

Full Length Research Paper

Mapping of lineaments for groundwater targeting in the basement complex region of Ondo State, Nigeria, using remote sensing and geographic information system (GIS) techniques

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Sustainable groundwater supplies in the terrain underlying by crystalline basement rocks require lineament analyses for proper sitting of boreholes. This study was carried out to illustrate the application and importance of Remote Sensing and Geographic Information System (GIS) techniques for efficient groundwater resource exploration and management. The study demonstrates the use of LANDSAT 7 ETM+ imagery, ASTER digital elevations models (DEMs) and geological maps for mapping and analyses of lineaments in the Basement Complex region of Ondo State, Nigeria. Digital image processing techniques involving linear / edge enhancements and directional filtering were applied on the image to enhance the edges of the linear features using ENVI 4.7. The enhanced image, normalized difference vegetation index (NDVI) image and hill shaded relief image (processed ASTER DEM) were visually interpreted through GIS overlay operations for lineaments extraction through on-screen digitizing using ArcGIS 9.3. The extracted lineaments were statistically analyzed to determine their lengths, densities and intersections. The results obtained were used to generate lineament density, lineament intersection map and rose diagram. The lineament / fracture analyses indicated that the area has numerous long and short fractures whose structural trends are mainly in the north-south and east-west directions. The cross-cutting lineaments are relatively high in areas around the central, north-eastern and south-western parts of the study area, and relatively low in the other areas. The zones of high lineament intersection density are feasible zones for groundwater prospecting in the study area. The study has led to the delineation of areas where groundwater occurrences is most promising for sustainable supply and hence, further geophysical survey can be concentrated.

Key words: Groundwater pattern mapping, lineament trend distribution, Landsat 7 ETM, NDVI.

INTRODUCTION

Structural trends such as discontinuities can be detected in many forms, such as faults, joints, bedding planes or foliations, and may be useful in several environmental applications including landslide studies, hydrogeology and mineral exploration. Such discontinuities can be detected in the form of lineaments detected not only using ground mapping but also using remotely sensed

data such as conventional aerial photographs and satellite imagery. Good correlation between structures mapped in the field and using the lineament system enables the lineaments to be regarded as representative of the structural manifestation of a particular area (Morelli and Piana, 2006).

Lineament in this study is defined as a mappable, linear feature of a surface whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differ from the pattern of adjacent features and presumably reflect some subsurface phenomenon

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(Hobbs, 1904; Latthman and Parizek, 1964; O'Leary et al., 1976). This definition is chosen because it is the most practical definition in the context of remote sensing image interpretation (Gupta, 1991).

Lineament analysis in hard-rock terrains has been performed widely as a means for groundwater exploration. Using remotely sensed satellite imagery, lineaments are detected by alignment trends of features such as vegetation, drainage patterns, outcrop truncations, soil moisture and topography. These can be identified with attributes including tone, color, texture, pattern and association. Such lineaments are indicative of secondary porosity in the form of fractures and if intersected by a well at depth, have the potential to supply large and reliable quantities of water (Meijerink et al., 2007; Kann and Glenn, 2006; Park et al., 2000; Mabee, 1999; Magowe and Carr, 1999; Edet et al., 1998; Sander et al., 1997; Kresic, 1995; Mabee et al., 1994).

Remote sensing provides a means for regional understanding of groundwater systems. Its data provides information on spatial patterns of groundwater dependent vegetation or salinization, and is often the only source to study the history of change. The interpretation of remotely sensed data for linear features mapping is an integral part of groundwater exploration programs in hard rock terrains (Greenbaum, 1992a, b; Gustafsson, 1993). Remote sensing with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within short time has become a very handy tool in assessing, monitoring and conserving groundwater resources. In addition, satellite data provides quick and useful baseline information on the parameters controlling the occurrence and movement of groundwater, such as geology, lithology geomorphology, soils, land use / cover, lineaments etc.

The study area falls within the basement complex region of Ondo State, Nigeria. It is underlain by rocks of crystalline basement complex (Rahaman, 1978). Crystalline basement complex rocks are practically impermeable and have no storage capacity. As a result of this, a groundwater resource in this type of terrain, which is widely spread in Africa, is limited. A groundwater reservoir, called an aquifer, is restricted to features produced by weathering and tectonic processes (Bello and Makinde, 2007). To ensure maximum and perennial yield, it is important that a borehole is located where it can penetrate the greatest possible thickness of regoliths, fractures, weathered rock formations, fissures and joint zones which are always manifested structurally as lineaments on the outcrops.

This research work focuses on developing a remote sensing and geographic information systems (GIS) methodology for regional groundwater potential evaluation. This regional study is important because with small-scale satellite imagery such as Landsat ETM+, the 'noise' caused by the detailed information provided by aerial photography disappears (Arlegui and Soriano,

1998). The objectives of this study are to: (i) produce a regional structural lineament map of the study area from remotely sensed data; (ii) determine the hydrogeological implication of the lineaments by integrating them with the available ancillary data digital elevation models (DEMs) and geological maps; (iii) analyze the lineament trend distribution of the study area using rose diagram, lineament density map and lineament intersection map; (iv) use normalized difference vegetation index (NDVI) analysis to correlate the potential of lineaments as recharge or discharge areas. The essence is to provide information that will point toward areas where untapped water resources may be located in future. This will result in recognition and delineation of aquiferous zones for potential groundwater development across the state.

Study area

The study area is located between latitudes $6^{\circ} 00'$ and $8^{\circ} 45'$ N and longitudes $5^{\circ} 30'$ and 6° E in Southwest Nigeria. It is bounded by Ekiti and Kogi States to the North; Osun and Ogun States to the West; Edo State to the East; and, Delta State and the Atlantic Ocean adjoins the southern portion (Figure 1). Geologically, the lithological units in the study area include migmatite, granite gneiss, quartzofeldspathic gneiss, Undifferentiated schist, pegmatite, porphyritic biotite and chanokitic rocks (Figure 2). The granitic rocks consist of quartz, feldspar and biotite and/or tourmaline. The age of the granites ranges from lower to upper triassic while the metasedimentary is thought to be upper paleozoic (Gobbet and Hutchison, 1973).

