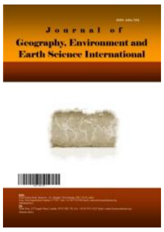

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Mapping of Geological Lineaments from Different Sun Elevation Angles Using Digital Elevation Model (DEM): A Case Study of Nigeria Geology Map Series Sheet 135 (Duhu Sheet)

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The study focuses on the mapping of geological lineaments from the following different sun elevation angles: 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° of the Digital Elevation Model (DEM). Four of the images with azimuth; 0°, 45°, 90° and 135° were combined to produce a single image with multi-illumination directions. The images with azimuth; 180°, 225°, 270°, and 315° were equally combined to produce another single shaded relief image with multi-illumination directions. The two multi-illumination direction images were used for the automatic lineament extraction using PCI Geomatica software. The extracted lineaments were overlaid, and duplicate lineaments were eliminated. The final lineaments of the study area were screened using high-resolution Google images for non-geological features. A total of 237 lineaments were extracted, with a total length of 649.77Km, a mean length of 2.742Km and standard deviation of 1.187. The dominant trending pattern in the final lineaments of the study area is NE-SW direction. The Lineament density for the study area ranges from 0 to 1.36 km/sqkm with about 69.1% of the study area being mapped as poor and low density while the high and very high densities area account for just about 30.9% of the study area.

Keywords: Lineament; SRTM DEM; hill shade; azimuth; mapping.

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1. INTRODUCTION

Lineaments have been defined as linear topographical or tonal features on the terrain representing zones of structural weakness. They are usually manifested as; shear zones/faults rift valleys truncation of outcrops, fold axial traces; joint and fracture traces, straight valleys, continuous scraps, straight streams segments and rock boundaries, a systematic offset of streams, sudden tonal variations and alignment of vegetation topographic, [1,2]. According to Abdullah et al. [3], shaded relief images generated from Digital Elevation Model (DEM) are helpful in identifying lineaments in different distinct relief and topography because this approach can enhance lineaments at specific orientations by simulating topographic illumination under various light directions. They further classified lineaments as positive and negative lineaments based on tonal variation. Positive lineaments, interpreted as linear ridges, scarps, ridges, troughs and craters are represented as light-toned lineaments while negative lineaments, representing joints, faults, and shear zones are seen as dark-toned lineaments. The Shuttle Radar Topography Mission (SRTM) DEM's shaded relief images and terrain derivative maps (slope, aspect and curvatures) have largely demonstrated their usefulness for lineaments and fault extraction [4].

The Shuttle Radar Topography Mission (SRTM), is a joint project of the National Aeronautics and Space Administration (NASA), the National Geospatial-Intelligence Agency (NGA) and the German and Italian Space Agencies. The SRTM was flown on Space Shuttle Endeavour from 11 to 22 February in 2000 to acquire a Digital Elevation Model (DEM) of all land between latitudes 60^{o} N and 56^{o} S, about 80% of the Earth's land surface [5,6]. SRTM data are organized into individual rasterized cells, or tiles, each covering 1^{o} by 1^{o} in latitude and longitude with a sample spacing for individual data points at 1 or 3 arc sec. Since 1 arcsec at the equator corresponds to roughly 30m in horizontal extent, the 1 or 3 arc sec are sometimes referred to as '30 m' or '90 m' SRTM data resolution respectively. Owing to its uniform resolution and accuracy over most of the Earth's surface, SRTM data has been used in various research fields including, but not limited to, geology, geomorphology, water resources and hydrology, glaciology, evaluation of natural hazards and vegetation surveys (Yang et. al., 2010).

Topographic attributes from SRTM DEM data can be extracted by applying special computer algorithms which include slope, aspect and shaded relief algorithms [3].

Many researchers have extracted lineament from Landsat and DEM imageries for various applications in the field of geosciences such as; water resource exploration and abstraction, hydrogeomorphology, ore and mineral exploration, and geological mapping for several purposes [7,8,9,10,11]. DEM, unlike Landsat images, has provided a higher detailed terrain and structural information of the Earth surface than Landsat images [8].

