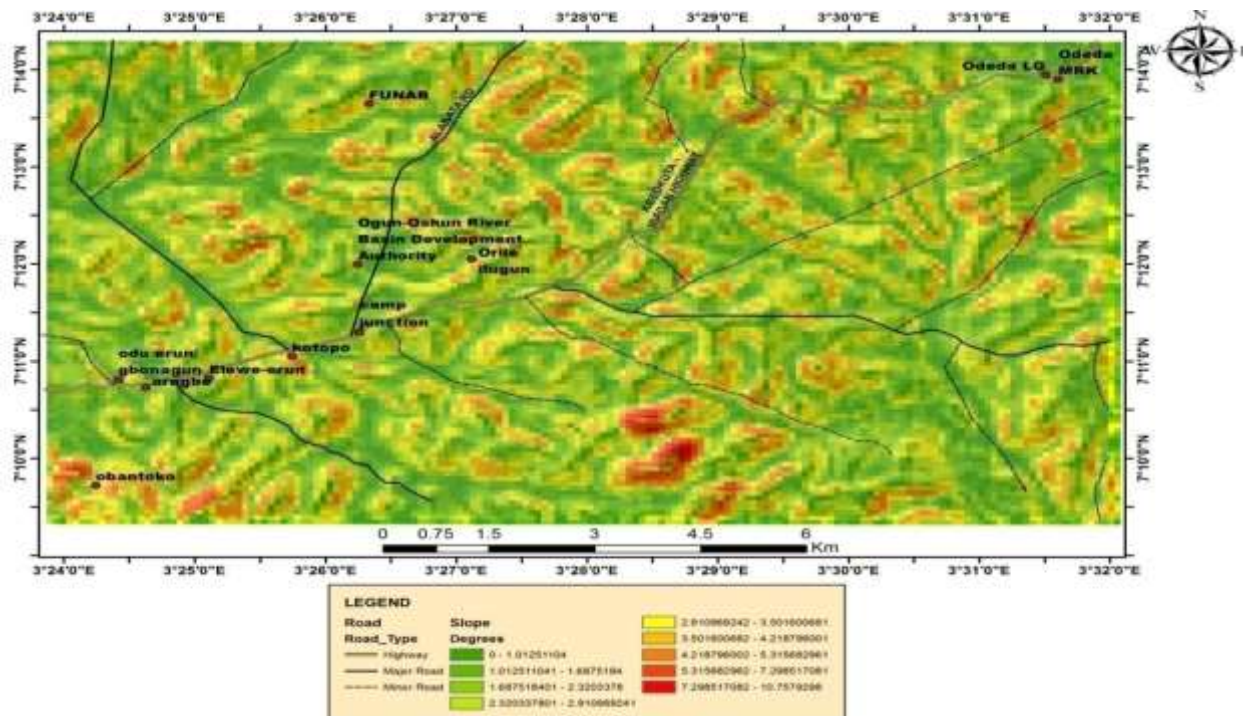


Figure 3: Slope of the study area

Drainage Density Map

The drainage density of the study area is categorized into five classes: From the analysis, areas with drainage density ranging from 1- 41km/km² are considered areas of good groundwater potentiality because of their low surface runoff and high rate of infiltration. Moderate

groundwater potentialities are assigned to areas with drainage density ranging from 41 to 62 km/km². Areas having drainage density greater than or equal to 66 km/km² were considered zones of low groundwater potentiality because of their high surface runoff and low infiltration. The thematic map of drainage density is shown in Figure 4.