Hydrogeology and geomorphology

Regolith and fractured basements generally occur in a typical basement terrain (Oduanya and Amadi, 1990). In tropical and equatorial regions, weathering processes create superficial layers with varying degrees of porosity and permeability. Studies have shown that the unconsolidated overburden could constitute reliable aquifer if significantly thick (Satpathy and Kanugo, 1976; Bala and Ike, 2001). In addition, the concealed basement rocks may contain highly faulted and folded areas, incipient joints and fracture systems derived from multiple tectonic events that they have experienced. These structures may house abundant groundwater in a typical basement setting. The detection and delineation of such structures that are diagnosed by lineaments may facilitate the identification of prospective groundwater zones. The region which lies within the tropical rainforest of Nigeria is characterized by two distinct seasons (wet from March to October and dry from November to February). The annual mean rainfall is about 1800 mm, while the annual mean temperature ranges between 24°C and 27°C .

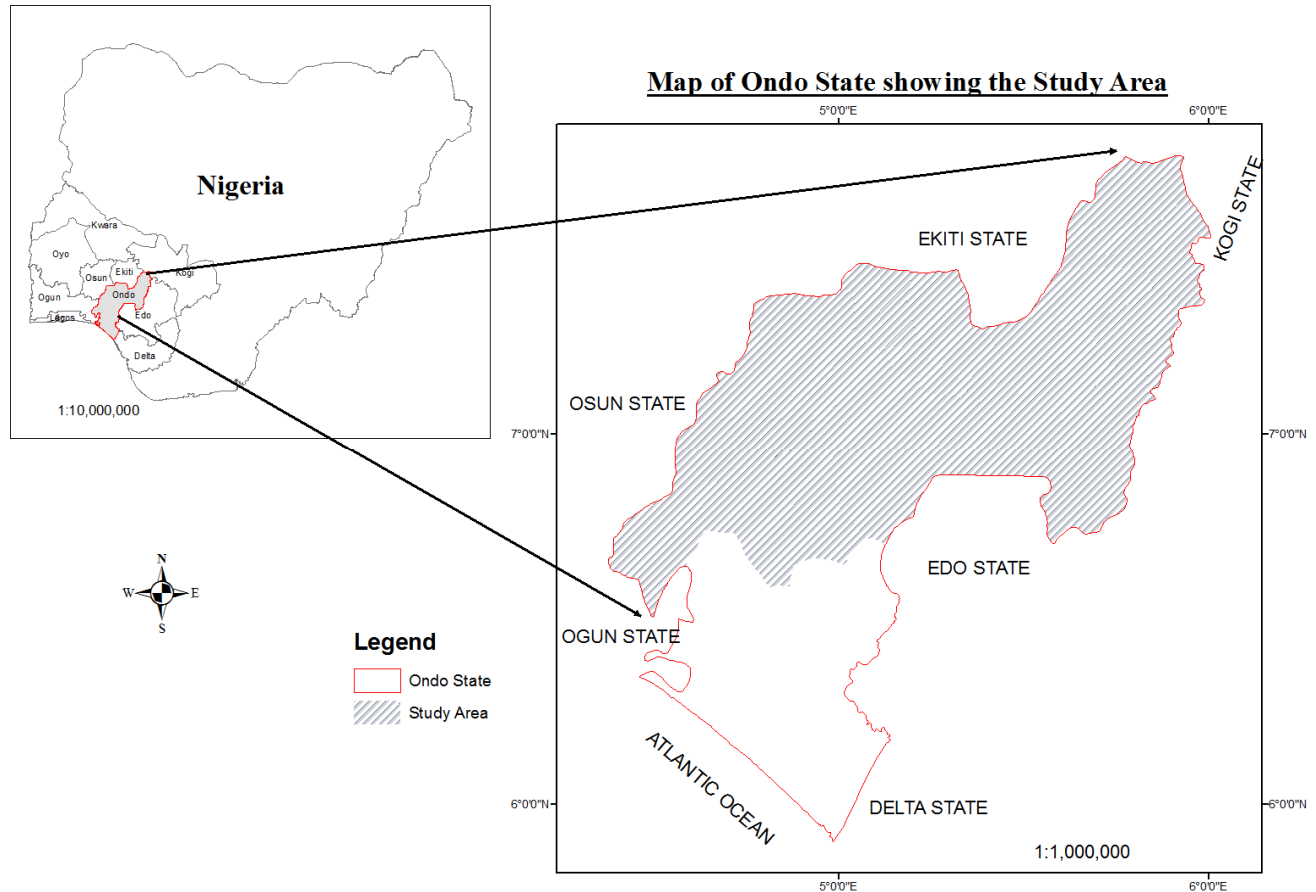


Figure 1. Location map of the study area.

MATERIALS AND METHODS

Image data

The main data used for the mapping of the study area's structural lineaments is LANDSAT 7 enhanced thematic mapper plus (ETM+) downloaded from global land cover facility as shown in Figure 3. The imagery used comprised of subsets from original scenes of path 189 and row 055 and path 190 and row 55 of 2001 and 2002 the respectively. Landsat 7 ETM+ has 30 m spatial resolution and an extra 15 m panchromatic (pan) band. Other ancillary data include ASTER DEM (downloaded from NASA's land processes distributed active archive center (LP DAAC)) and geological map (sourced from Nigeria Geological Surveys Agency (NGSA), 2006) of the study area.

Lineament mapping

Lineaments were delineated by visual interpretation of false color composite (FCC), which was fused with the 15 m Pan 2001 and 2002 imageries to enhance the interpretation. The ideas of various bands combination was borrowed from the findings of scientific researchers such as Suzan and Toprak (1998) who suggested that band 7 should be used, upon inspection of both imageries, band 4 was found to be the best in showing the textural features. More so, the use of band 4 was also suggested by Juhari and Ibrahim (1997), Pradeep et al. (2000), and Syed and Saied (2004) for

lineament interpretation. Bands combination of 4 (Red band), 7 (Near infrared) and 1 (Blue band of the visible spectrum) were fused together to generate a false colour composite image (FCC, 471) for linear geological features enhancement in ENVI 4.7 window interface. Further visual interpretation was improved by using a 99% linear contrast stretch, in which 1% of the lower and higher digital number (DN) values in the histogram by assigning DN values 0 and 255 to black and white respectively while the remaining values were distributed linearly between these values (Arlegui and Soriano, 1998) (Figure 4). In order derive the geomorphologic context of the terrain, the DEM data was subjected to surface analysis embedded in the 3D analyst tool in ArcGIS to produce the a hillshaded relief image for the study area (Figure 5). The enhanced Landsat image using ENVI 4.7 tool following the pre-processing – Composite bands combination and directional image filtering procedures was draped on the shaded relief for the mapping of the linear features (Figure 6).