Sarat et al., [12] first demonstrated the role of light in observing an object. They found that when an object is illuminated with light from a few angles it causes what is known as the False Topographic Perception Phenomenon (FTPP). The perception of valleys as ridges and vice versa is the result of FTPP having a strong influence on the identification of lineaments from different azimuth angles. Some azimuth angles are very good to provide a higher number of lineaments with great accuracy where FTTP is not detected or corrected.

This study aims at applying GIS technology to automatically extract, map and analyze lineaments from multi-directional light sources (different sun azimuth angles) shaded relief images derived from DEM data set of the Nigeria geological map series Sheet 135 known as Duhu sheet.

1.1 Study Area

The study area lies between northings $10^{o}30'$N to $11^{o}00'$N and eastings $13^{o}00'$E to $13^{o}30'$E in the North-eastern part of Nigeria. The area is characterized by hills to the southeastern and eastern parts, with other areas having low undulating topography. According to Nigerian Geological Survey Agency, NGSA [13], the area is part of Mandara Mountains which together with the adjacent Hawal and Adamawa Massifs form the northeastern basement complex of Nigeria, which is underlain mainly by granite and pegmatite with minor quartzite. Outcrops are restricted to the eastern part of the study area, as the western side is characterized by pond and flood plains. Granites are the most dominant rock in the study area. They grade from fine to medium to coarse and even porphyritic grains. Drainage pattern is of the dendritic type, typical of a basement area.

2. MATERIALS AND METHODS

The materials used in this work are the DEM image of the study area retrieved from the Shuttle Radar Transmission Mission (SRTM) of 1 arc (30 m) resolution obtained from USGS website and Google earth. While the respective software packages are ERDAS Imagine 2015, PCI Geomatica 2015, ArcGIS 10.5 and Rockworks 2016. The method employed consists of the following sequences as illustrated in the flow chart diagram in Fig. 1.

The first step is the generation of eight shaded relief images from the following sun illumination angles (azimuth); 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° using ERDAS Imagine software. A solar elevation angle of 30° and an ambient light setting of 0.20 was chosen to ensure good contrast [3].

After the generation of the eight shaded relief images, four of the images with azimuth; 0°, 45°, 90° and 135° were combined to produce a single image with multi-illumination directions. Equally, the images with azimuth; 180°, 225°, 270°, and 315° were combined to produce another single shaded relief image with multi-illumination directions.

The production of the two multi-illumination direction images of the shaded relief images was followed by automatic lineament extraction. The "Lineament Extraction" (LINE) algorithm of PCI Geomatica software was used to automatically extract lineaments in this work. The algorithm consists of edge detection, thresholding and curve extraction steps [14]. These steps were carried out on the two multi-illumination direction images with the six default parameters; RADI, GTHR, LTHR, FTHR, ATHR and DTHR of the algorithm. The input of these parameters are usually pixel or threshold values that control the process of the lineament's extraction. They are briefly explained according to Hubbard et al., [9] as;

RADI (Filter radius) specifies the pixel distance of edge detection filtering such that smaller values can be used to detect more detail, but larger values can be used to minimize the detection of noise.

GTHR (Gradient threshold) specifies the minimum threshold change in brightness, which defines an edge pixel.

LTHR (Length threshold) specifies the minimum threshold of curvature (in pixel distance) used for mapping curved features as valid lineaments.

FTHR (Line fitting error threshold) specifies the maximum error (in pixel distance) allowed in fitting a vector GIS arc or polyline to pixels defining a curved feature, such that lower values yield better fits using a number of shorter line and arc segments, while higher values yield coarser fits using longer lines and arcs with fewer segments.

ATHR (Angular difference threshold) specifies the maximum angle (in degrees) between two neighboring polyline or arc segments, below which they can be linked into a single vector polyline or arc.

DTHR (Linking distance threshold) specifies the minimum distance (in pixels) between the end points of two polyline or arcs for them to be linked.

The extraction process is manipulated by changing the values of the six parameters in order to obtain the most suitable pixel and threshold values. General properties such as the size of the study area and data resolution were taken into consideration [15,9]. The parameters values used in this work are presented in Table 1.

The LINE module extracts all linear features from an image and records the polylines in a vector layer [16]. The extracted lineaments were compared with a topographical map, high-resolution Google images and drainage map of the study area to screen and eliminate non-geological lineaments such as roads, drainage, footpaths, field boundaries etc.