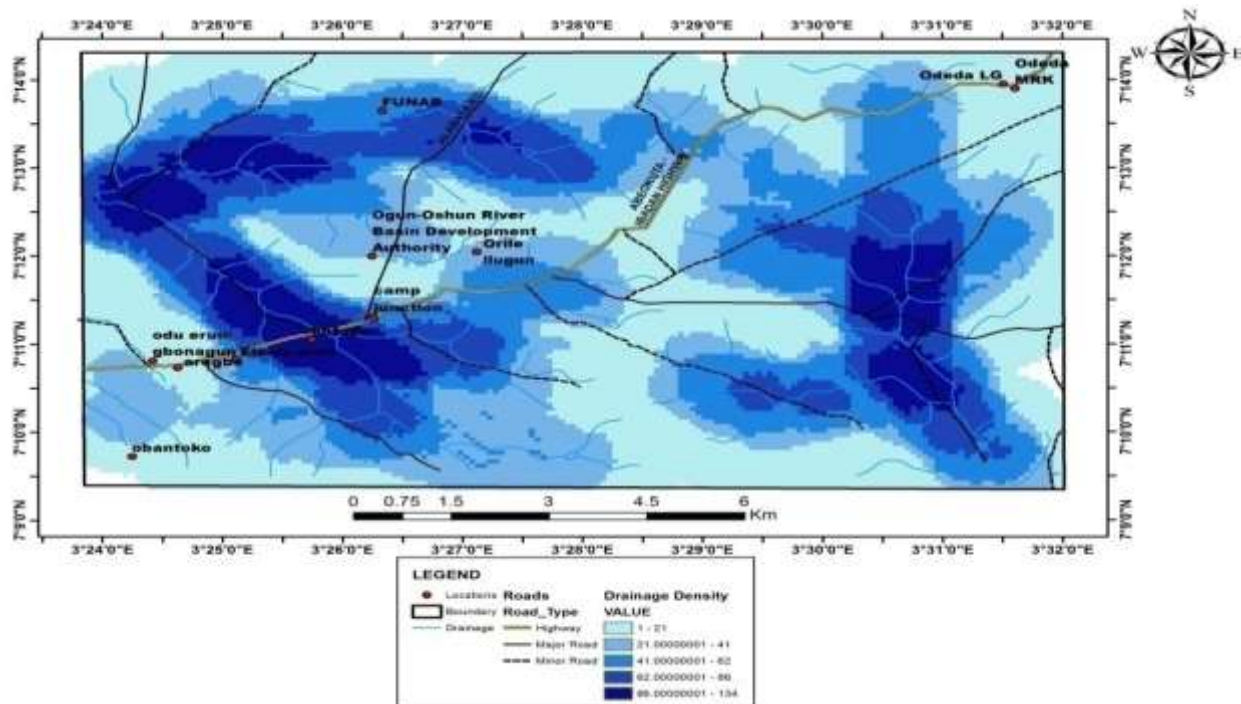


Figure 4: Drainage density of the study area.

Lineament Density Map

Lineaments are underlying geological features such as faults, pores and fractures. They are responsible for secondary porosity and permeability. The lineament of an area describes the groundwater zones present there, owing to the fact that they serve as openings for aquifers. The lineament density of the study area ranges from 0 km⁻¹ to 7.9548

km⁻¹ with the lineament being well distributed the analysis of lineament, have revealed that areas having lineament are good potential zones while areas without it denoted poor potential zone as shown in Figure 5. The rose diagram (Figure 6) of the faults and fractures of the lineament map shows the length and direction of the lineaments in the study area under consideration.