The lineament mapping is aided by the existence of the geomorphological features such as aligned ridges and valleys, displacement of ridge lines, scarp faces and river passages, straight drainage channel segments, pronounced breaks in crystalline rock masses, and aligned surface depressions (Koch and Mather, 1997; Hung et al., 2005). The study was keenly interested in topographically negative lineaments, which may represent joints, faults and, probably, shear zones (Juhari and Ibrahim, 1997; Koch and Mather, 1997; Solomon and Ghebream, 2006). The non-geological lineaments such as paths, roads, power cables and field boundaries in the study area were eliminated using

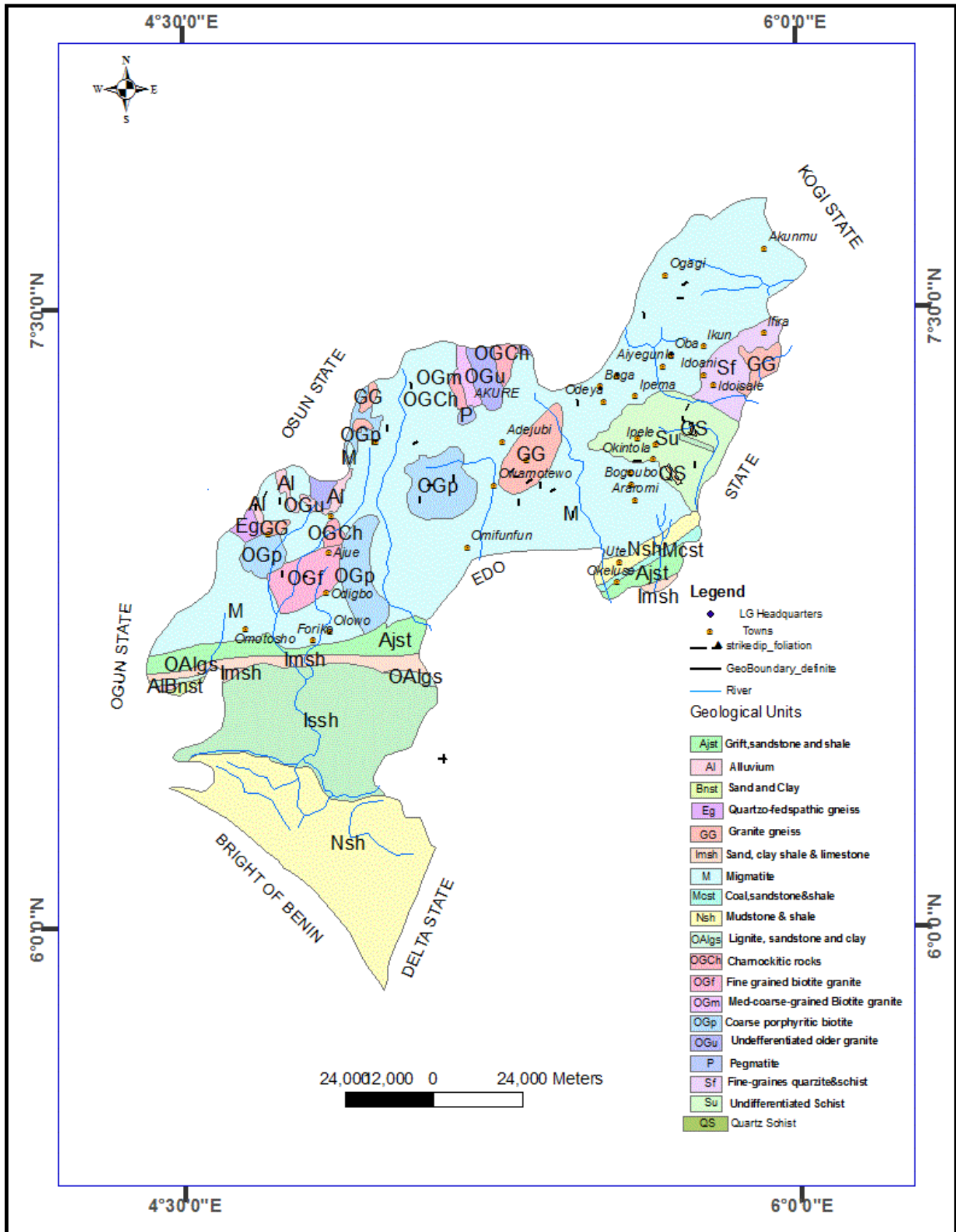


Figure 2. Generalized geological map of Ondo State (Adapted from NGSA, 2006).