Table 1. Parameters and values of automatic extraction process

Parameters	Description	Values
RADI	Filter radius (pixels)	5
GTHR	Edge gradient threshold	5
LTHR	Curve length threshold (pixels)	30
FTHR	Line-fitting error threshold	3
ATHR	Angular difference threshold (degree)	20
DTHR	Linking distance threshold (pixels)	1

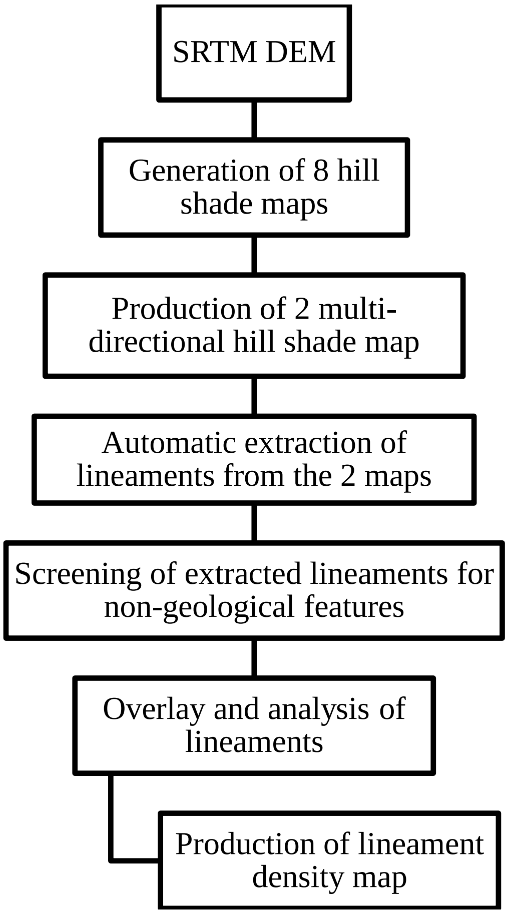

Fig. 1. Flowchart of lineaments extraction

After this elimination process, the remaining geological lineaments from the two multi-illumination direction images are stored in separate GIS shape files and analysed for the number and length of lineaments. This was followed by combining the two GIS shape files into a single shape file to eliminate any duplicates. From this output, the total lineament map of the study area was generated, statistically analyzed and a rose diagram generated using Rockworks software to determine the orientation of the lineaments. In the final stage, the lineaments'density map of the study area was produced.

3. RESULTS AND DISCUSSION

The result of the generated eight hill-shaded relief maps from the sun illumination angles (azimuth) of; 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° is presented in Fig. 2(a – h). The combined hill-shade image of azimuth 0°, 45°, 90° and 135° and that of azimuth 180°, 225°, 270°, and 315° are respectively present in Fig. 3a and b) with their automatic extracted lineaments.

The combined extracted lineaments from the two multi-illumination direction images of the hill shaded relief images were overlayed and mapped out to give an overall total lineament map of the study area as presented in Fig. 4 with the statistical analysis in Table 2.

A total of 151 lineaments have been extracted from the combined hill-shaded images of azimuth 0°, 45°, 90° and 135° while 191 lineaments from the combined hill-shaded images of azimuth 180°, 225°, 270° and 315° (Table 2). The combined western azimuths (180°, 225°, 270° and 315°) is observed to have a greater number of extracted lineaments than the combined eastern azimuth (0°, 45°, 90° and 135°). This is in agreement with the work of Oguchi et al., [17] where they observed that certain illumination angles are easier to identify a fault which some angles failed to reveal the fault.

