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SRTM-DEM Fracture Mapping for Groundwater Potential around Oyo and Ogun States, Southwestern Nigeria

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Abstract

The geological lineaments and drainage patterns from the SRTM DEM data of the section of southwestern Nigeria, covering Oyo and Ogun states, were extracted in order to investigate the groundwater potential of the study region. The main objective of this study is to delineate the geological structure of the region, to enhance near-future groundwater exploitation of the region. The SRTM DEM data utilized in this study covers the latitudes 7'00˚N to 8'00˚N and longitudes 3'00˚E to 4'00˚E. The data were analyzed for lineament density and lineament intersection. Similarly, flow direction and flow accumulation tools were applied to the fill sink SRTM DEM data to extract the drainage network over the study area. It was observed from the SRTM DEM Image that areas with low elevation exhibit the highest flow accumulation, as evidenced in the northeastern, Abeokuta north, Ibadan southeast, Ibadan northwest, Oyo east, Oyo west, and Iwajowa regions of the study area. This suggests a high groundwater potential, as water naturally flows from higher elevations to lower points. Some lineaments show alignment with the drainage patterns of the study area. These lineaments influenced the drainage system of the study area. It was observed that the flow of the drainage patterns in the study area coincided with or aligned with the Northwest-Southwest lineament orientation.

Subject Areas

Environmental Sciences

Keywords

Groundwater Exploration, Lineament, Hydrogeology, Drainage Pattern, Remote Sensing

1. Introduction

Water is an important resource, and guaranteeing its appropriate management is essential to assuring the welfare of communities all over the world, particularly since water is essential for a wide range of applications, including domestic, commercial, industrial, agricultural, and recreational uses [1]. Effective groundwater prospecting and resource management require an understanding of the subsurface factors that affect groundwater availability [2]. Many geological formations' groundwater flow and storage are significantly influenced by fracture systems [3]. The occurrence and movement of groundwater are influenced by the pathways that these fracture systems provide for water to penetrate and flow through the subsurface [4]. Therefore, it is essential to identify and describe fracture systems to identify potential groundwater resources and maximize their use. The study and mapping of geological characteristics from a spatial and temporal viewpoint have benefited greatly in recent years from the development of remote sensing technologies [5].

The Shuttle Radar Topography Mission (SRTM) data is considered one of the best satellite imageries for identifying subsoil fracture systems and assessing their impact on groundwater exploration due to its high resolution, penetrating radar technology, global coverage, historical data, and open accessibility, making it a valuable resource for scientific research and environmental management [6]. The National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS) launched the Shuttle Radar Topography Mission (SRTM DEM) satellite in the year 2000. SRTM C-Band, a Synthetic Aperture Radar (SAR), a radar device placed on Space OV-105, was used to gather data. The Earth's surface was targeted by the radar, which sent out signals that were reflected and recorded. With an accuracy of about 16 meters, these signals enabled the mission to measure the elevation of the terrestrial surface. The mission offered a spatial resolution of roughly 90 meters and covered the majority of the Earth's land surface between 60 degrees north and 56 degrees south latitude. Numerous applications make use of the SRTM DEM data from this mission [7]-[9].

This research project's main goal is to utilize the SRTM DEM downloaded from the United States Geological Survey Agency (USGS) to delineating the fracture networks that act as conduits for groundwater repositories using the remote sensing methods and image processing algorithms in the parts of Ogun and Oyo States of Nigeria, utilizing the following objectives: 1) Extract the geological lineaments; which is defined as a linear or curvy linear structure on the earth surface that reflect and underline geological structure such as a fault fracture zone, or lithological contact. They often correspond to a zone of increased rock permeability due to fractures or faults; these zones can act as pathways for groundwater flows, influencing their locations and movement within aquifers; 2) Delineate lineament density and lineament intersection points from the extracted lineaments; 3) Determine the implication of the extracted lineaments on the groundwater prospection of the study area in **Figure 1** and **Figure 2**.

2. Geology and Hydrology of the Study Area

Oyo State is an inland state in southwestern Nigeria. Its capital is Ibadan, the third most populous city in the country [10]. Oyo State is bordered to the north by Kwara State, to the east by Osun State, and to the southwest by Ogun State and the Republic of Benin. With a projected population of 7,840,864 in 2016, Oyo State is Nigeria's fifth most populous State [11]. Oyo State is located in southwestern Nigeria and features a diverse rock composition, primarily consisting of metamorphic rocks such as schists and gneisses, abundant granite formations, and various mineral deposits including tantalite, talc, and beryl [12]. These rocks hold geological significance and economic potential, with granites serving as a prominent source of construction materials, while the region's geological mapping aids in resource management and environmental assessments [13]. Oyo State is rated 14th in terms of size, with about 28,454 square kilometers. Old hard rocks and dome-shaped hills make up the scenery, which rises gently from 500 meters above