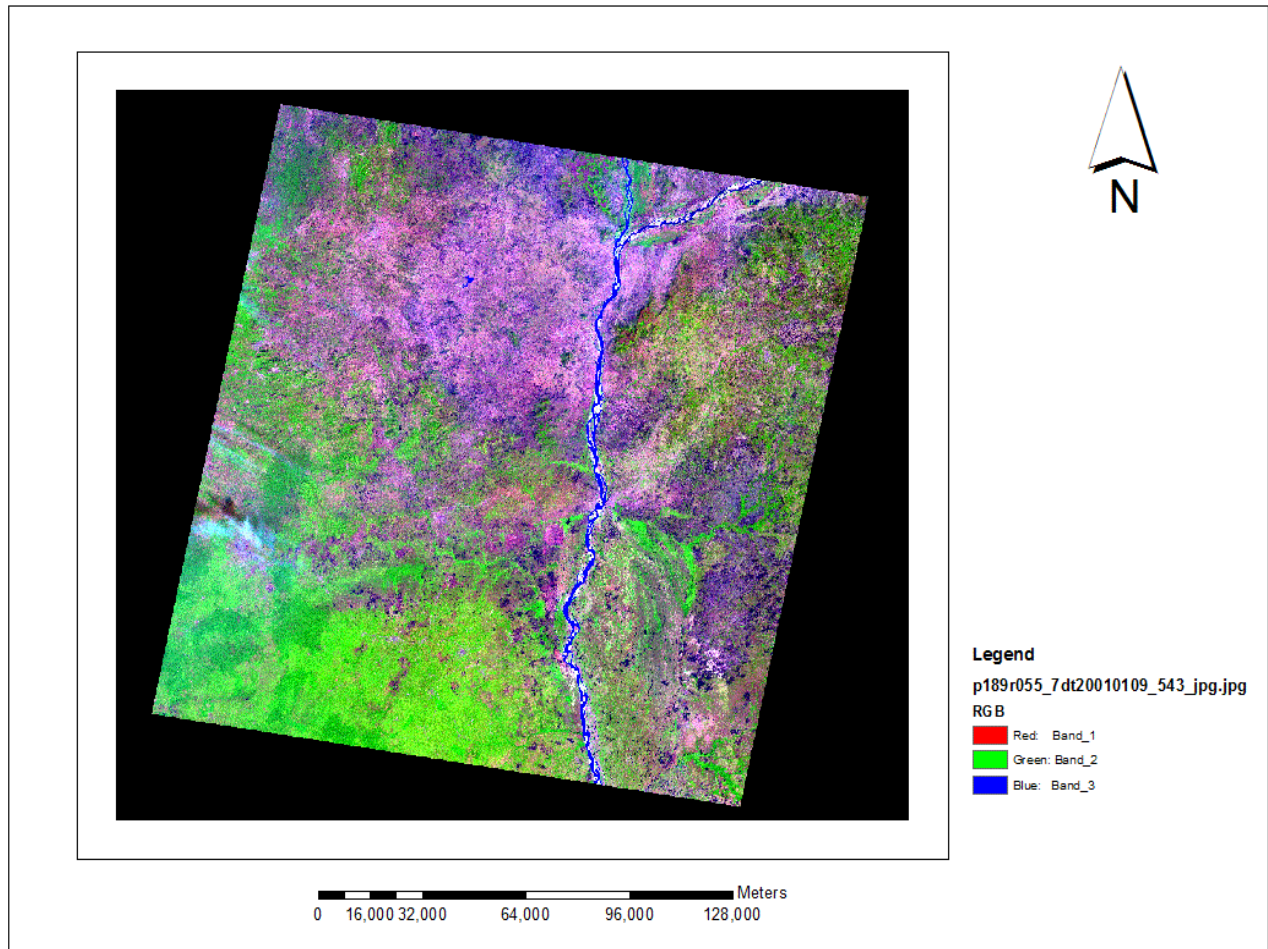


Figure 3. A Scene of Landsat 7 (ETM+) image.

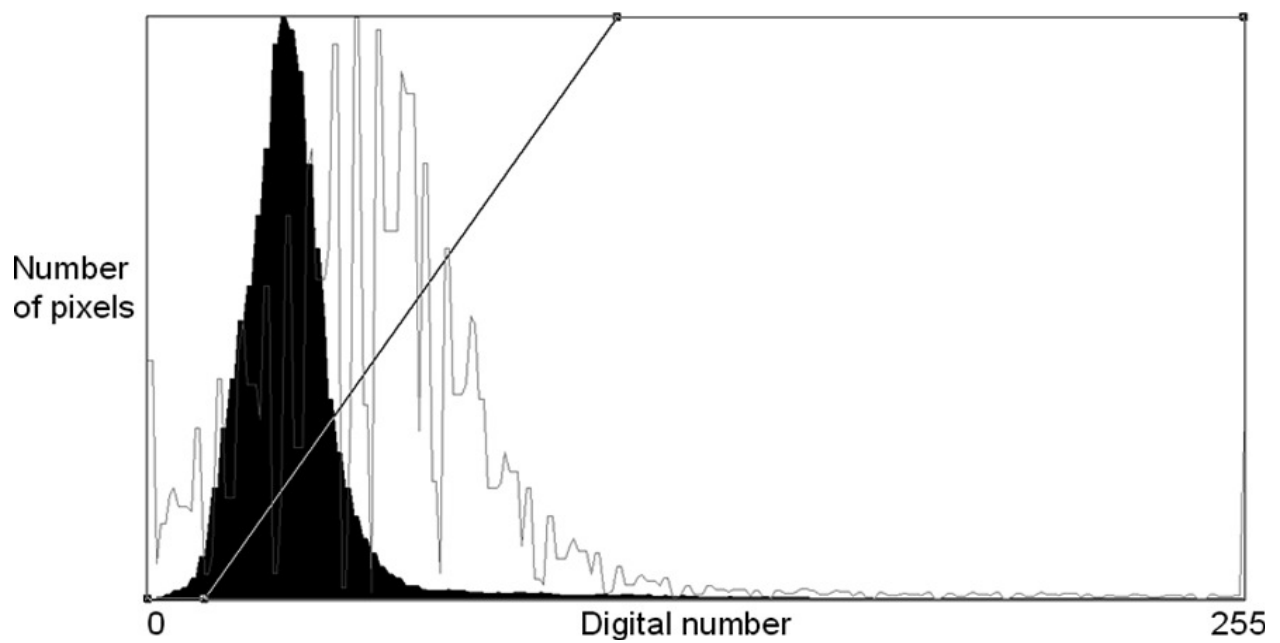


Figure 4. A typical histogram figure of linear contrast stretch of bands.