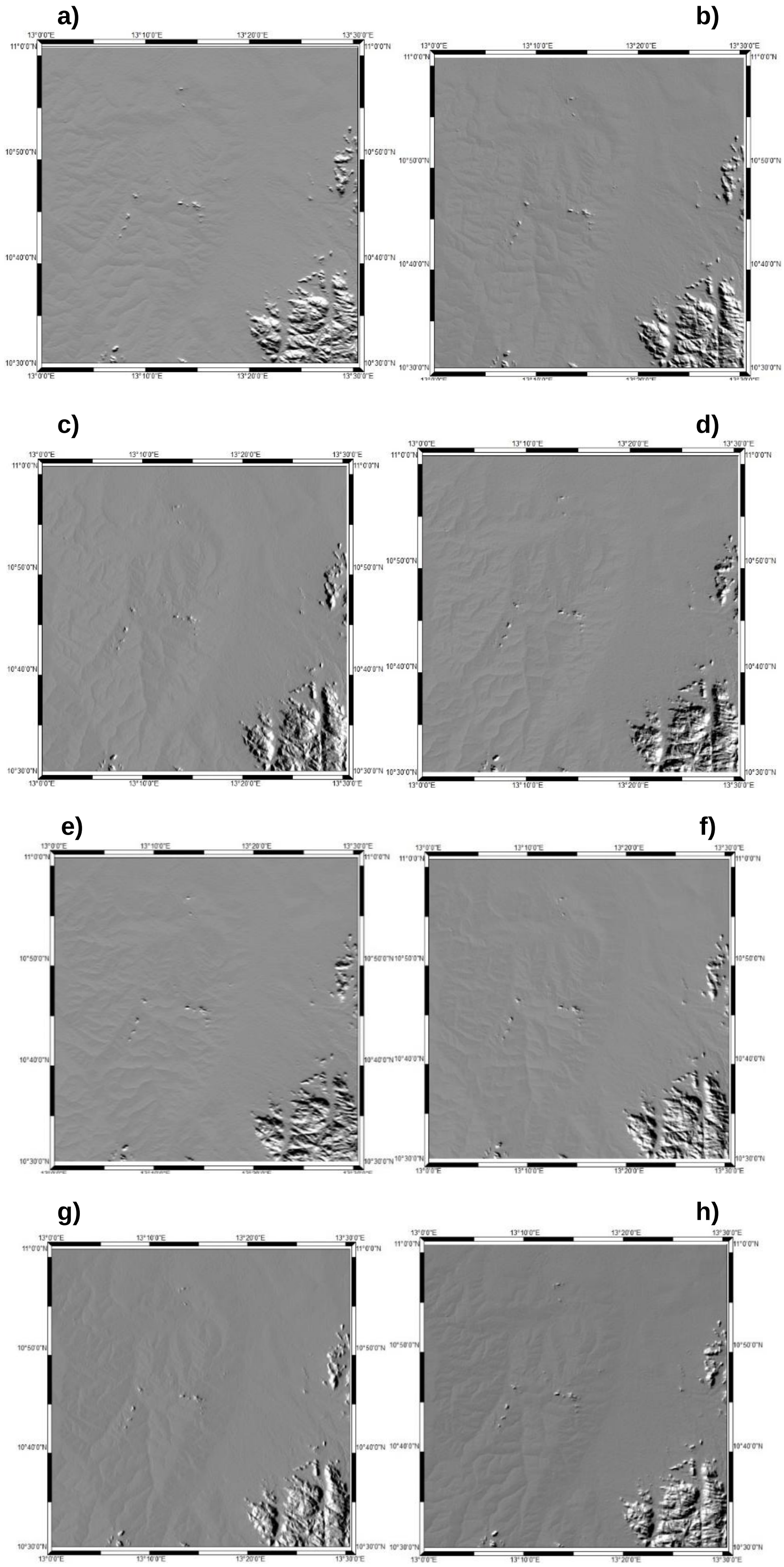

Fig. 2a-h. Hill shaded image of azimuths 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° respectively

