

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)

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. 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, DEM, Hill shade, Azimuth, Mapping.

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 scarp, straight streams segments and rock boundaries, a systematic offset of streams, sudden tonal variations and alignment of vegetation topographic, (Raj et.al., 2017; Gupta, 1991). According to Abdullah et al. (2010), 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.

Many researchers have extracted lineament from remotely sensed images 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 (Das et al. 2018; Das and Pardeshi 2018; Hubbard et al. 2012; Aluko and Igwe, 2018; Kamil and Setiawan, 2022)

DEM data are digital elevation data sets recording the topographic surface expression of any area. Topographic attributes from DEM data can be extracted by applying special computer algorithms which include slope, aspect and shaded relief algorithms. (Abdullah et. al., 2010). DEM, unlike Landsat images, represents true real projections with no distortion; tonal variations

are entirely identified with relief, the sun position can be placed anywhere above the terrain surface, and in most cases, DEM has better resolution than satellite images (Schowengerdt and Glass, 1983). DEMs shaded relief images and terrain derivative maps (slope, aspect and curvatures) have largely demonstrated their usefulness for lineaments and fault extraction. Sarat et. al., (2007) 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 FTTP 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.

STUDY AREA

The study area lies between northings $10^{\circ}30'N$ to $11^{\circ}00'N$ and eastings $13^{\circ}00'E$ to $13^{\circ}30'E$ 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, NGS (2006), 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 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.

MATERIALS AND METHOD

The material used in this work are the DEM image of the study area retrieved from the Shuttle Radar Topographic Mission (SRTM) and google earth. While the respective software are ERDAS Imagine 2015, PCI Geomatica 2015, ArcGIS 10.5 and Rockworks 2016. The method employed consists of the following sequences.

The first step is the generation of eight shaded relief maps from the following sun illumination direction (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 (Abdullah et al., 2010).

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 (PCI Geomatica, 2001). These steps were carried out on the two multi-illumination direction images with the six default parameters (RADI, GTHR, LTHR, FTTH, 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., 2012 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 (Kusak and Krbcova, 2017; Hubbard et. al., 2012). The parameters values used in this work are presented in Table 1.