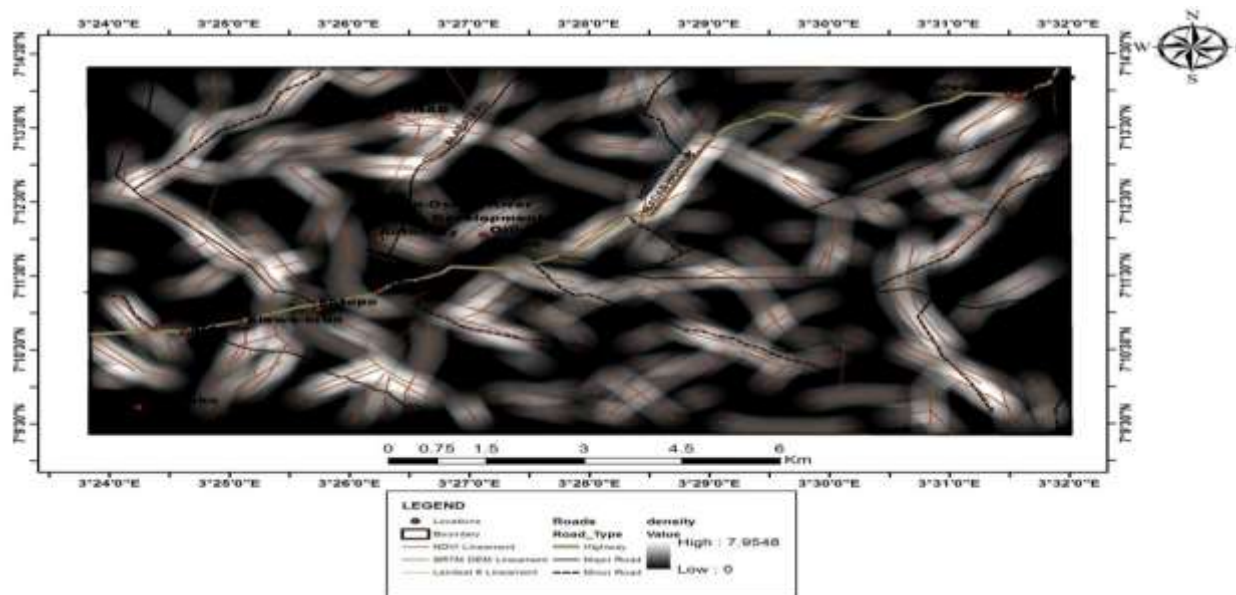


Figure 5: Lineament density of the study area

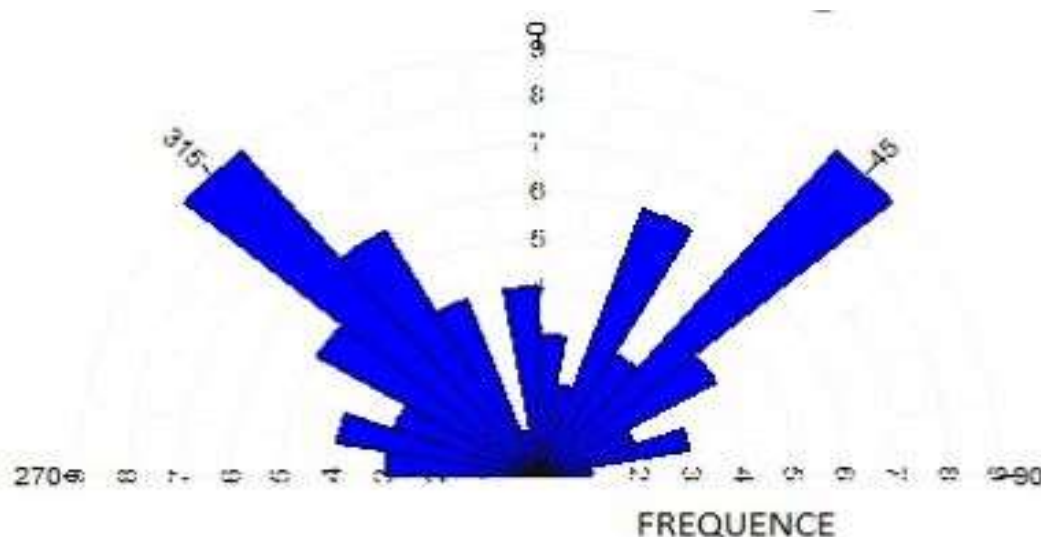


Figure 6: Rose diagram of lineaments in the study area.

Land Use/ Land Cover Map

Land use/land cover is an important feature in mapping groundwater, its feature influences groundwater in terms of its distribution, quality and quantity. Four training samples were obtained for the land

use/ land cover map; bare soil, settlement, vegetation and wetlands. The analysis of land use/land cover map of the year 1984, 2000 and 2015, (Figures 7, 8 and 9) have revealed the various changes that have affected the training samples over the period of 31 years. Figures 10, reveals the

changes in the training samples as presented in Figure 10. The various changes in the training samples of the three consecutive years were determined. It was observed that there is decrease in vegetation and an increase in bare soil from the year 1984 to 2000 which could be as a result of various human activities such as building and deforestation. People tend to settle in areas that favorable zones. The percentage increase in wetland training samples from 0.12% in 1984 to 3.4% in 2015, is as a result of deforestation and

settlements. In 1984 the percentage of vegetation in the study area was 63.5% leading to most of the water coming from the recharge zones to be used for photosynthesis. This has made the wetlands to cover as small as 0.12%. In 2015, the percentage of area covered by wetlands have increased to 3.4% due to the fact that various human activities has been encouraged and the movement of water to different parts of the study area is now encouraged.