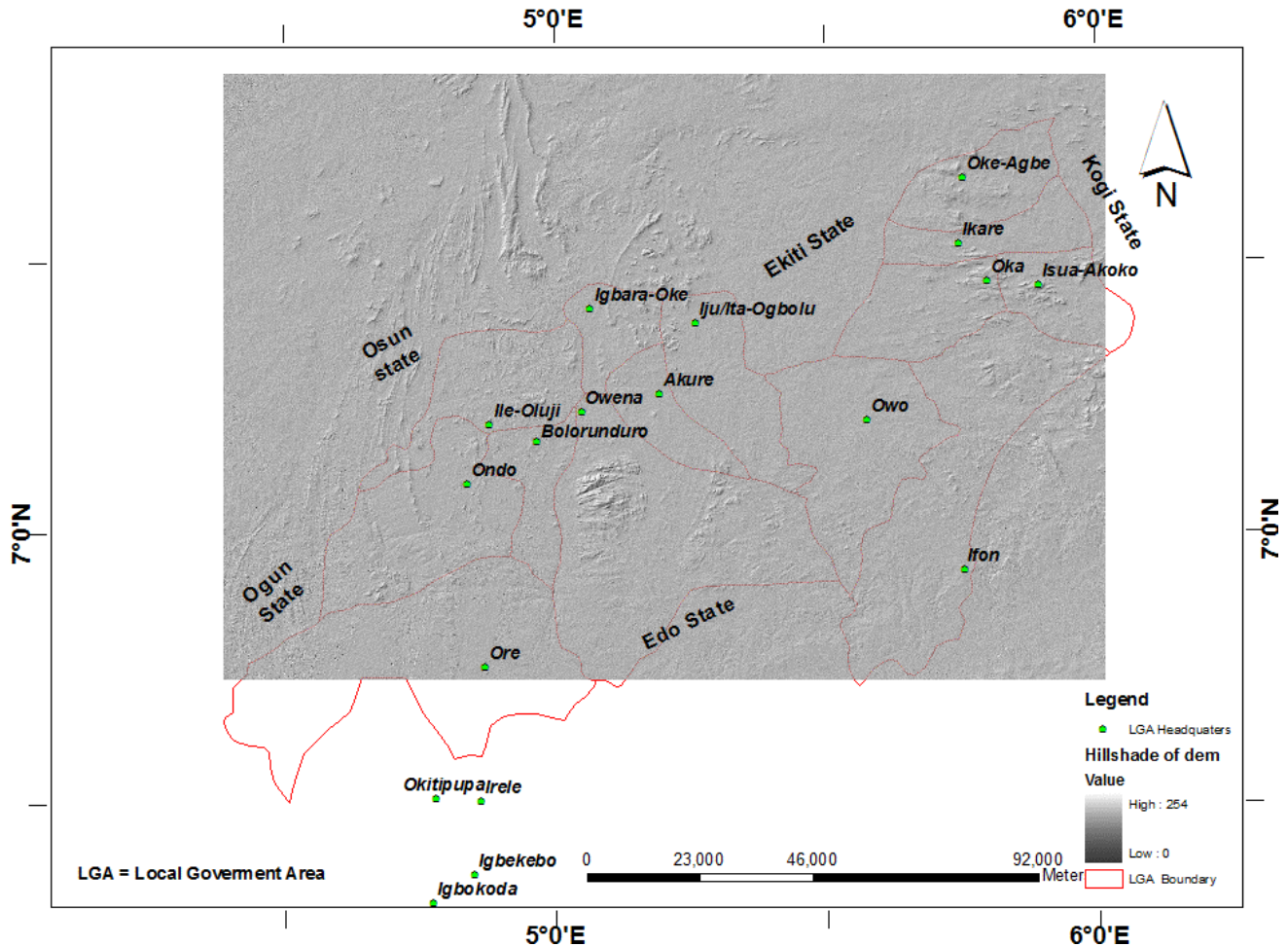


Figure 5. Hillshaded image obtained from ASTER DEM data.

the topographical map (Yassaghi, 2006) The identified linear features on the enhanced landsat imageries (2001 and 2002 images) exported from the ENVI 4.7 window, visualized and digitized using the ArcGIS 9.3. Figure 7 presents the regional lineament map of the study area

Vegetation index evaluation of lineament potential

The Normalized difference vegetation index has background theory whose index is based on the difference in reflectance in the near-infrared (NIR) and red bands of the electromagnetic spectrum (EMS). Its valid results fall between -1 and +1. The higher values indicate more green vegetation.

The NDVI equation is:

$$NDVI = \frac{(NIR - red)}{(NIR + red)}$$

In this study, a thematic map that shows the vegetation cover and its alignment in the study area was generated based on the theory above using ENVI 4.7 tool. The NDVI method has been used to identify and map geologic linear features (lineaments) in hard-rock terrains based on tone, color and textural identifying pattern

(Bruning, 2008). Boyer and McQueen (1964) established the usefulness of NDVI in detecting fractures and faults which can be associated with the occurrence of vegetation alignment. The mapping of such structural features will facilitate groundwater accumulation in a rocky terrain where permeability and porosity is of negligible value. Hence, the NDVI image map generated for the study area was interpreted, and areas with denser and active vegetation defining linear features were mapped, as shown by areas with light tones in Figure 8.

RESULTS AND DISCUSSION

Lineament analysis

The mapped structural lineaments were analyzed using lineament density (LD) and lineament frequency (LF) parameters (Solomon and Ghebreab, 2006). The results of the analysis are presented as lineament density map, lineament intersection map and rose diagram (Figures 9, 10 and 11 respectively). The lineament density variation map (Figure 9) shows the lineament numbers to be of the ranges varying between 7 and 16. The denser lineaments