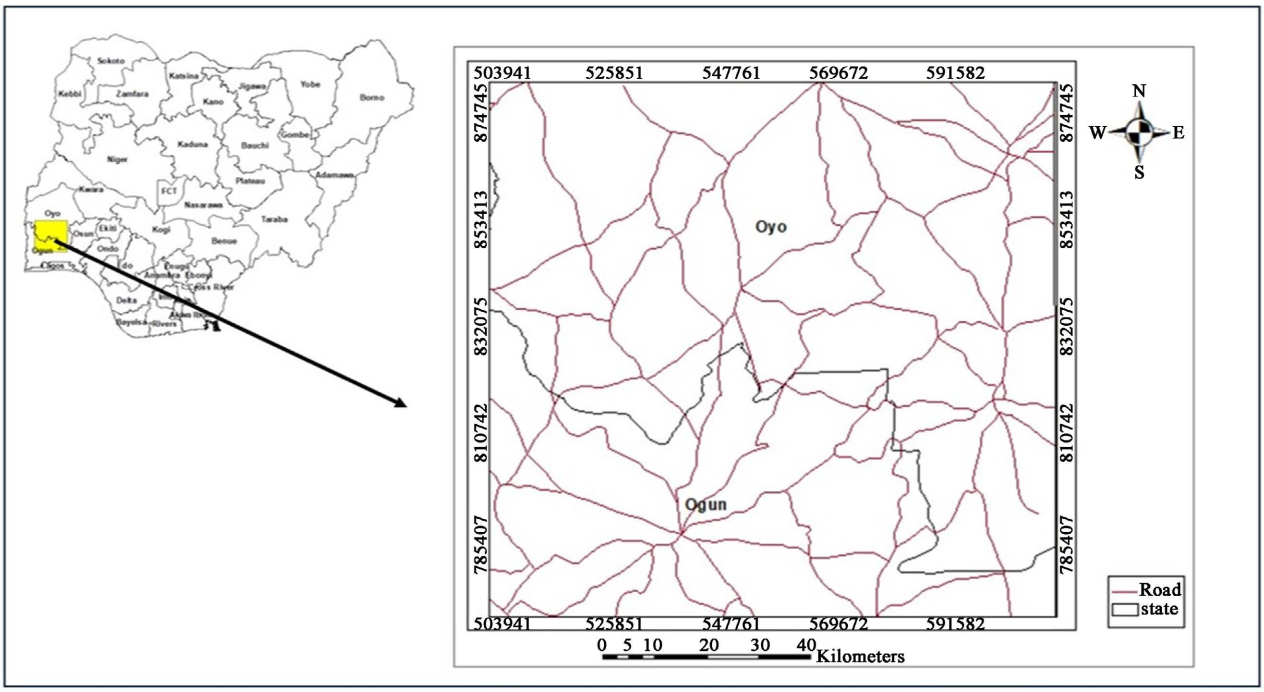

Figure 1. The map of the study area.

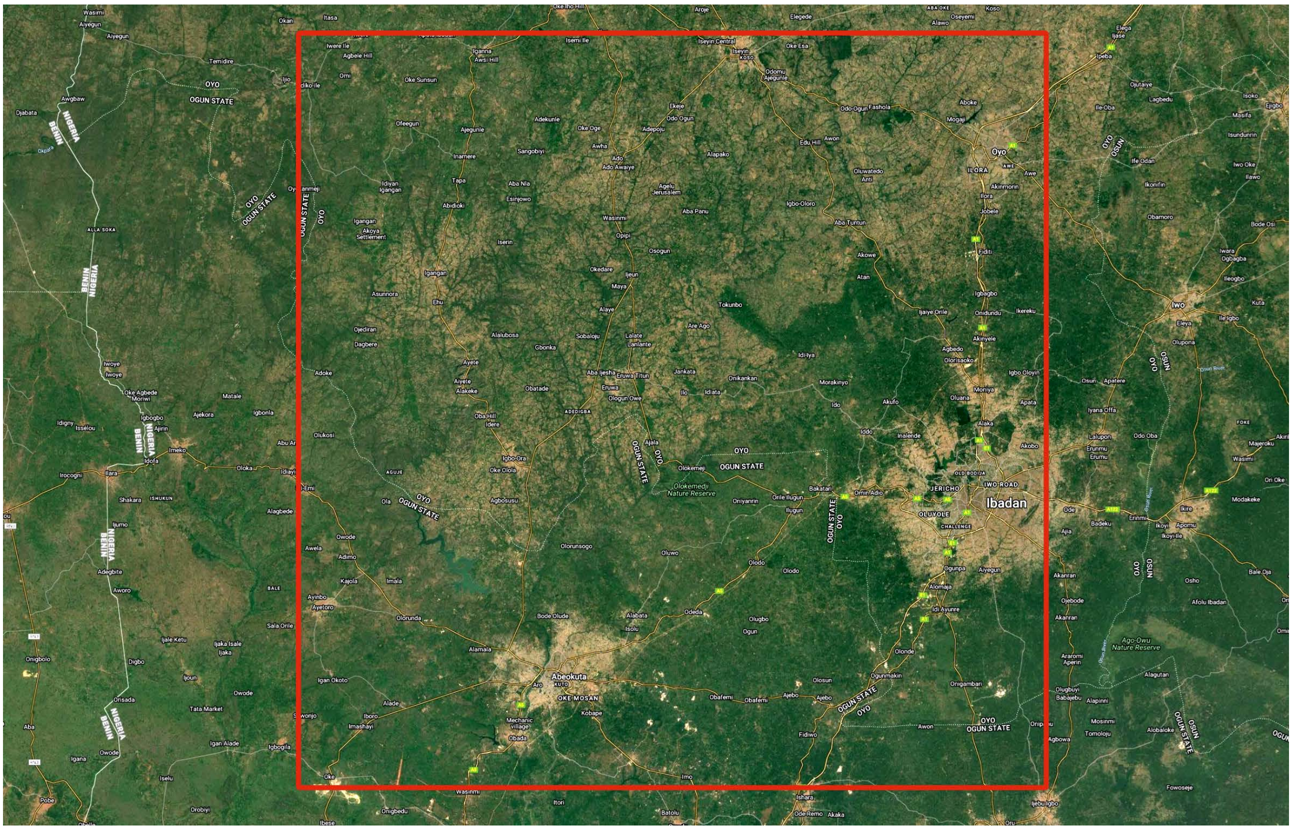

Figure 2. The satellite image map of the study area.

sea level in the south to 1200 meters above sea level in the north [14]. This upland is the source of several significant rivers, including the Ogun, Oba, Oyan, Otin, Ofiki, Sasa, Oni, Erinle, and Osun Rivers. The climate is equatorial, notably with dry and wet seasons with relatively high humidity. The dry season lasts from November to March while the wet season starts in April and ends in October. The average daily temperature ranges between 25˚C (77.0˚F) and 35˚C (95.0˚F), almost throughout the year [15].

Similarly, Ogun State is located in southwestern Nigeria and is bounded by Oyo and Osun States to the north, Lagos State to the south, Ondo State to the east, and the Republic of Benin to the west. The geology of Ogun State is made up of sedimentary and basement complex rocks. The sedimentary rocks consist of Abeokuta, Ewekoro, Oshosun and Ilaro Formations, Coastal Plain Sand and Recent Alluvium deposits [16]. The basement complex comprises of migmatites, gneisses, granites and schists. The mineral resources found in Ogun State include limestone, chalk, phosphates, and clay. Other minerals found in the state are gold, talc, feldspars, cassiterite, columbite, granite, mica, iron ore, kaolin, tourmaline, and aquamarine [17]. The climate of Ogun State follows a tropical pattern with the rainy season starting about March and ending in November, followed by the dry season. The mean annual rainfall varies from 128 cm in the southern parts of the State to 105 cm in the northern areas. The average monthly temperature ranges from 23˚C in July to 32˚C in February.