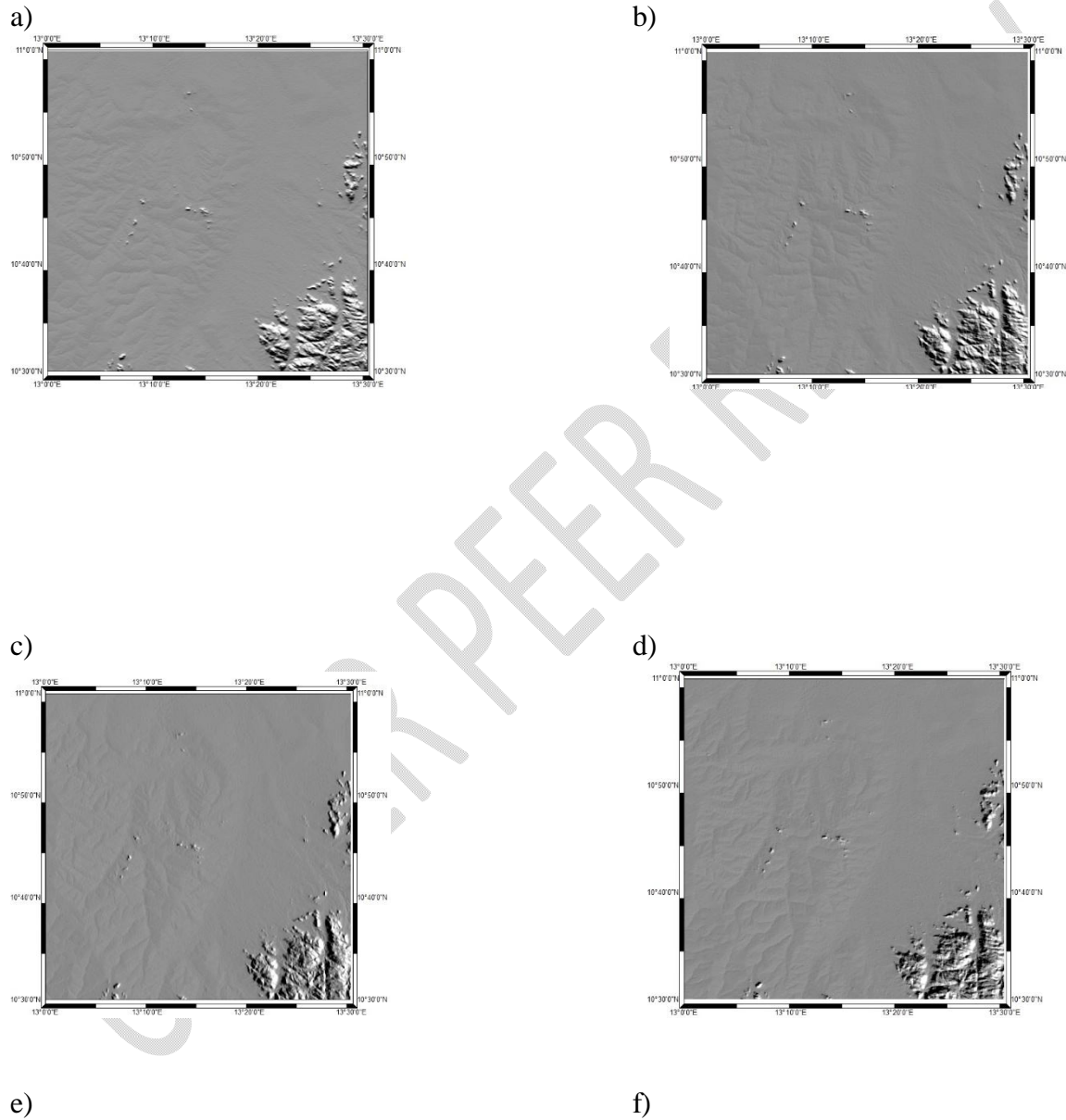
Table 1: Parameters and values of automatic extraction process.

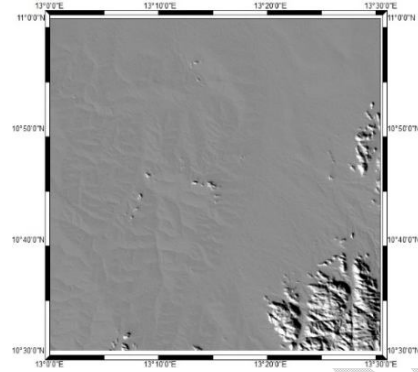
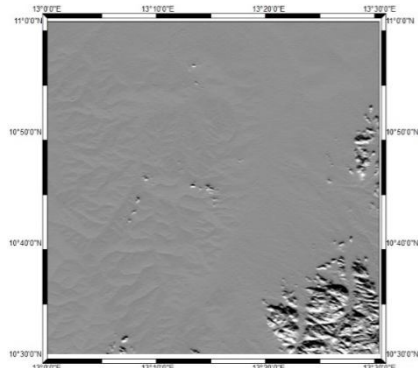
Parameters	Description	Values
RADI	Filter radius (pixels)	50
GTHR	Edge gradient threshold	10
LTHR	Curve length threshold (pixels)	30
FTHR	Line-fitting error threshold	3
ATHR	Angular difference threshold (degree)	15
DTHR	Linking distance threshold (pixels)	10

The LINE module extracts all linear features from an image and records the polylines in a vector layer (Manjare and Pophare, 2019). 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. 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. In the final stage, the orientation of lineaments of the study area was also analysed and a rose diagram generated using Rockworks software.