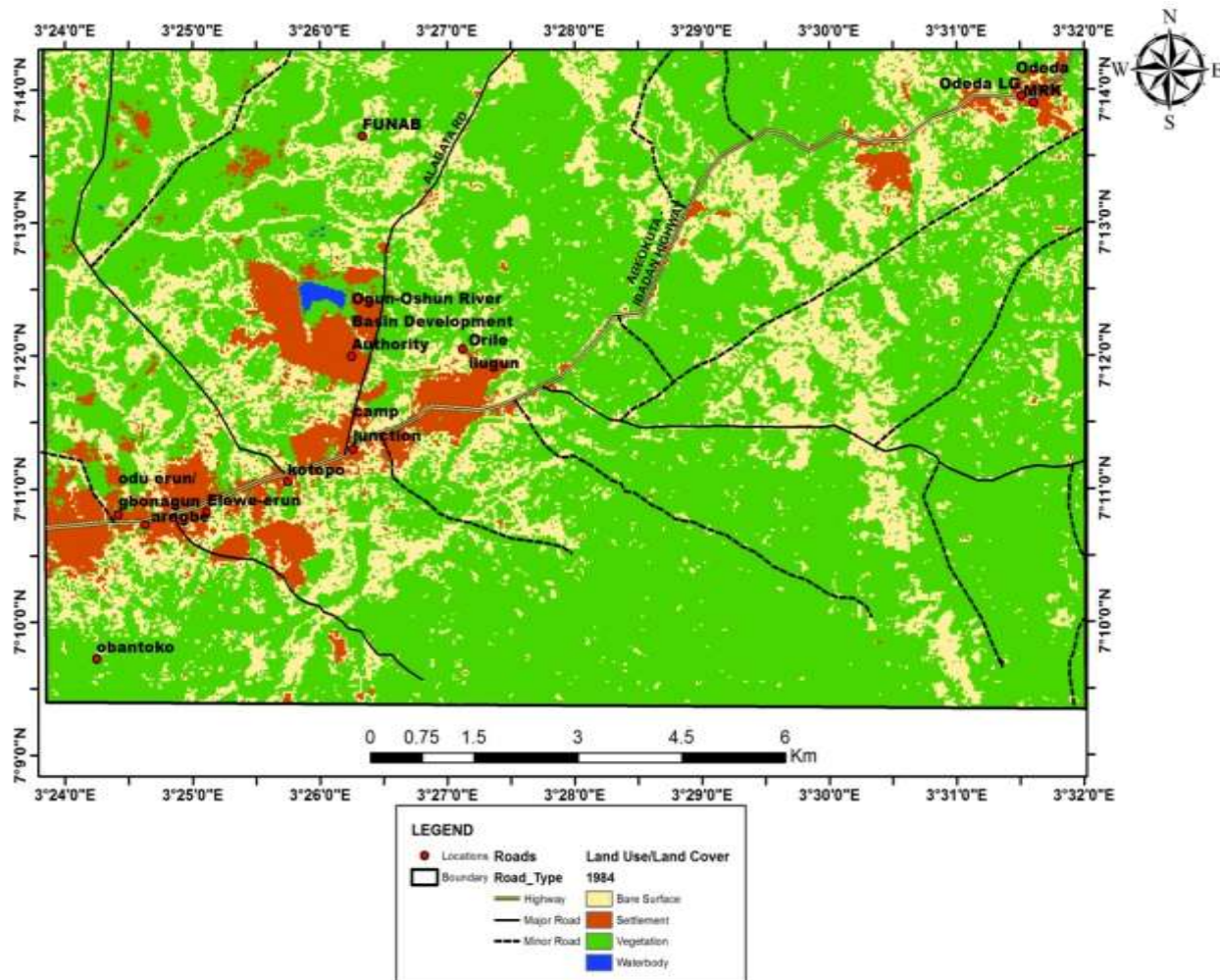


Figure 7: Land use/Land cover for the year 1984

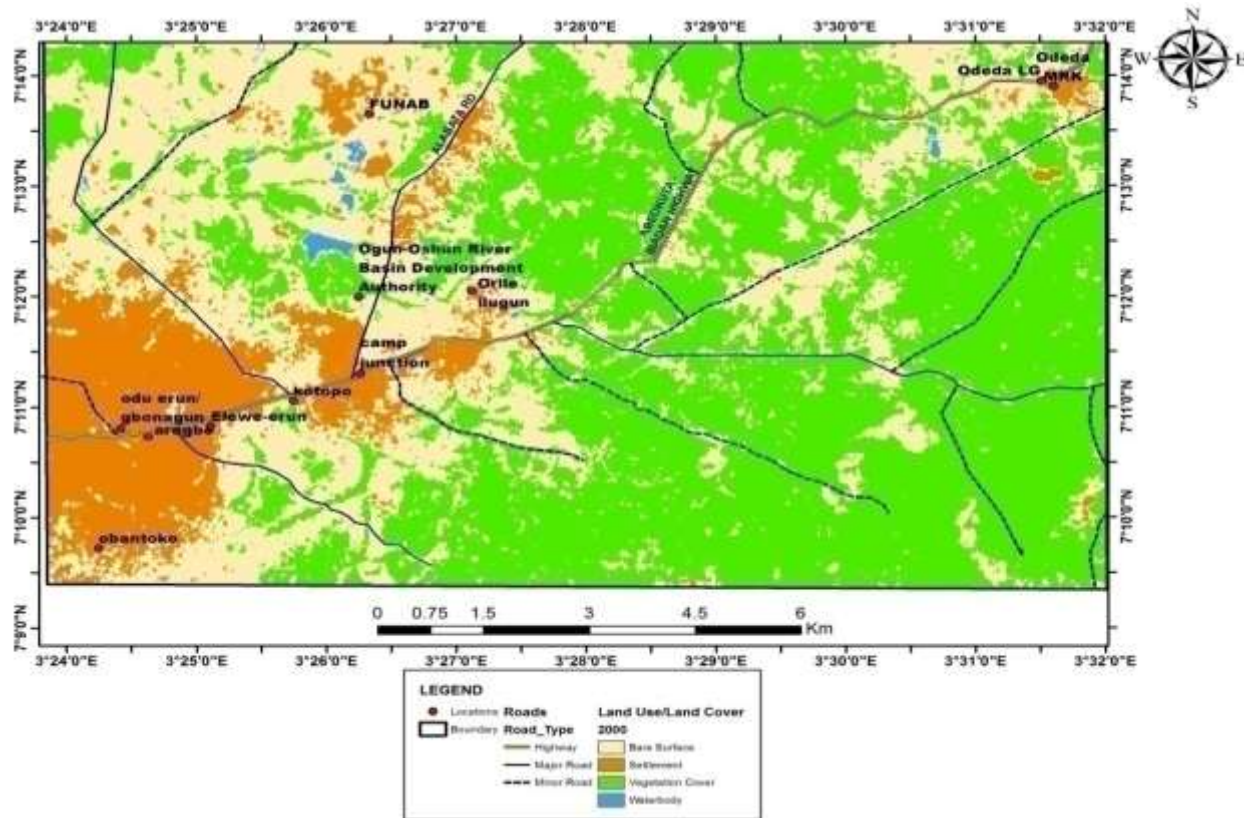


Figure 8: Land use/Land cover for the year 2000

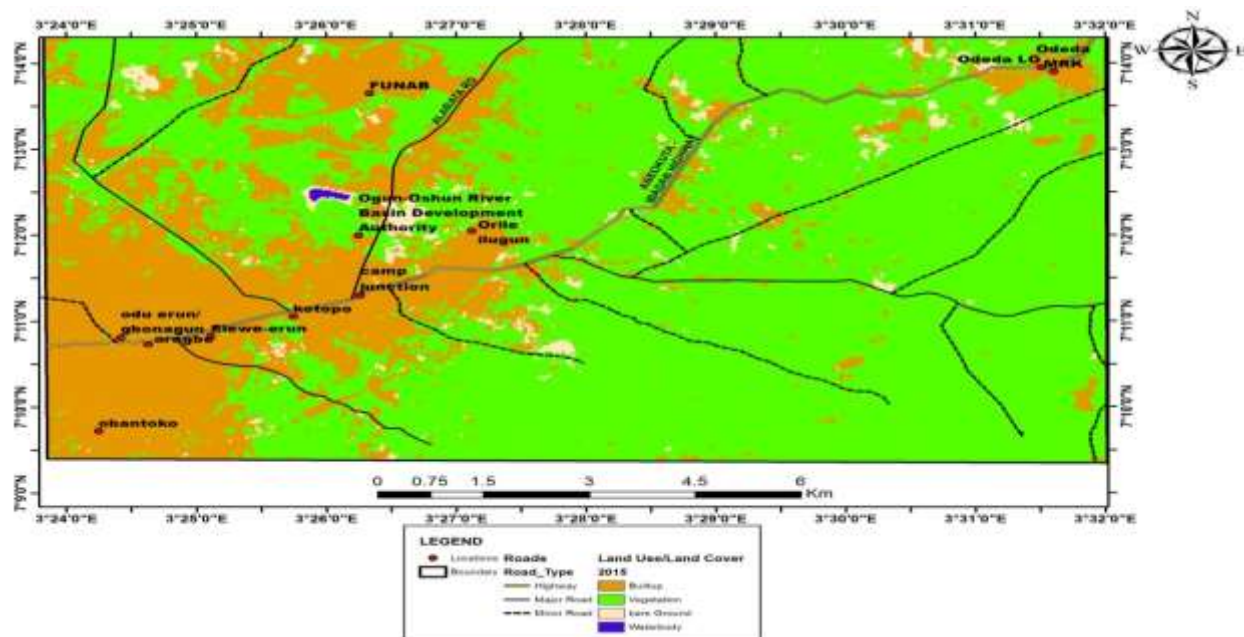


Figure 9: Land use/Land cover for the year 2015.

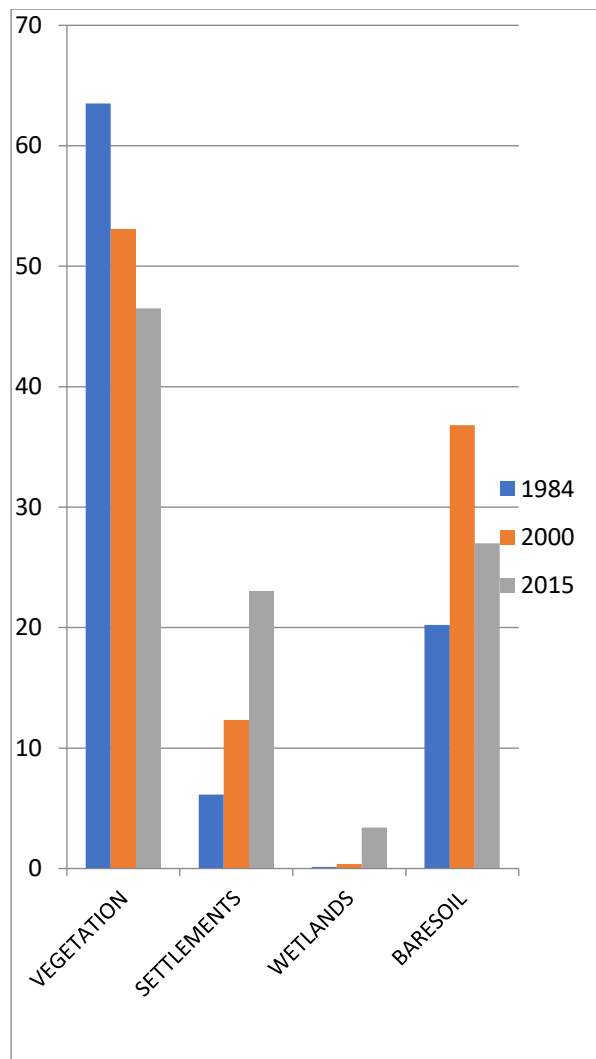


Figure 10: Chart showing the various changes in land use /land cover of the study area from 1984, 2000 to 2015.

Soil Map

Soil is an important parameter for modelling groundwater potential zones. Soil type and texture of a region determines the rate of infiltration and surface runoff. Regions covered with highly porous soil sample denote high groundwater potentiality while the reverse is for region of low groundwater potentiality (Rajasekhar et al., 2014). The analysis of soil of the study area reveals that the study area is majorly covered with well-drained soil of ferruginous soil associated with fine, medium granite and gneiss as their parent rock (Figure 11). These associations are categorized as soils for groundwater recharge and discharge due to their porous nature.