Hydrology of the Study Area

The water that is located within the Earth's subsurface, in the saturated zone under hydrostatic pressure below the water table is known as groundwater, it is accessible through borehole drilling or hand dug-well. Groundwater is known to be more appropriate and often meets the criteria of quality water required for domestic and industrial needs. This is the most widely used sources of water in most African countries, including Nigeria inclusive. In Nigeria, groundwater is located in the sedimentary terrain where it is abundant everywhere within the terrain and less difficult to exploit and in the basement complex terrain where it is usually complicated and often difficult to locate, especially in areas underlined by crystalline basement rocks. In this work, the study region is situated within the basement complex of southwestern Nigeria. The area is dominated by Precambrian undifferentiated basement rocks. These rocks are characterized by low porosity and permeability, hence the scarcity of water within the basement complex zones. However, ground water tends to accumulate within the Basement complex rocks that have been fractured or weathered, which in turns must have influenced its porosity and permeability. Groundwater occurrence in both Ibadan and Abeokuta (region of study) is in pockets restricted by fractures and weathered zones of the Basement Complex rocks underlying the site. The occurrence, appropriation and stream of groundwater is spasmodic and it is controlled by the dynamic connections of different natural factors such as geotectonic structures, lithology, overburden thickness, weathering grade, geomorphology, fracture extent, drainage pattern, land use/cover and Climate.

3. Materials and Methods

3.1. Materials

The materials used for this study are SRTM DEM data downloaded from the United States Geological Survey (USGS), a Geological map of the study area, ArcGIS, QGIS, Rockwork software, and Microsoft Office.

3.2. SRTM DEM Data Specification:

SRTM DEM data is a near-global elevation dataset, with coverage from −60 to 60 degrees latitude. It is a breakthrough in digital mapping of the world and provides a major advance in the accessibility of high-quality elevation data for large portions of the tropics and other areas of the developing world. The data is organized into individual rasterized cells of 1, 3, or 30 arcsec. It is used for purposes as diverse as geology, geomorphology, water resources and hydrology, glaciology, evaluation of natural hazards, and vegetation surveys. The data is currently distributed free of charge by USGS and is available for download from the national map seamless data distribution system, or the USGS FTP site.

3.3. Methodology

The SRTM DEM data 1 arc second (30 Meters resolution) bounded by Latitudes

7'00˚N to 8'00˚N and Longitudes 3'00˚E to 4'00˚E was downloaded from United State Geological Survey (USGS) and used for analysis. Fill sink tool was applied on the SRTM DEM data of the study area to correct imperfections and inconsistencies in the elevation values caused by various factors. It was used for sink removal, hydrological analysis and data smoothing. Applying the fill sink tool on SRTM DEM data helps to improve the accuracy, reliability, and visual quality of the elevation model, making it suitable for applications in hydrological analysis. Thereafter, flow direction tool was applied on the fill sink SRTM data to determine the direction of water flow at each cell in the terrain, enabling various applications related to watershed delineation, flood modelling and erosion analysis. Furthermore, flow accumulation tool was applied on the flow direction SRTM DEM data to calculate the accumulated flow of water, enabling tasks such as watershed delineation, stream network extraction and hydrological analysis in order to extract the drainage patterns. In order to extract the lineaments over the study area, the hillshade tool on the arcgis software using solar azimuth of angle 315 degree for the NE-SW and 45 degree for NW-SE was applied on the fill sink SRTM DEM data, then the lineaments were manually extracted Furthermore, statistical analysis comprising of lineament density, lineament intersection point and intersection density were determined from the lineament extracted by hillshade raster analysis of angle 315˚ and elevation of 45˚, 200˚ and elevation of 50˚, 100˚ and elevation of 60˚, then finally 50˚ and elevation of 90˚ of the study area in line with

4. Result

The SRTM DEM imagery (**Figure 3**) shows the elevation of the study area. The highest elevation is about 421 m above the sea level and this is observed between the northern and northeastern region of the study area. It is represented with reddish color on the map. The lowest elevation is about 16 m above the sea level and it is observed in the southern part of the study area. It is represented with green on the map. Two shaded relief imageries of contrasting illumination directions of 45 degree and 315 degrees were generated and combined to produce a shaded relief image having illumination from all four directions (**Figures 4-7**). The omnidirectional shaded relief image was used to generate the lineaments within the study area.

4.1. Lineament Analysis

Figure 8 and **Figure 9** show the lineament map and rose diagram of the delineated lineaments. These lineaments might be interpreted as fractures or faults along the basement rock, which may serve as a groundwater reservoir. The lineaments that align with the drainage patterns are known as the morphological lineaments [18], and these lineaments influence the drainage in the study area. The inferred lineament map and the associated rose diagram indicate that the study area is bisected by many major and minor contours that trend in various directions. The major lineament trends are in NE-SW and E-W directions, while the minor lineament

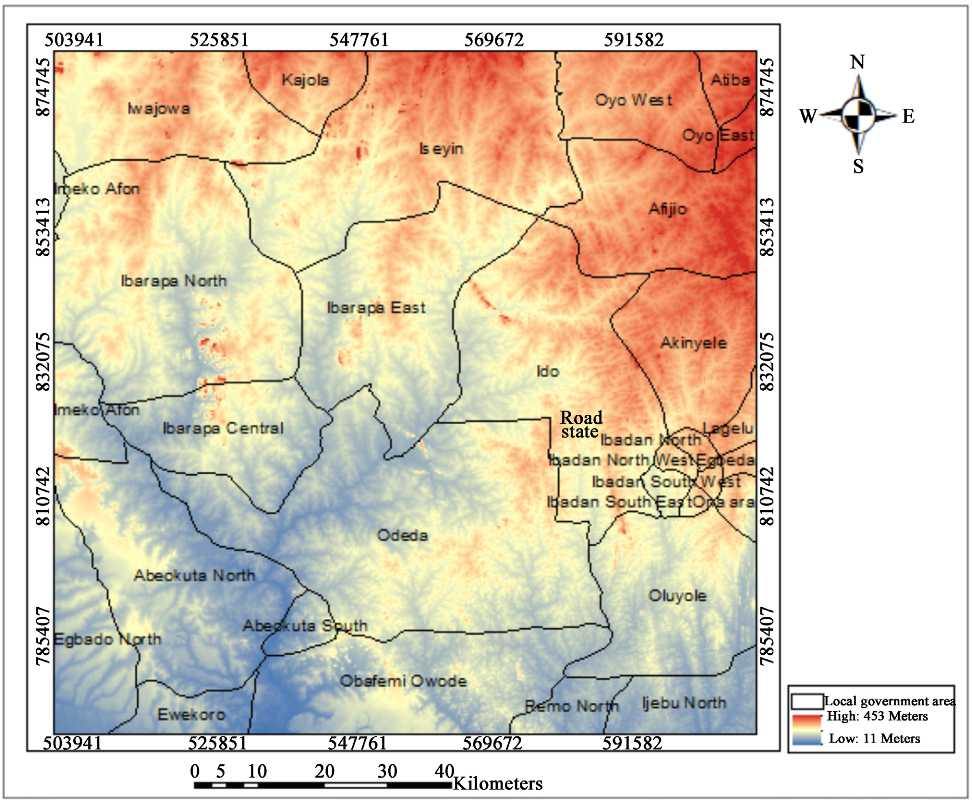

Figure 3. SRTM DEM imagery of the study area.