RESULTS AND DISCUSSION

The result of the generated eight hill-shaded relief maps from the sun illumination direction (azimuth) of; 0° , 45° , 90° , 135° , 180° , 225° , 270° , and 315° using ERDAS Imagine software is presented in figure 1(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 figure 2a and b) with their automatic extracted lineaments.





g)

h)

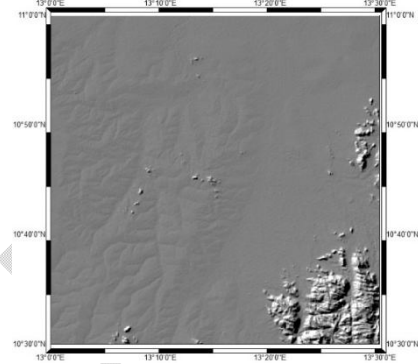
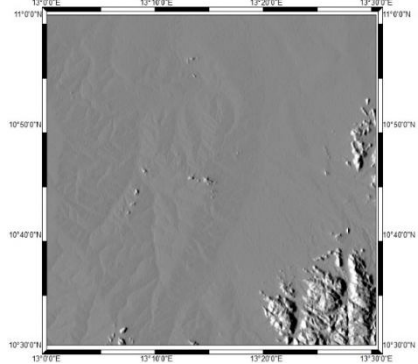


Fig 1a-h). Hill shaded image of azimuths 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° respectively.

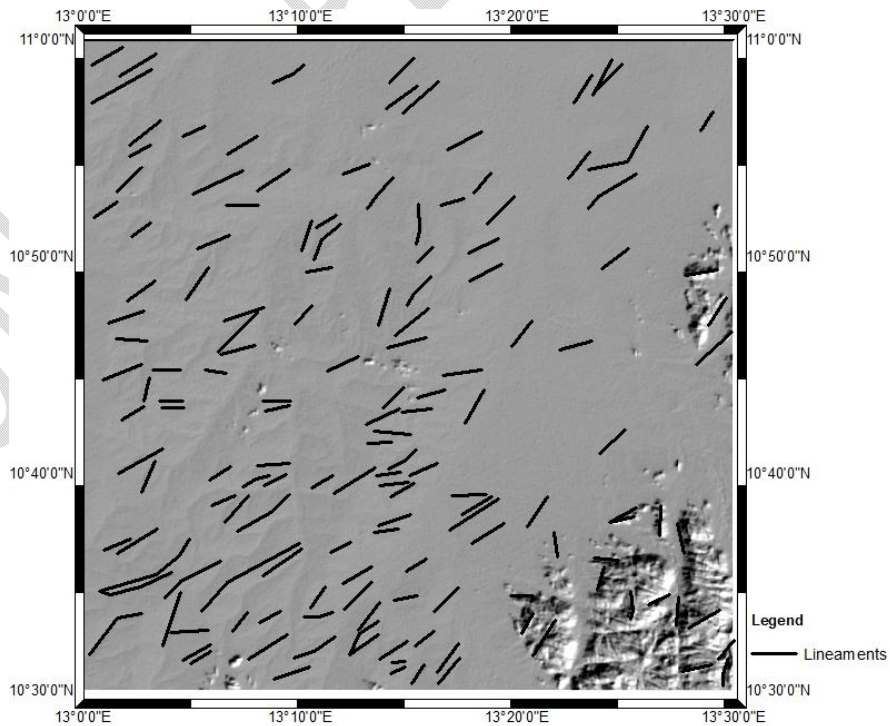


Fig. 2a) Combined hill-shade image of azimuth 0°, 45°, 90° and 135° with the automatically extracted lineaments