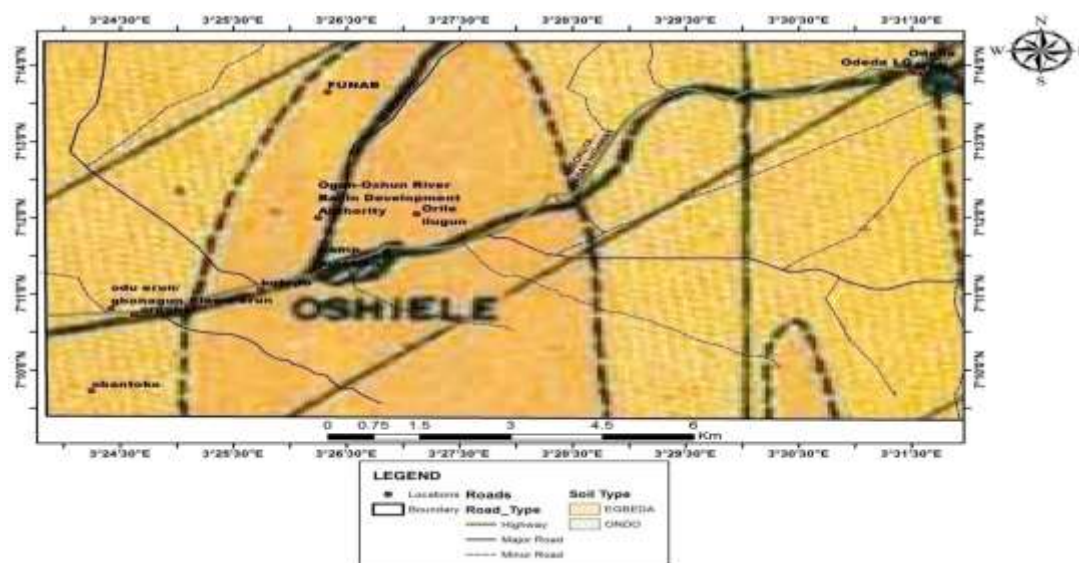


Figure 11: Soil map of the study area.

Normalized Differential Vegetation Index Map

Normalized differential vegetation index is the reflection of vegetation in the red and near infrared region. Figure 12 reveals the greenness and density of the vegetation. The type of vegetation cover in an area shows the potentiality of such areas. Densely vegetated areas are usually characterized with high groundwater

potentiality and vice versa. The Normalized Differential Vegetation Index values of the study area ranges from 0.0582 to 0.3282. The analysis revealed that areas having a low Normalized Differential Vegetation Index value of 0.0582 are bare soil, watersheds and rock outcrops. Shrubs, grasslands, annual and perennial vegetation have a high Normalized Differential Vegetation Index value of 0.3282.

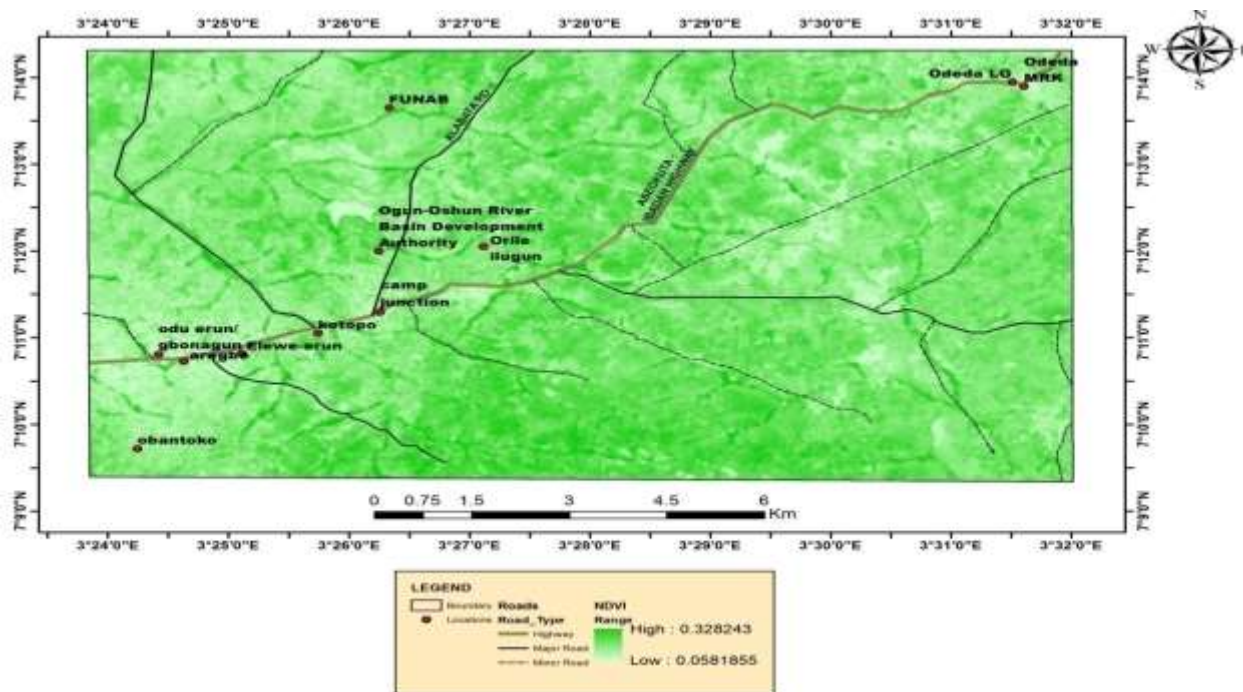


Figure 12: Normalized Differential Vegetation Index of the study area

Lithology

The underlying lithology of the study revealed that the study area was dominated with porphyroblastic gneiss with an intrusion of coarse porphyritic biotite and biotite Muscovites granite with clear disposition of different zone with distinct

anomaly ranges as shown in Figure 13. Figure 13 shows that the dominated region is related to basement structure (weathered layer) having sufficient faults and fractures are denoted as having good groundwater potentiality while poor fractured lithology is categorized as regions of low groundwater potentiality.