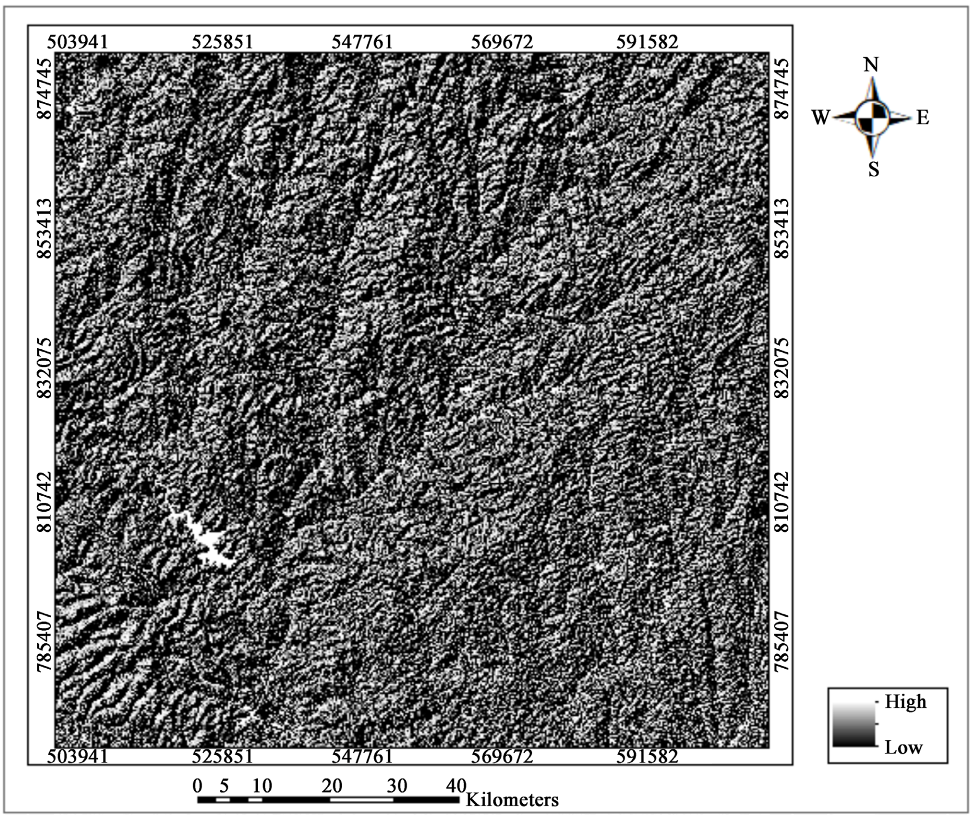

Figure 4. Shaded relief image of angle 315˚ and elevation of 45˚.

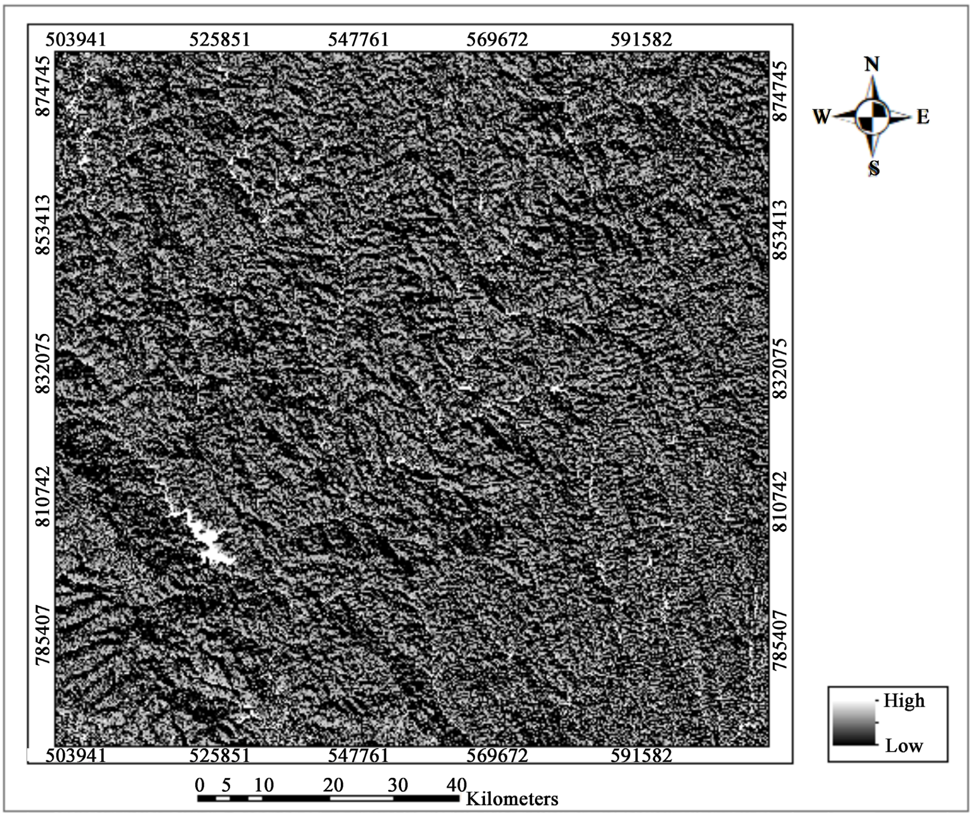

Figure 5. Shaded relief image of angle 200˚ and elevation of 50˚.