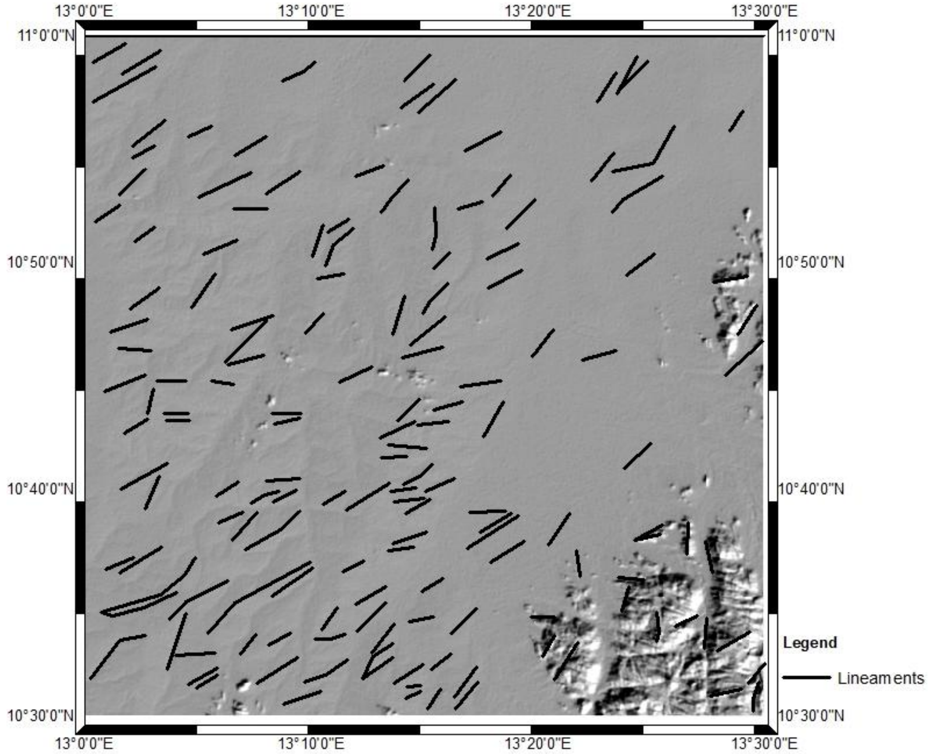

Fig. 3a. Combined hill-shade image of azimuth 0°, 45°, 90° and 135° with the automatically extracted lineaments

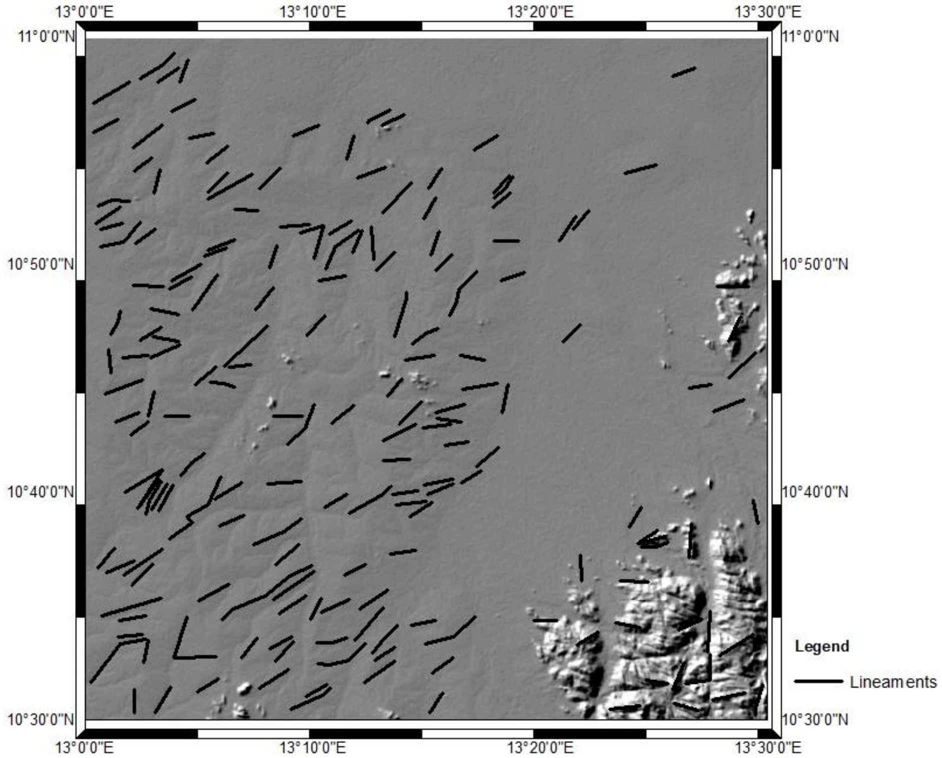

Fig. 3b. Combined hill-shade image of azimuth 180°, 225°, 270°, and 315° with the automatically extracted lineaments