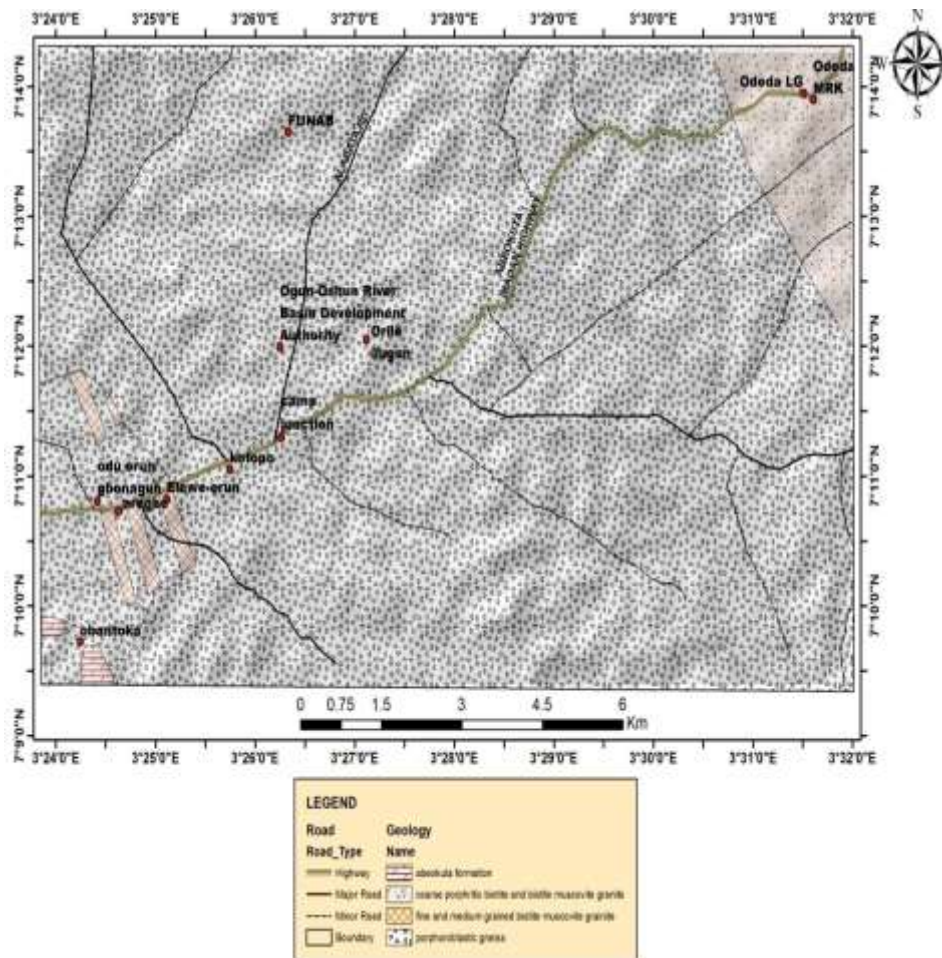


Figure 13: Lithology of the study area

Groundwater Potential Zones

In this study, groundwater potential zones of the study area were delineated using the integration of different thematic layer by Fuzzy Logic approach. The obtained potential zones from the Fuzzy Logic approach were used for the classification of the study as; Poor, Low, Moderate, High and Very High. The final potential map is

graphically and statistically represented in Figures 14 and 15 respectively.

From the analysis, it was discovered that about 1.9%, 10.2%, 33.7%, 44.90% and 9.2% of the study area are categorized as regions having poor, low, moderate, high and very high groundwater potentiality respectively.