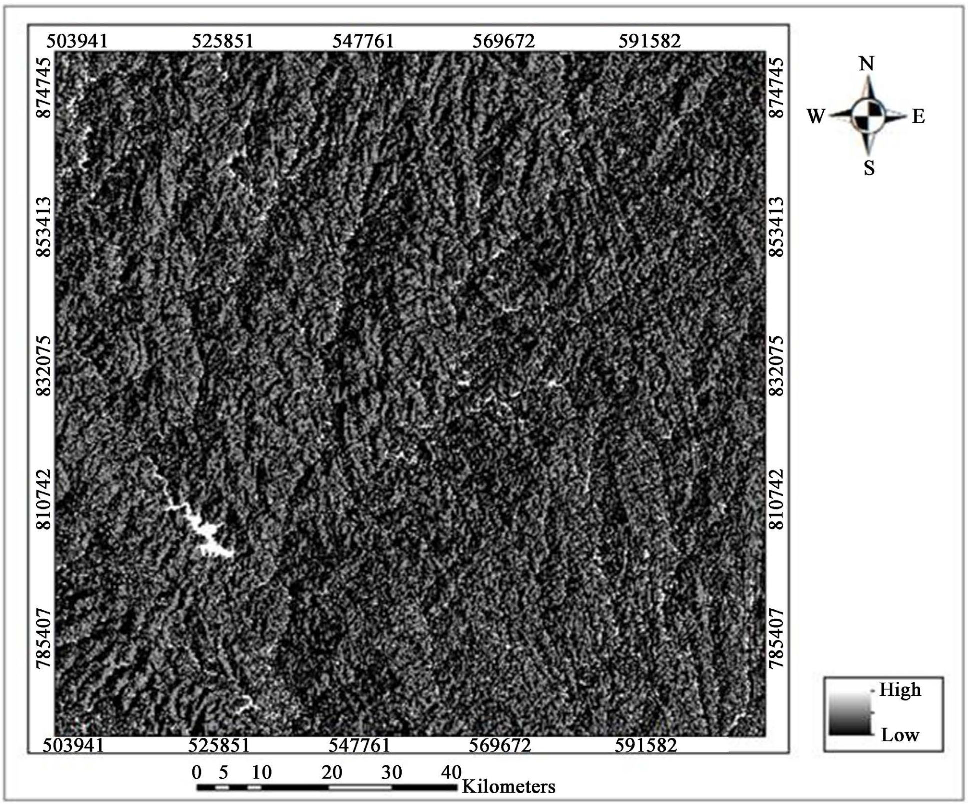

Figure 6. Shaded relief image of angle 100˚ and elevation of 60˚.

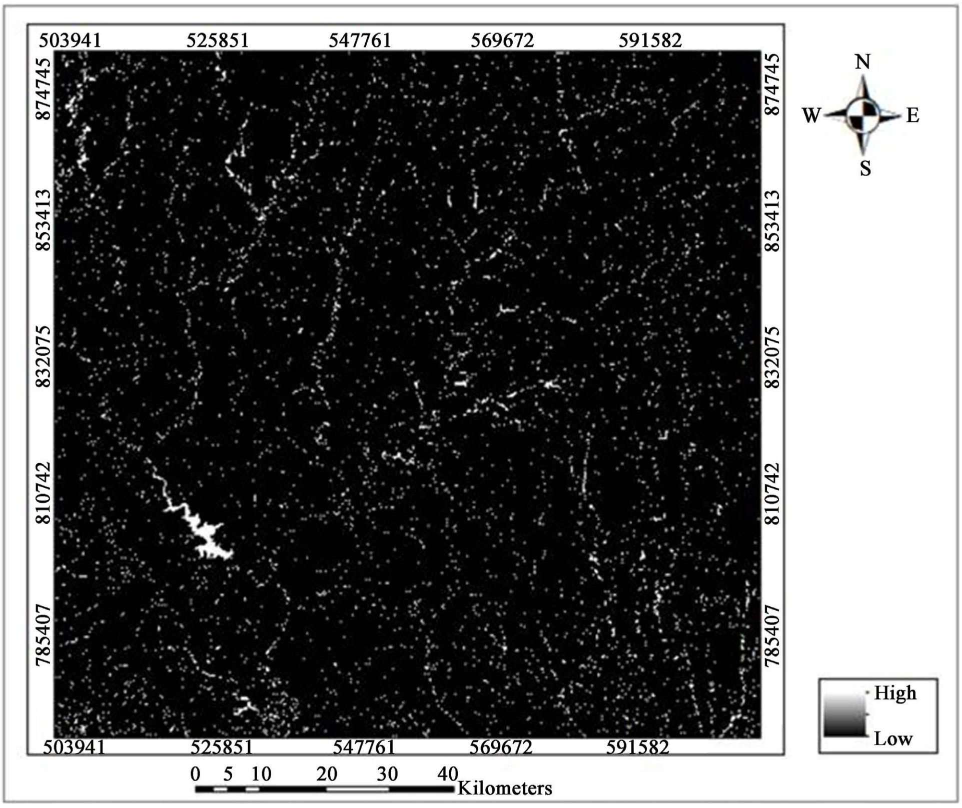

Figure 7. Shaded relief image of angle 50˚ and elevation of 90˚.

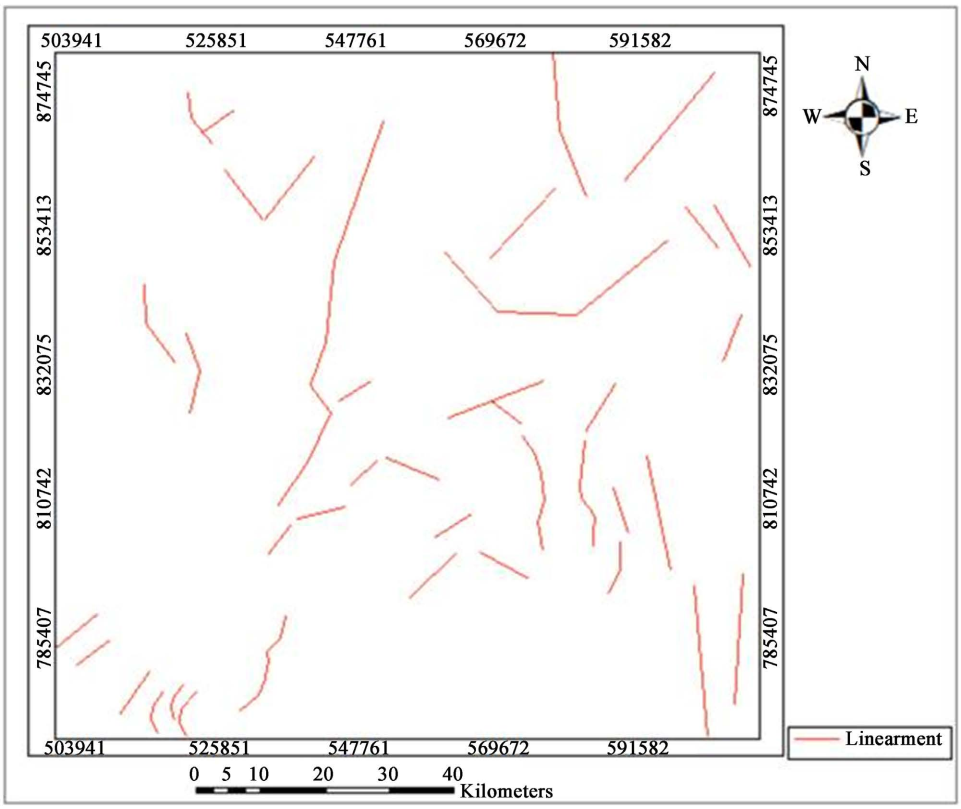

Figure 8. Extracted lineaments over the study area.