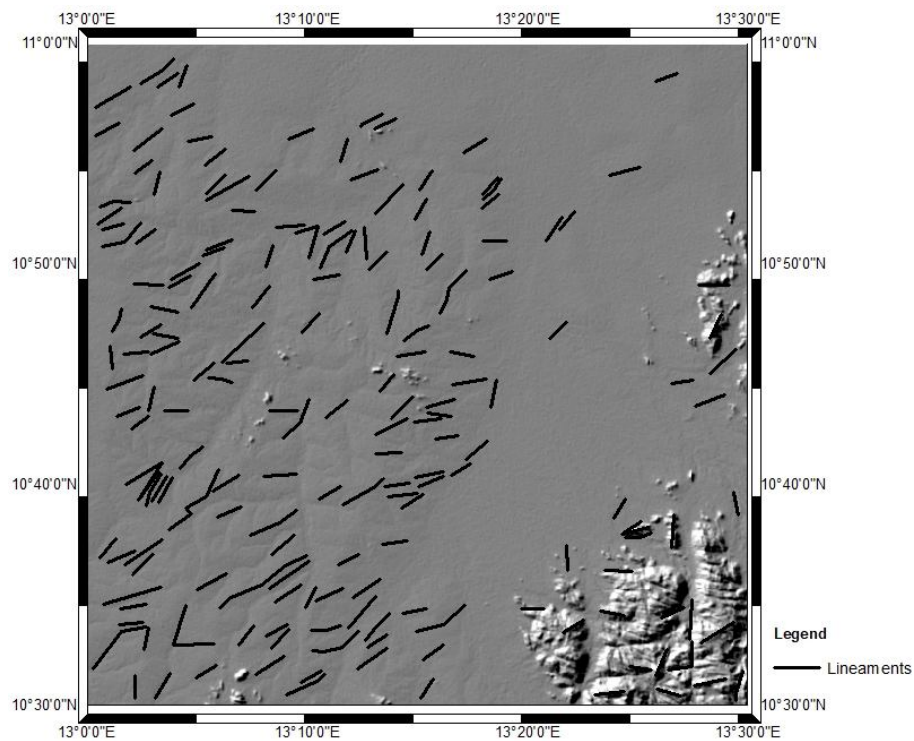


Fig. 2b) Combined hill-shade image of azimuth 180°, 225°, 270°, and 315° with the automatically extracted lineaments

The combined extracted lineaments from the two multi-illumination direction images of the shaded relief images were overlaid and mapped out to give an overall total lineament map of the study area as presented in figure 3 with the statistical analysis in Table 2.



Fig. 3: 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	2.43
Total length (km)	453.97	494.37	647.77

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., (2003) where they observed that certain illumination angles are easier to identify a fault which some angles failed to reveal the fault.

The total length of combined hill-shaded images of multi-directional with azimuth 0°, 45°, 90° and 135° is 452.97Km with a minimum length of 1.16Km, maximum length of 10.12Km and a

mean length of 3.01Km. The combined hill-shaded image with azimuth 180°, 225°, 270° and 315° has a total length of 494.37Km, minimum length of 1.83Km, maximum length of 10.13Km and mean length of 2.59Km.

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 and a mean length of 1.19Km. From the Histogram plot of the total lineament length of the study area (Figure 4), the lineaments show a positive skewness, which is an indication that most lineaments in the study area are not extensive (Ishaku and Abubakar, 2016).

The orientation of the lineaments represented by the rose diagrams in figure 5 shows the trend in terms of the length and directional frequency which are an indication of the dominant directions of the lineaments. The dominant trending pattern in the lineaments is NE-SW direction.