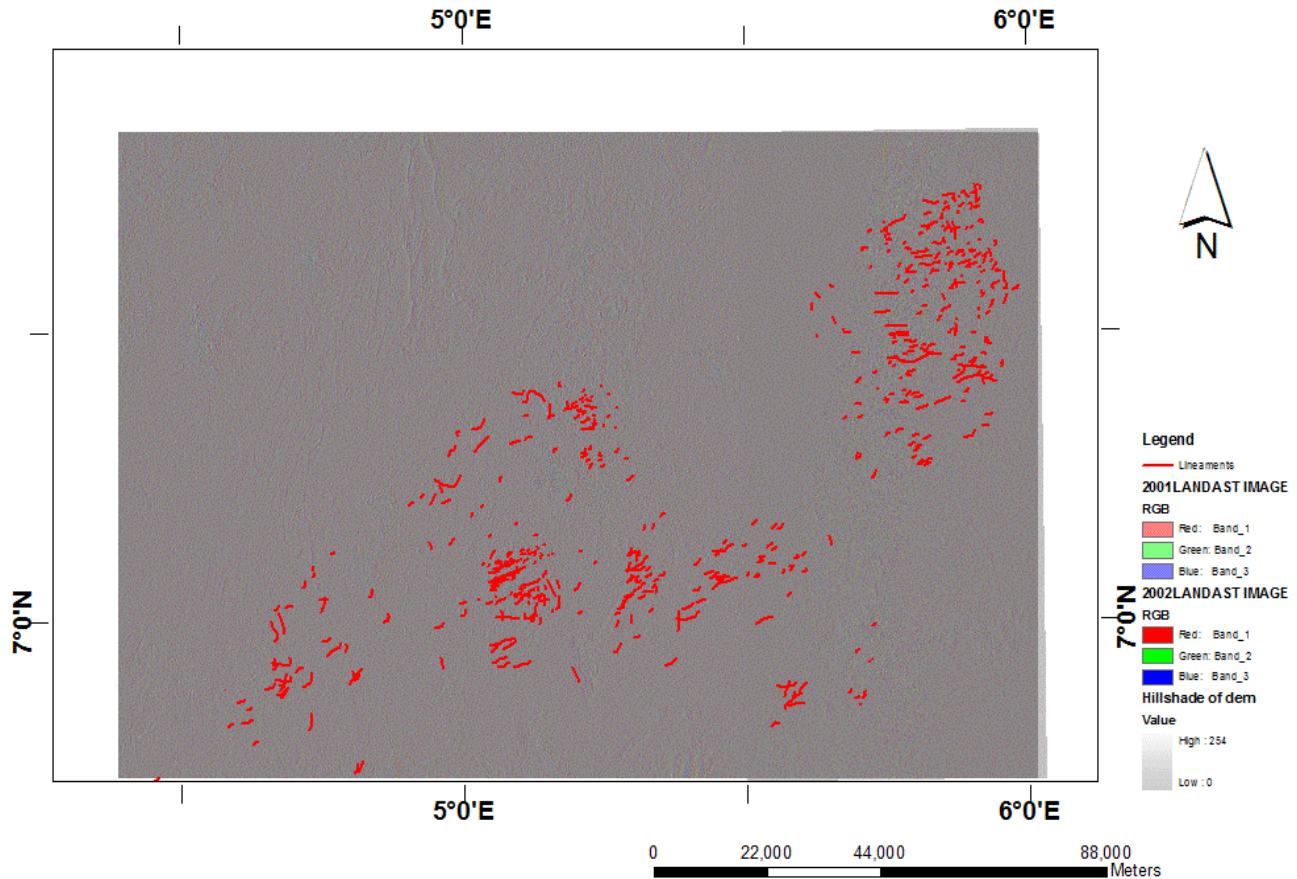


Figure 6. The composite images showing the linear features.

typified the intensity of rock fracturing, which is a prerequisite for development of hollow passages over an area. The areas around the central, north-eastern and south-western parts of the study area has a relatively high density value (> 8) while the south-eastern, western, southern, north-eastern, and western parts of the study area are covered by density values (< 8). According to Edet et al. (1998), the zones of relatively high lineament density are identified as zones of high degree of rock fracturing, which are prerequisite for groundwater conduit development in an area. The lineament intersection map (Figure 10) provides interpretation of hidden subsurface tectonic configuration in the form of linear feature intersection / cross cutting geological structures, which are indicators of deep seated fracture / fault medium. A comparison of Figures 9 and 10 shows that the areas underlain by high density are characterized by relatively high lineament intersection value. The zones of high lineament intersection over the study area are feasible zones for groundwater targeting in the study area. The rose diagram (Figure 11) shows the directional frequency of the mapped lineaments over the area of study. It was interpreted as a statistical means of representing the anisotropy of the fractured environment, as well as

fissure development tendency on a regional scale. The rose diagram of the detected lineaments show two prominent trends in the directions of the N-S and E-W axes, which are also the principal directions of the regional structures in basement complexes of Nigeria. A comparison of Figures 9 and 11 shows that the two prominent lineament trends (E-W and N-S) are correlated with high density variation zones of the study area. This can be an indication of the directions of groundwater movement in the studied area. The research findings of Owoade and Moffat (1989) in determining the groundwater prospects in South-western Nigeria corroborate the above hydrogeological deduction which emphasized that groundwater movement and its accumulation always explored the fissures / fractural / weathered column of the basement rocks. Therefore, the fracture anisotropy of the detected lineaments trends presented in Figure 11 can be investigated for groundwater potential of the study area.

Conclusions

The study has demonstrated the importance of lineament

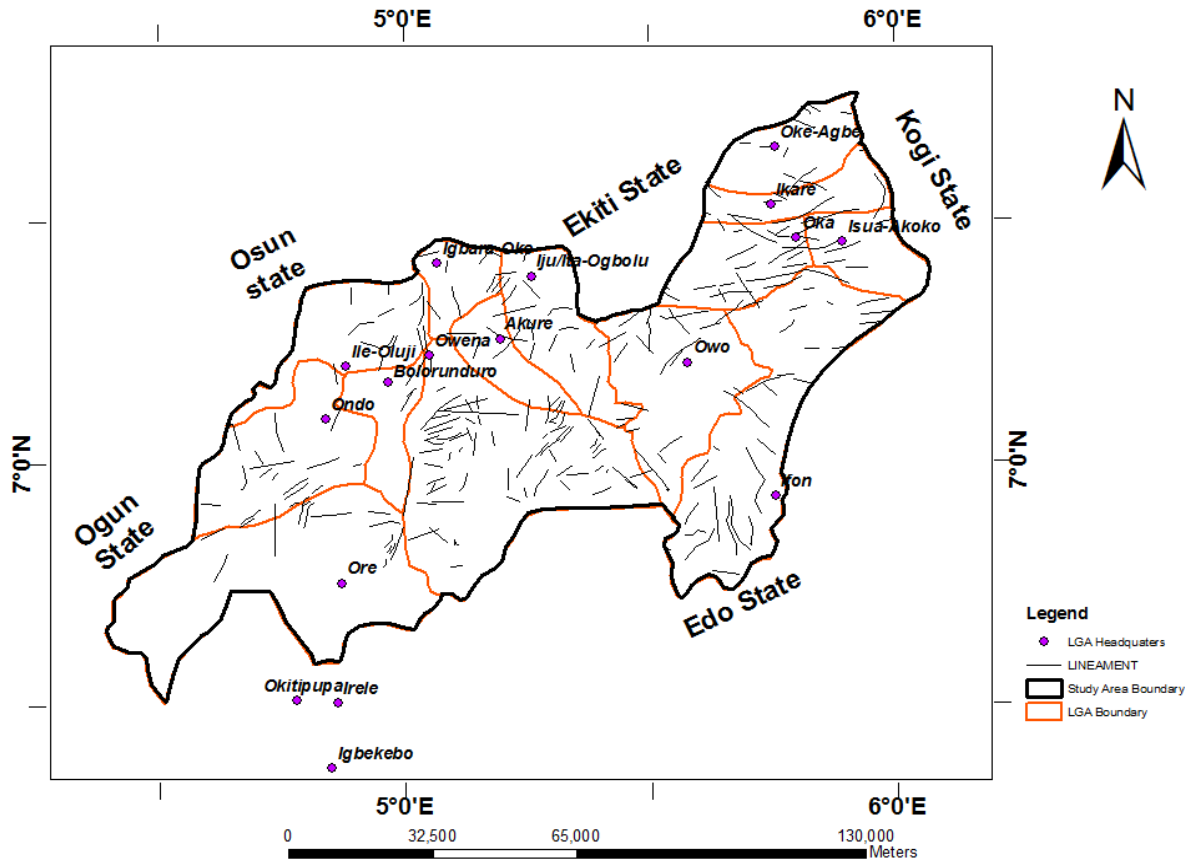


Figure 7. Regional lineament map of the study.