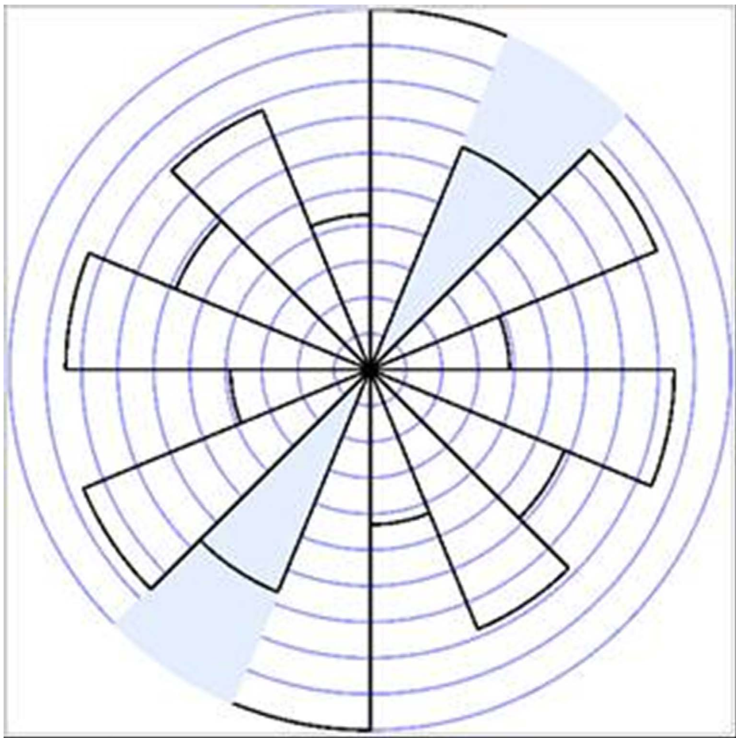

Figure 9. The rose diagram.

trends are in the NNE-SSW, ENE-WSW, NNW-SSE and WNW-ESE directions.

4.2. Lineament Density

The analysis and the interpretation of lineament distribution can also be presented by computing the lineament densities over the study area (**Figure 10**). Lineament density gives important information on geological structures that are favorable for groundwater accumulation and movement [19]-[23]. The zones with lineament density are identified as zones with a high degree of rock fracturing, which is needed for groundwater conduit development in an area. An area with high lineament density is good for water development. According to the lineament density map obtained in this study (**Figure 10**), the study area was classified into four zones and ranked according to their significance to groundwater prospecting. The first zone with deep green is characterized by density values between 0.074046694 and 0.192796247 kilometers is an area with very low groundwater. The second classification with light green is the zone of low yield for groundwater prospect, ranging between 0.192796247 and 0.3115458 kilometers in the area. The third class, with the color of orange, is a zone of moderate groundwater prospect with the density value ranging between 0.3115458 and 0.430295354 kilometers. Areas with density values between 0.430295354 and 0.549044907 kilometers with red have high fracture density and are attributed to extensive fracturing. These areas are classified as zones of high groundwater yield potential which is observed around Abeokuta north, Ibadan southeast, Ibadan northwest, Oyo east, Oyo west, and Iwajowa of the study area.

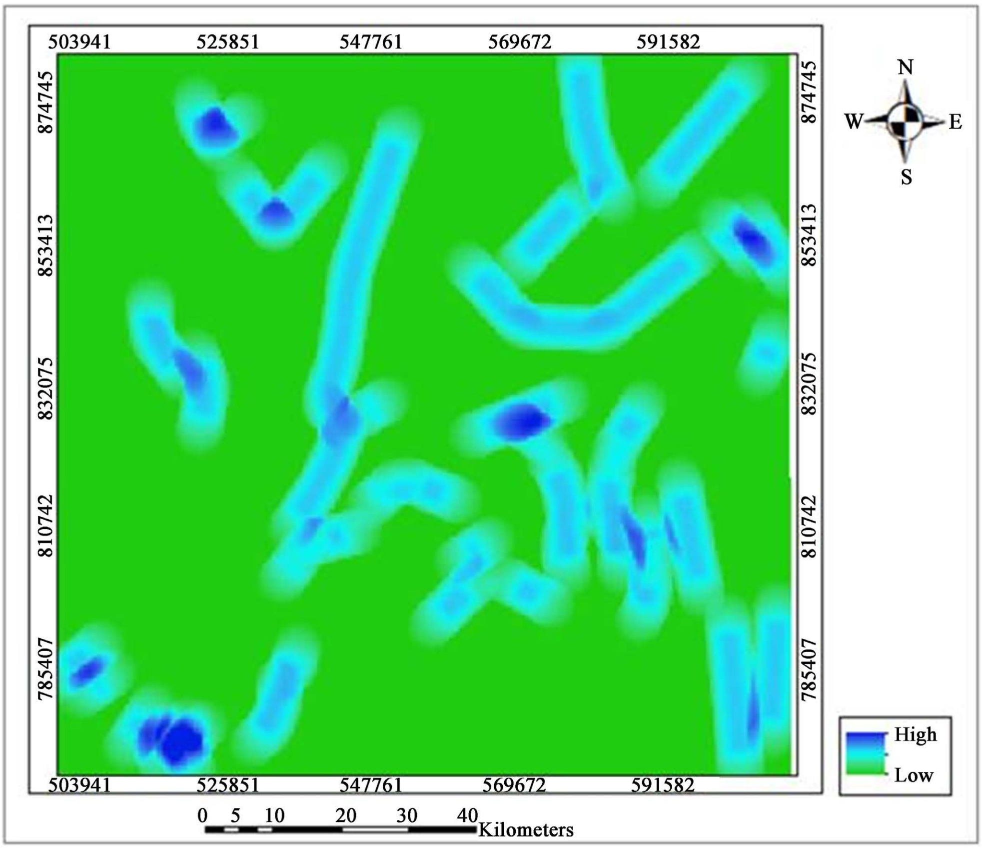

Figure 10. Lineament density map over the study area.