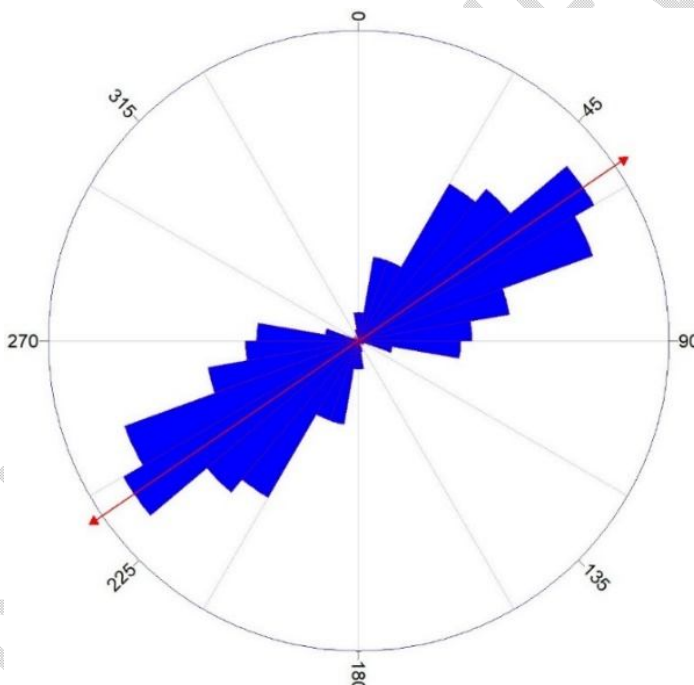


Fig. 4: Rose diagram of the lineament map

Lineament density

The lineament density calculates the magnitude of lineaments per unit area (Fig. 5). 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 for the study area ranges from 0 to 1.36 km/sqkm (Fig. 5).

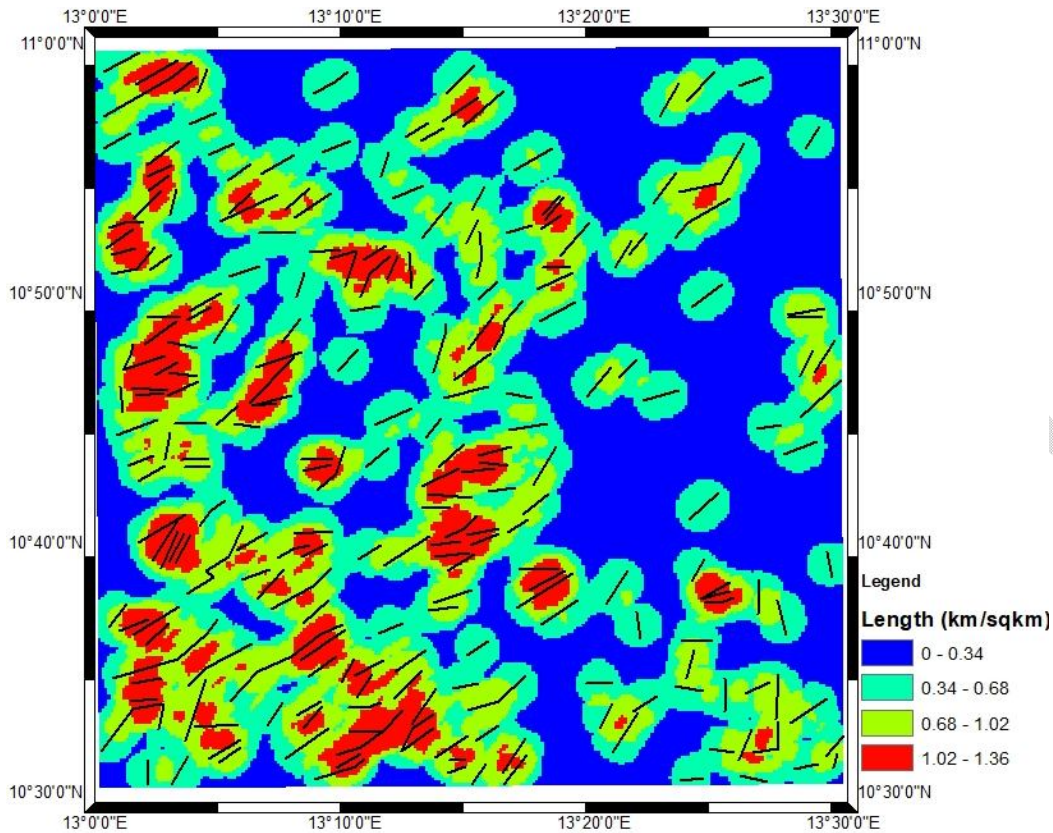


Fig. 5; Lineament density map of the study area

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

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 522.20sqkm 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.