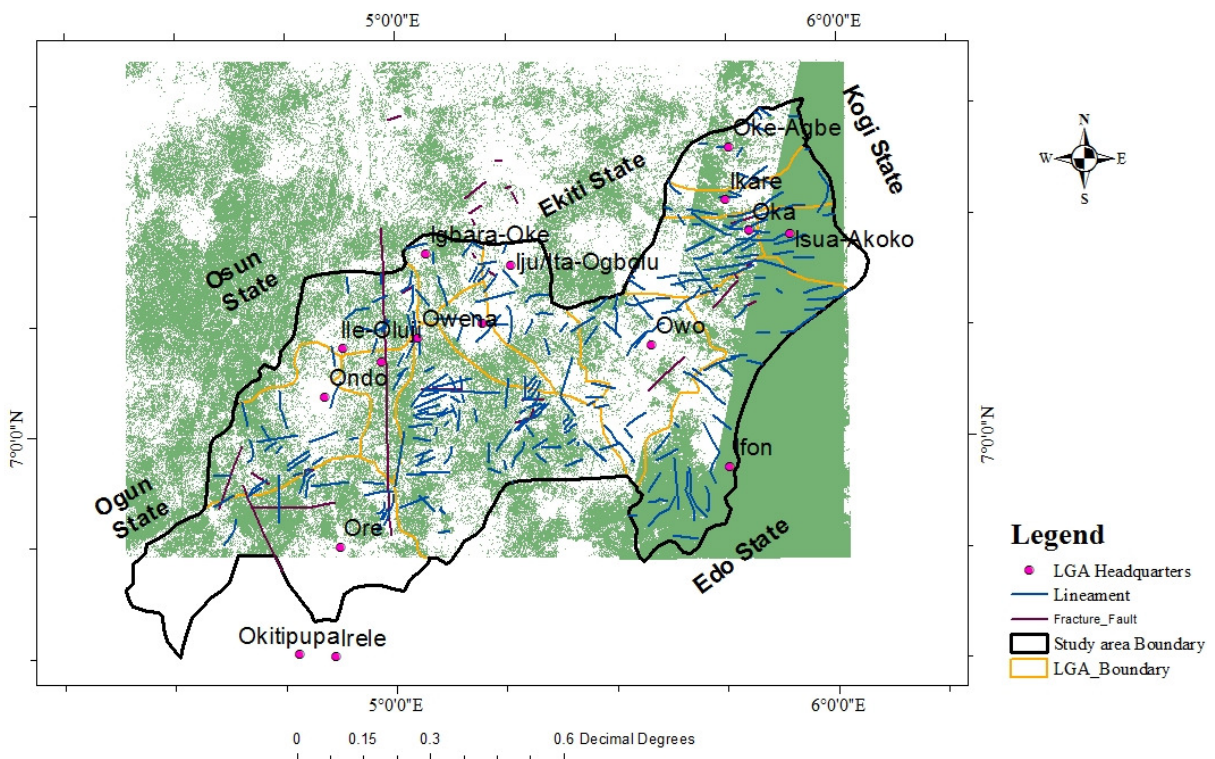


Figure 8. NDVI structural analyzed map of the study area.

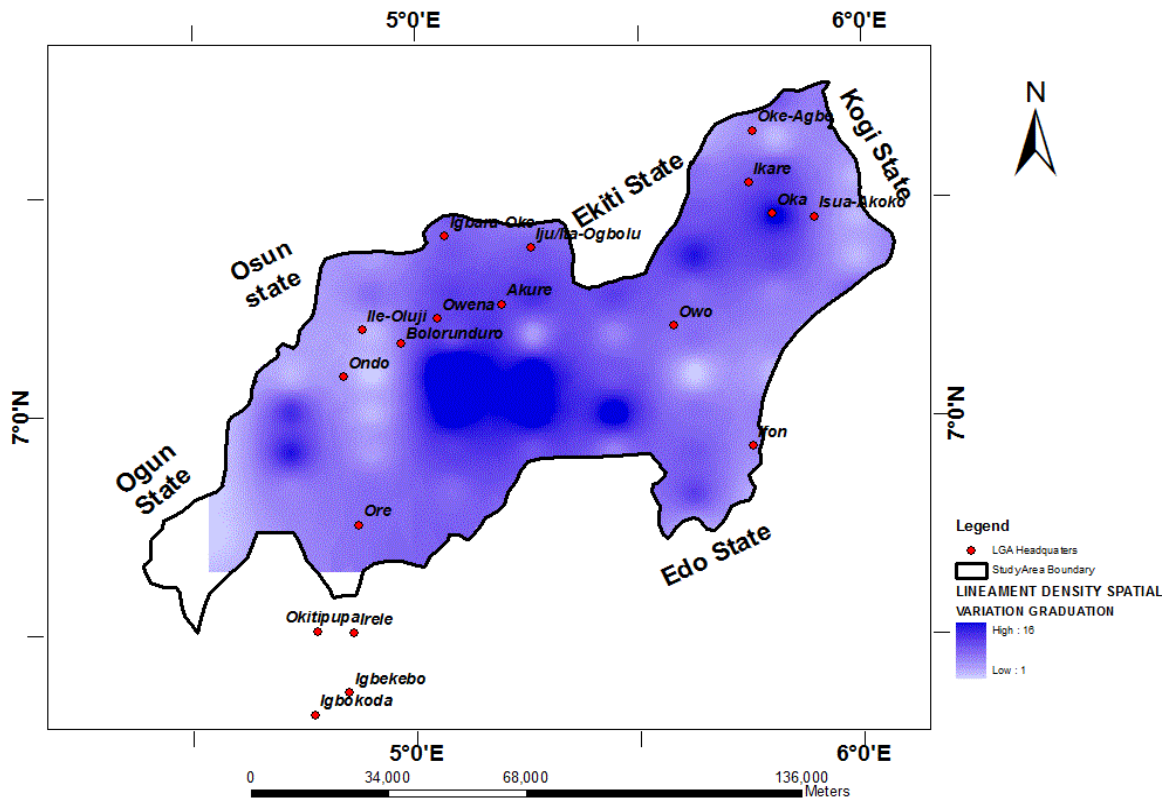


Figure 9. Regional lineament density variation in the study area.