4.3. Lineament Intersection

Figure 11 shows the lineament intersection map within the study location. Lineament intersection is a point of major weakness (node point) between two or more lineaments [19] [20] [23]. The nodal points indicate the major point of interest since the lineament showcases permeable zones [22]. The lineament intersection map shows that the intersected structures are concentrated most in the southwestern and southeastern regions of the area of interest. Other parts of the study area (northern, northeastern, and northwestern) have little or no lineament intersection, which is indicative of a low groundwater prospect. An area with a high concentration of lineament intersection is indicative of high prospects for groundwater potential [24].

4.4. Drainage Pattern

The SRTM DEM imagery was also used to generate the drainage pattern map as shown in Figure 12. The drainage pattern shown in Figure 12 consists of major and minor rivers. The drainage patterns and accumulation over the study area shows that the area with low elevation (Abeokuta north and Abeokuta south) have the highest drainage accumulation. The higher drainage accumulation rate is indicated with figure four (4) and three (3) which stands for the stream ordering on the drainage map (Figure 12) which indicates that water moves from the

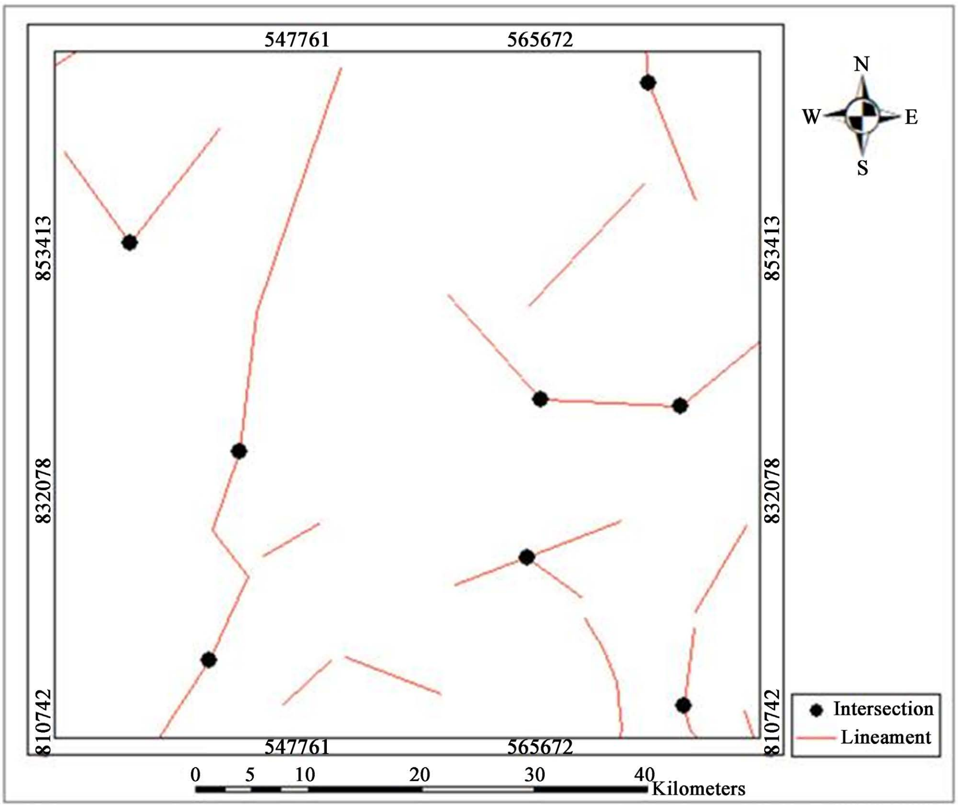

Figure 11. Lineament intersection map over the study area.

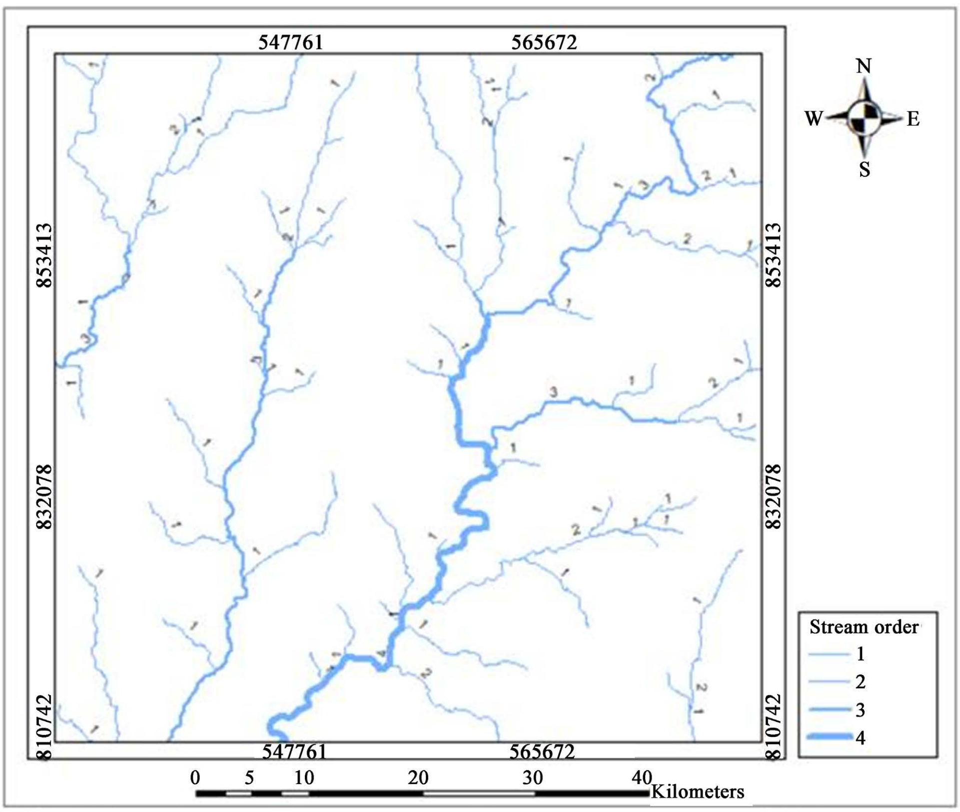

Figure 12. Drainage network of the study area.

highest elevation to the lower point. A moderate rate of accumulation is indicated with figure two (2) and one (1) which can be found in various places in the study area. The drainage patterns within the study area depends on the rock type and structures within the rock [25]. The composite lineament overlaid on the drainage networks (**Figure 13**) showed that the directions of some surface lineaments are in-line with the directions of some tributaries (e.g., river channels in the over-shaped A, B, C and D), which supports the evidence of a structurally controlled drainage patterns [26]. In cases where lineaments are located close to the drainage line with similar directions, the lineaments are delineated as morphological lineaments and might have induced the drainage system [27]. The surface lineaments extracted from the SRTM imageries are denser because the datasets respond to the surface radiation reflectance of the geological units [26].