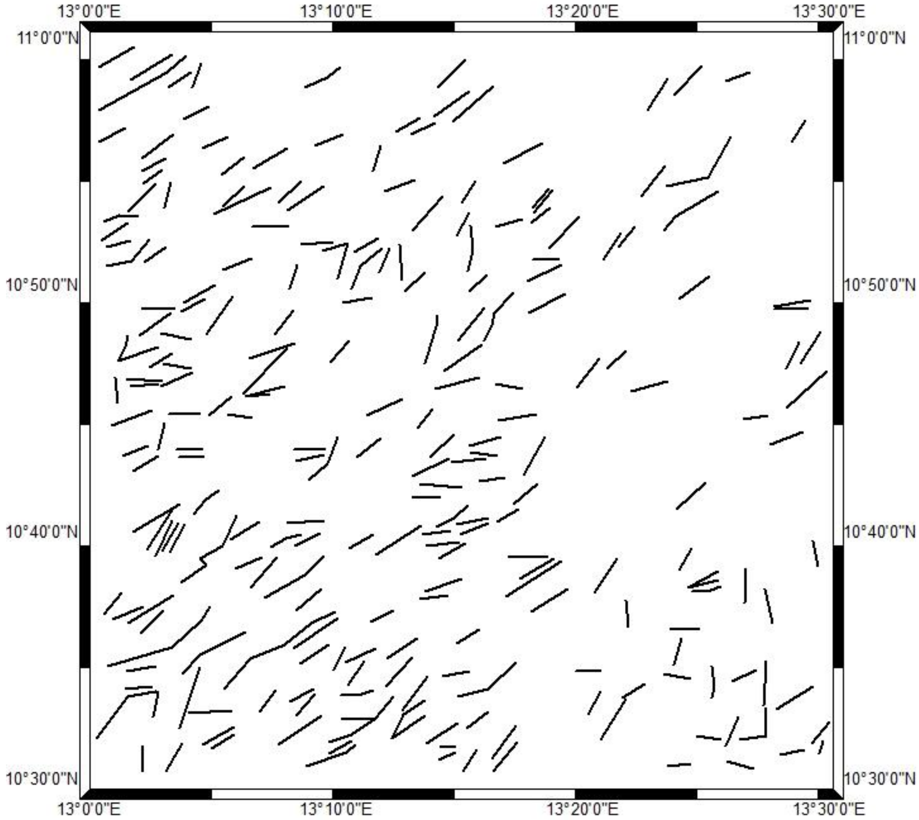

Fig. 4. Total lineament map of the study area

Table 2. Basic statistics of the automatic lineaments' maps

	Lineaments of the combined hill-shade image of azimuth 0°, 45°, 90° and 135°	**Lineaments of the combined hill-shade image of azimuth 180°, 225°, 270°, and 315°**	**Overlay lineaments of the study area**
Number of Lineaments	151	191	237
Min. length (km)	1.16	1.83	1.16
Max. length (km)	10.12	10.13	1.83
Mean length (km)	3.01	1.11	2.74
Total length (km)	453.97	494.37	647.77

The total length of combined hill-shaded images of multi-directional with azimuth 0°, 45°, 90° and 135° is 452.97 Km with a minimum length of 1.16Km, maximum length of 10.12Km and a mean length of 3.01 Km. The combined hill-shaded image with azimuth 180°, 225°, 270° and 315° has a total length of 494.37 Km, minimum length of 1.83 Km, maximum length of 10.13 Km and mean length of 2.59 Km.

The total number of lineaments in the study area that were mapped out from the overlay of the extracted lineaments from the two multi-directional sun angle hill-shaded images are 237, with a total length of 649.77Km with a mean length of 2.74Km and standard deviation of 1.19. From the Histogram plot of the total lineament length of the study area (Fig. 5), the lineaments show a positive skewness, which is an indication that most lineaments in the study area are not extensive [18].

The orientation of the lineaments represented by the rose diagrams in Fig. 6 shows the trend in terms of the length and directional frequency which is an indication of the dominant directions of the lineaments. The dominant trending pattern in the lineaments is NE-SW direction.