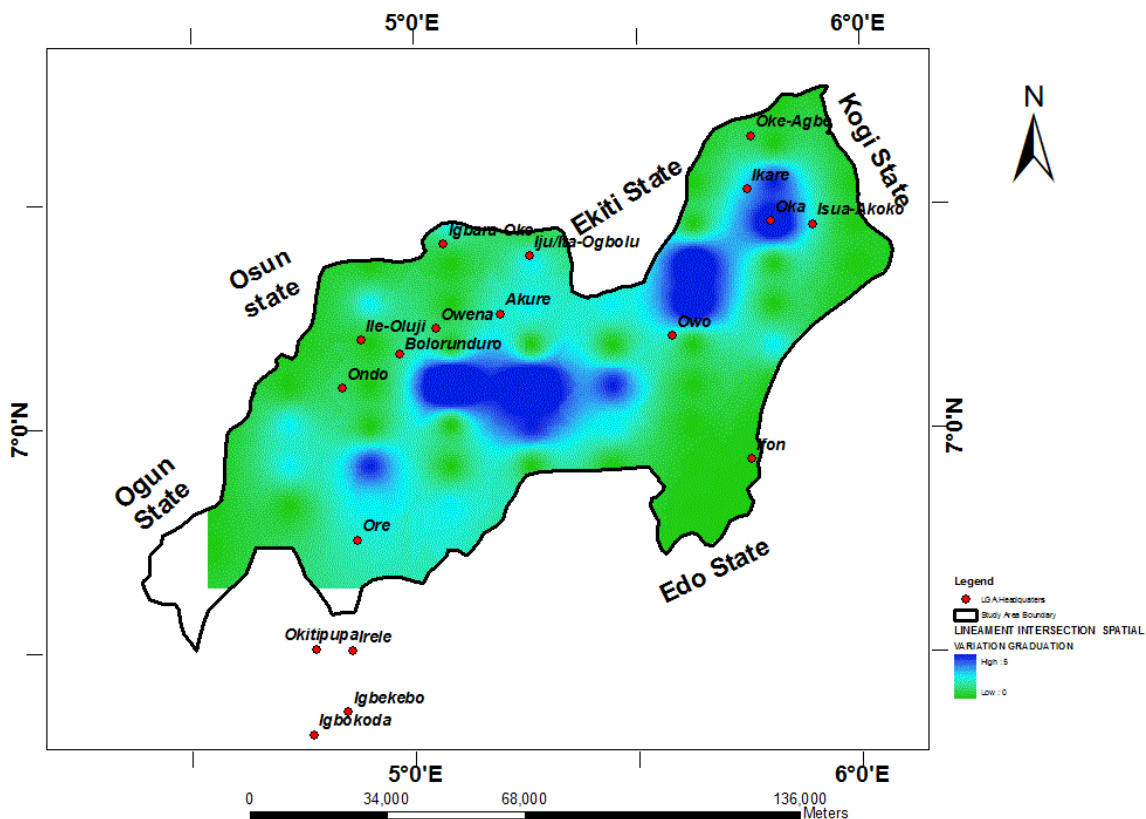


Figure 10. Regional lineament intersection variation in the study.

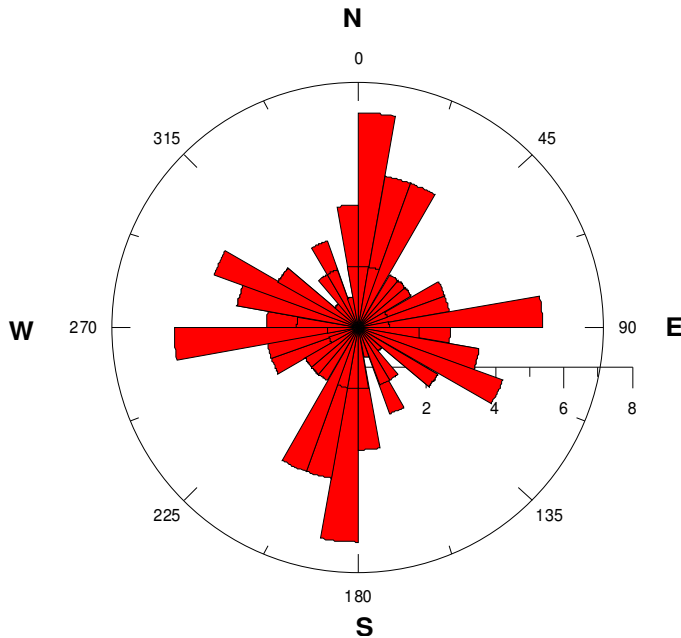


Figure 11. Rose diagram of the lineament orientation.

mapping to evaluate the regional groundwater potential of a typical basement terrain involving the integration of remote sensing and GIS techniques. This involved the interpretation and GIS analysis of landsat image data acquired for the years 2001 and 2002, ASTER DEM data of 30 m pixel size for the preparation of various thematic maps (geology, drainage pattern, NDVI, hill shaded relief image, regional structural lineament, lineament density and lineament intersection).

The results of the analyzed lineament/fracture indicated that the area has numerous long and short fractures whose structural trends are mainly in the north-south and east-west directions. The cross-cutting lineaments are relatively high in areas around the central, north-eastern and south-western parts of the study area, but relatively low in the other areas. The zones of high lineament intersection density are feasible zones for groundwater prospecting in the study area, and hence, it is suggested that these zones be combed with detailed geophysical mapping for quantitative evaluation of the groundwater potential of the study area.

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