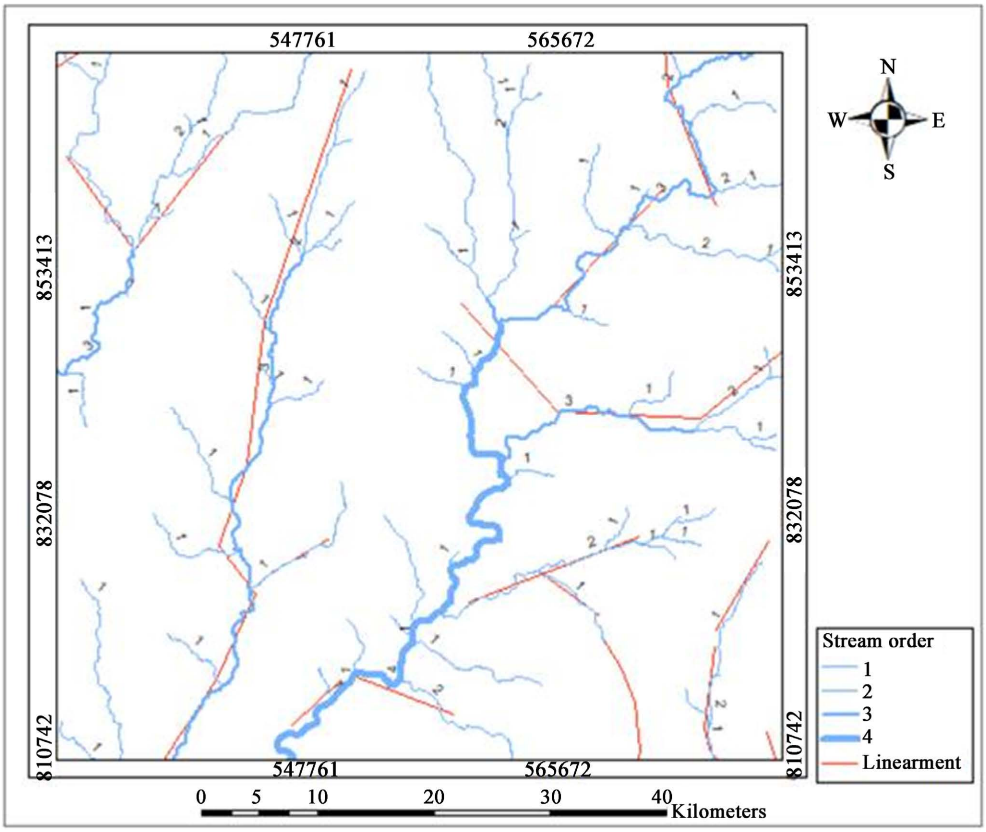

Figure 13. Lineament overlaid on the drainage network.

5. Discussion

We understand the importance of this study, which is beyond the laboratory exercise and may require practical utilization by the government agencies or policymakers. In that way, we carefully deploy the technique of manual extraction of lineaments from the SRTM hillshade image. This technique has an advantage over the automated method of lineament extraction from the hillshade: 1) Detailed analysis, 2) Contextual understanding, 3) Accuracy, 4) Flexibility and 5) Quality control.

Owing to the rapid increase in the national population and Infrastructural development at all tiers of government in Nigeria, an increasing use of groundwater for industrial and domestic purposes has led to depletion of groundwater level in some of the highly industrialized states and cities of Nigeria in Oyo and Ogun states (study region). Since water is an essential ingredient of life, the science and study of its availability would assist governments and other relevant agencies in search of it, for rural and urban developmental planning: settlement, agriculture, and industry. The geospatial techniques are highly efficient and very useful in carrying out regional studies of geological features that serve as a host to groundwater accumulation. However, the identified features: lineament, lineament density, and the drainage network, necessitate geological ground trotting for those of the features that are on the surface and geophysical investigation for those of the features that are buried within the subsurface.

6. Conclusion

In this study, SRTM DEM data were interpreted to extract the lineaments and drainage pattern in the study area to determine the structural relationship between the drainage pattern, remote sensing-derived lineaments, and groundwater potential in parts of Ogun and Oyo state, south-western Nigeria. It was observed from the SRTM DEM data that the highest elevation, which is about 421 m above sea level, is between the northern and northeastern parts of the study area, and the lowest elevation is about 16 m above sea level in the southern part of the study area. The directional analysis of the composite lineament map revealed a major lineament trend in the NE-SW and E-W directions. Other lineament trends observed in the study area are in the NNE-SSW, ENE-WSW, NNW-SSE, and WNW-ESE directions. Visual comparison of lineament density and intersection points revealed that the areas with high density values also have a high cluster of intersection points, which indicates high groundwater potential. These areas are evident in the southwestern and southeastern (Abeokuta north, Ibadan east) parts of the study area. The drainage patterns consist of major and minor rivers. The highest drainage accumulation rate is in red on the drainage map, and it indicates that water moves from the highest elevation to the lower point. A moderate rate of accumulation (yellow and green) can be found in various places in the study area. The composite lineament overlaid on the drainage networks in this study showed that the river channels in the over-shaped A and B are structurally controlled. The study concluded that areas with high lineament density and intersection density are probable areas for high groundwater prospects, and it will be good for groundwater development in the study area.

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: A.B. Arogundade, O.A. Albert; data collection: A.P. Adesope; analysis and interpretation of results: F.O. Adeoti, A.A. Eluyemi, P. Adetokunbo, Mako Sitali, R.B. Adeshina; draft manuscript preparation: A.O. Olorunfemi, M.O. Awoyemi. All authors reviewed the results and approved the final version of the manuscript.

Availability of Data

SRTM was obtained from: https://earthexplorer.usgs.gov/.

Materials

Internet service and software were obtained from the Afrigist.

Ethics Approval

This study requires no ethical approval because it does not deals direcly with human beings neither does the research pertains to animal.

Conflicts of Interest

The authors declare no conflicts of interest.

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