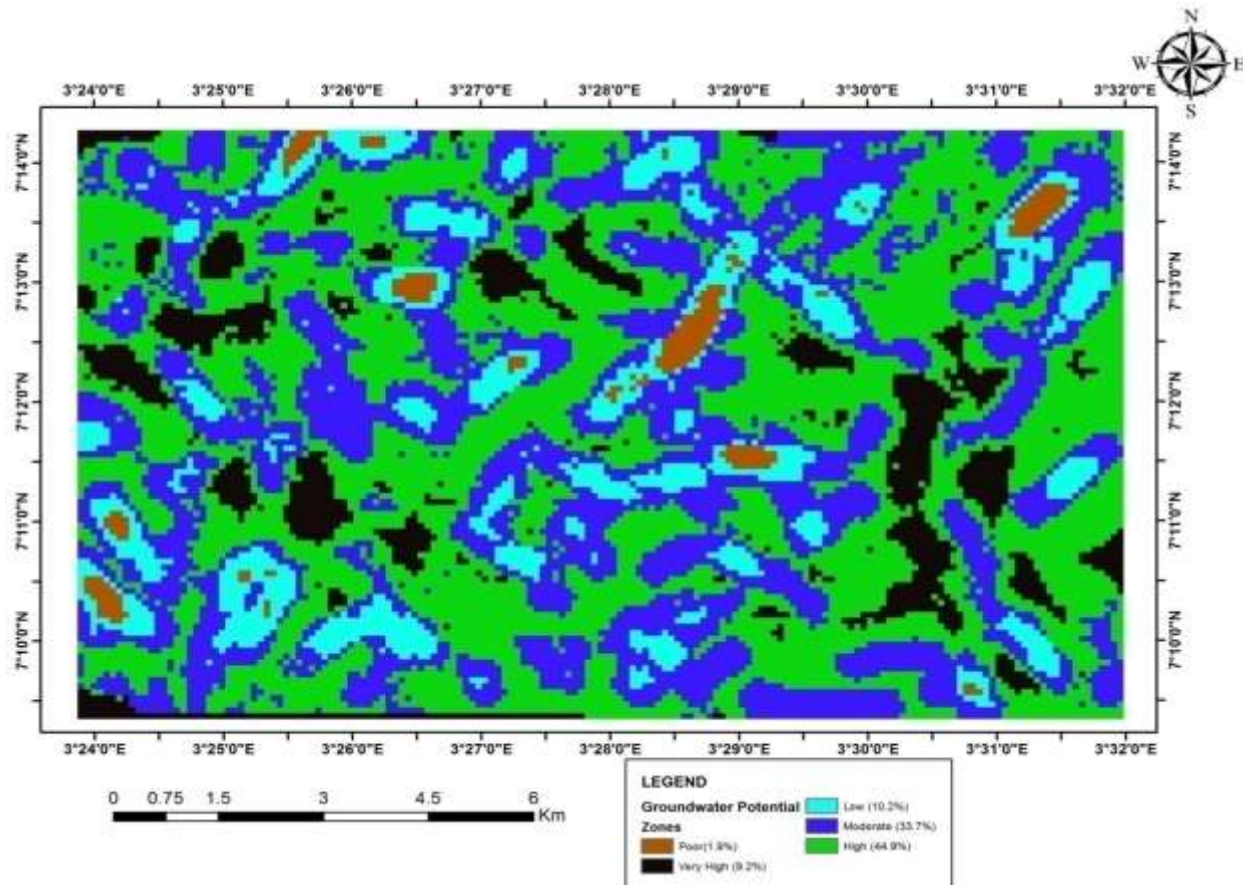


Figure 14: Groundwater Potential Zones Map

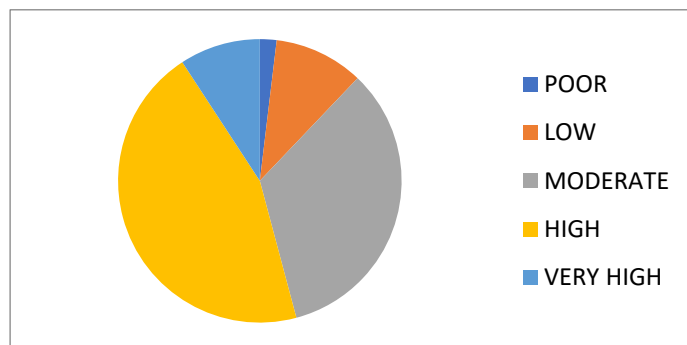


Figure 15: Percentage of groundwater potential zones (GWP).

Conclusion

Groundwater mapping is one of the main tools for efficient and controlled development of groundwater resources. These maps are used by decision makers to allocate, develop and manage groundwater within a national water policy.

Integrated RS and GIS techniques prove to be rather satisfactory options for groundwater mapping in Odeda. A remote Sensing (RS) and GIS technique are found efficient to minimize time, labour and money and thereby enables quick decision making for sustainable water resources

management. Satellite imageries, topographic maps and conventional data were used to prepare the thematic layers of drainage density, lithology, lineament density, land use/land cover, soil type, water bodies density, normalized difference vegetation index (NDVI), slope. The various thematic layers are assigned proper weightage and then integrated in the GIS environment to prepare the groundwater potential zone map of the study area.

The use of Remote Sensing (RS) and Geographical Information System (GIS) in delineating groundwater potential zones in parts of Odeda within Abeokuta, Ogun State, have revealed that about 1.9%, 10.2%, 33.7%, 44.90% and 9.2% of the study area are categorized as regions having poor, low, moderate, high and very high groundwater potentiality respectively. It can also be concluded that, parts of the study area having well fractured lithology were considered areas with little influence due to the presence of high drainage and slope. However, areas having low drainage density and slope resulted in good groundwater potentially owing to the fact that the lithology of the study area is well fractured. This research work would be used as a guide for effective conservation, exploration and exploitation of groundwater in the study area.

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