The lineament density calculates the magnitude of lineaments per unit area. It aids in expressing the spatial variation in the geologic or geomorphologic processes taking place on the subsurface, surface or terrain of the area under investigation. Lineament density map produced from the total lineaments of the study area (Fig. 7) ranges from 0 to 1.36 km/sqkm and classified as poor, low, high and very high-density area based on the lineament length per unit area (Table 3).

The statistical description of the lineament density map presented in Table 3 shows that areas of poor and low densities make up the greater part of the study area, with a total area of about 522.20 sqkm and 422.23sqkm respectively. This land mass accounts for about 69.1% of the study area. The high and very high densities area account for just about 30.9% of the study area with an area of about 296.97sqkm and 126.57sqkm respectively.

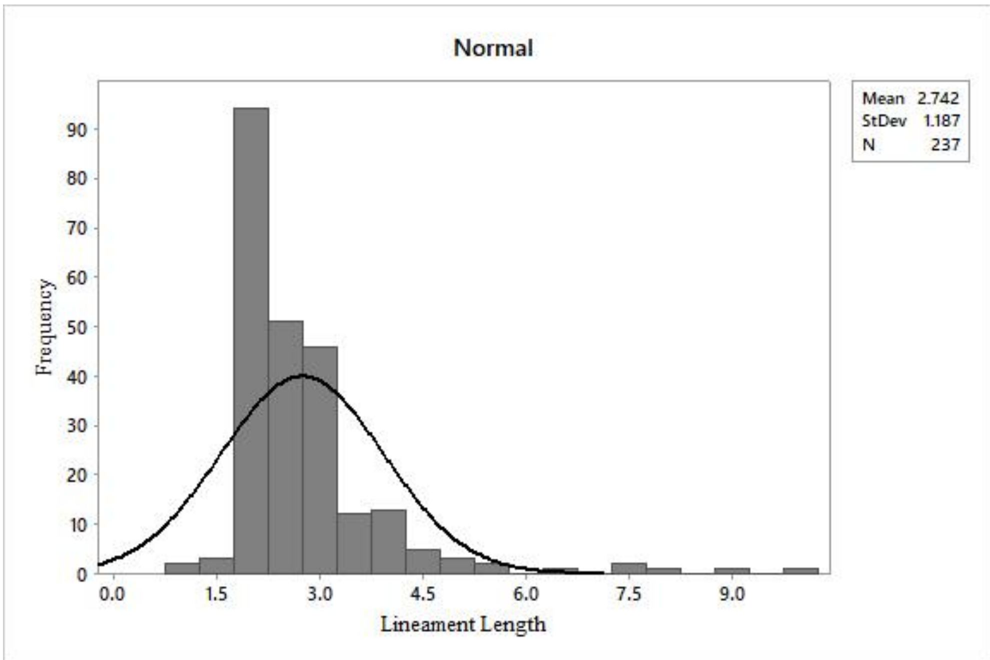

Fig. 5. Histogram of the total lineament of the study area

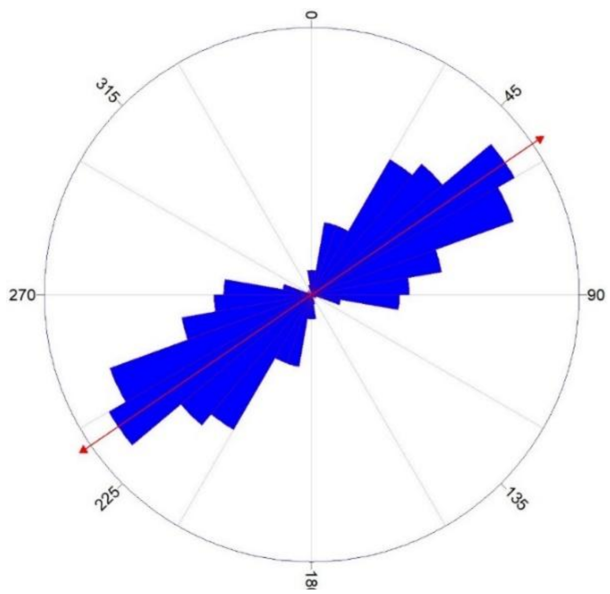

Fig. 6. Rose diagram of the lineament map

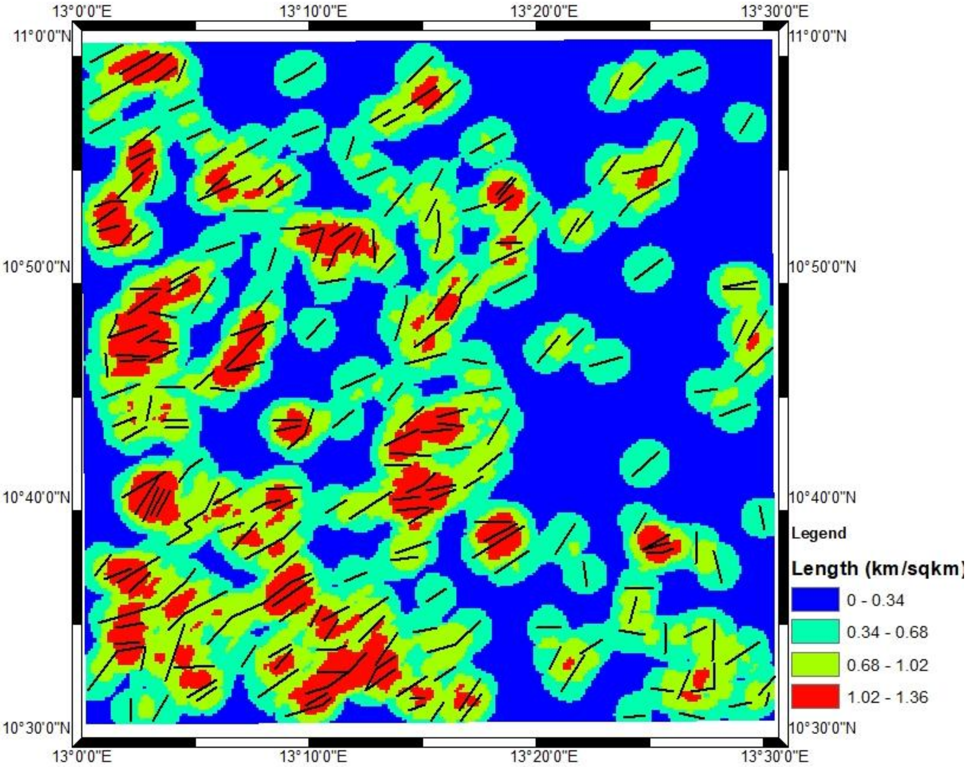

Fig. 7. Lineament density map of the study area

Table 3. Statistical description of lineament density map of the study area

S/N	Lineament density (km/sqkm)	Area (sqkm)	Description
1	0 – 0.34	522.20 (38.2%)	Poor
2	0.34 – 0.68	422.23 (30.9%)	Low
3	0.68 – 1.02	296.97 (21.7%)	High
4	1.02 – 1.36	126.57 (9.2%)	Very high

4. CONCLUSION

The study demonstrates the use of SRTM DEM with 30 m spatial resolution for lineament extraction. Hill-shaded relief images with variations of azimuth were employed for the automatic extraction. Lineament extracted from the multi-directional Sun angle (180°, 225°, 270°, 315°) gives a greater number of both lineaments and total lineaments' length than that of the multi-directional Sun angle (0°, 45°, 90°, 135°). It is therefore clearly understood that the most common method to extract lineaments from a single azimuth angle cannot provide detailed information of available lineaments of an area. However, more accurate information can be extracted by tracing the lineaments from different azimuth angles, to give the true picture of the number and length of lineaments [19]. Apart from this finding, the present study provides information about the lineament dataset and density map of the Nigeria Geology Map Series Sheet 135 (Duhu Sheet) which could be useful for groundwater and mineral resource exploration and management. Further work using aeromagnetic map can also be employed to extract the geologic features in the study area and compared with the extracted lineaments from SRTM DEM. Meanwhile, a very low frequency (VLF) electromagnetic method of geophysical method can be used for possible identification and confirmation of the extracted lineaments.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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