CONCLUSION

The study demonstrates the use of DEM with 30m 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 (Jawahar et al.2017).

REFERENCES

- Abdullah, A., Akhir, J. and Abdullah, I. (2010) Automatic Mapping of Lineaments Using Shaded Relief Images Derived from Digital Elevation Model (DEMs) in the Maran - Sungai Lembing Area. *Electronic Journal of Geotechnical Engineering*, 15, 949957.
- Aluko O. E and Igwe O (2018). Automated Geological lineaments mapping for groundwater exploration in the basement complex terrain of Akoko-Edo area, Edo-State Nigeria using remote sensing techniques. *Modeling Earth Systems and Environment*. <https://doi.org/10.1007/s40808-018-0511-4>
- Das, S., and Pardeshi, S.D (2018) Comparative analysis of lineaments extracted from Cartosat, SRTM and ASTER DEM: a study based on four watersheds in Konkan region, India. *Spat Inf Res* 26(1):47–57
- Das S, Pardeshi, S.D Pallavi P. Kulkarni PP and Arjundode (2018) Extraction of lineaments from different azimuth angles using geospatial techniques: A case study of pravara basin, maharashtra, India. *Arabian journal of Geosciences* 11:160
- Gupta, R.P. (1991) *Remote Sensing Geology*, Berlin, Heidelberg: Springer-Verlag.
- Hubbard BE, Mack TJ, Thompson AL (2012) *Lineament Analysis of Mineral Areas of Interest in Afghanistan*, U.S. Geol Sur Open-File Report 2012–1048: 28 p
- Ishaku, Y.M. and Abubakar, Y.I (2016). Lithological mapping and lineament analysis in Zaria and its Environs using remote sensing technique. *Zaria Geographer* Vol. 23, (1), 62-82.
- Jawah, N., Raj, P. A and Muthukrishnan A (2017). Extraction and analysis of geological lineaments of kolli hills, Tamil Nadu a study using remote sensing and GIS. *Arab j Geos* 10:195
- Kamil F and Setiawan B (2022). Lineament extraction and the correlation to vegetation and moisture indices for groundwater prediction in south Bengkulu, Indonesia. *Bulletin of Geology*, Vol. 6, NO. 2, DOI: 10.5614/bull.geol.2022.6.2.7
- Kusak and Krbcova (2017): Analysis of the relationship of automatically and manually extracted lineaments from DEM and geologically mapped tectonic faults around the Main Ethiopian Rift and the Ethiopian Highlands, Ethiopia *AUC Geographica*, 52, No. 1, pp. 5–17
- Manjare B. S and Pophare A. M (2019). Lineament Mapping Using Shaded Relief Images Derived from Digital Elevation Model. *JGSR*, Vol. 4, No.2, pp. 155-161.
- Nigerian Geological Survey Agency, (2006). *Geological Map of Latitude 11° 30' -13° 30' and Longitude 4° 00' and 6° 00'*

Oguchi T, Aoki T, matsuta N (2003) Identification of an active fault in the Japanese aips from DEM based hill shading comput Geosci 29:885-891

PCI Geomatica (2001) PCI Geomatica user's guide version 9.1, Ontario. Canada: Richmond Hill.

Raj, N.J, Prabhakaran A, Muthukrishnan A (2017) Extraction and analysis of geological lineaments of Kolli hills, Tamil Nadu: a study using remote sensing and GIS. Arab J Geosci 10:195.

Sarat A, Sudipta S, Ghosh P, Swapnamita C (2007). A new technique to remove false topographic perception phenomenon and its impacts in image interpretation (2007) International journal of remote sensing 28 (5) : 811-821

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