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Automatic Extraction and Analysis of Lineaments for Assessing Groundwater Potential towards Sustainable Development in the Owo Area of Ondo State, Nigeria

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ABSTRACT: Understanding a region's tectonic history, groundwater accumulation, and environmental planning requires a thorough evaluation of the topography. A feasible groundwater mapping technique is the automatic extraction and analysis of lineaments. Applying the LINE Algorithm to band-8 (15m resolution) of Landsat-7 Enhanced Thematic Mapper Plus (ETM+) imagery, this study focuses on lineaments delineation in the Owo area of Ondo State, Nigeria. Band 8 was found to be the most suitable for automatic delineation due to its high resolution. Six parameters were used for lineament discrimination, including filter radius, line fitting error threshold, gradient threshold, length threshold, angular difference threshold, and linking distance threshold. The length of the extracted lineaments varied from 285.01 to 1331.72 meters, with a total length of 21,806.90 meters. The average lengths for the various orientations of lineaments were discovered to be comparable, ranging from 0.38km to 0.39km. It was identified that East-West, North-South, Northwest-Southeast, and Northeast-Southwest were the four main directions. The results showed that regions with high lineament concentrations also have a high tendency, making them ideal locations for groundwater targeting. This work further supports the value of satellite imagery for groundwater investigation, particularly in areas with complex subsurface terrain.

KEYWORDS: remote sensing, GIS, automatic extraction of lineaments, lineament density profile, groundwater, Akoko, Nigeria

I. INTRODUCTION

Most rural communities in Nigeria rely on surface water for their water needs, but during the dry season, when surface water sources dry up, there is a need to explore groundwater. Using Remote Sensing and GIS techniques to identify areas with groundwater potential can be a quick solution to this problem. Through ground mapping or the processing of remotely sensed data, lineaments such as faults and cracks can be found, and they can be useful in locating groundwater sources[1-4]. Groundwater occurs in the pores of underground rocks and its movement depends on the porosity and permeability of the rock material. Groundwater can be found in areas with sedimentary or crystalline rocks[5]. Mapping linear features through the use of remote sensing data plays a crucial role in understanding groundwater occurrence, especially in areas with hard rock terrain. Lineament maps are often seen as a key factor in the success of groundwater exploration, regardless of the geological environment [6]. Lineament mapping for groundwater

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exploration typically relies on geomorphological features such as ridges, valleys, displacement of ridge lines, escarpment walls, river networks, straight segments of drainage channels, discontinuities in rock masses, and aligned surface depressions[7-10]. Traditionally, these features were extracted manually from aerial photographs and satellite images by identifying darker or lighter discontinuities in color compared to the surrounding area[11]. This manual interpretation was then followed by image processing techniques like image rationing, fusion, and edge detection filtering [1, 12, 13]. These features were extracted to analyze their length, direction, density, orientation, and intersections for modeling groundwater, predicting geohazards, and exploring minerals.

However, manual methods have limitations such as difficulty and inaccuracies. As a result, computer algorithms have gained popularity as an alternative method. Researchers have explored various inputs for these algorithms, including Landsat-7 Enhanced Thematic Mapper Plus (ETM+) satellite data [14-16] and digital elevation models (DEM) [4, 17-20]. The use of digital satellite photography has also led to the exploration of computer-assisted feature extraction algorithms. One common method used in automatic feature extraction is edge filtering. The popularity of methods utilizing automatic feature extraction algorithms is increasing [21-24]. To achieve better results, it is necessary to explore the capabilities of the panchromatic band of Landsat-7 ETM+ with its high 15m resolution for lineament mapping. Numerous researchers have demonstrated the efficacy of various automatic feature extraction techniques. In this study, the LINE module of PCI Geomatica and band-8 of Landsat-7 ETM+ images were used to extract features. The LINE algorithm is essentially based on Canny's edge enhancement method [25]. Additionally, statistical techniques such as frequency of length, rose diagram, lineament density maps, and profiles were employed to analyze the extracted features [26-29].

II. STUDY AREA

The study area is situated in Ondo State, in the southwestern region of Nigeria. It is located at approximately Latitude 70 00' & 70 20' N and Longitude 50 10' & 50 45' E (Fig. 1). The terrain in the area of study is mainly lowland observable in the southwestern part with the lowest elevation of about 180 meters above sea level, some highland features observable in the northern part with elevation reaching up to about 700 meters. The study area has its major drainage flowing from the northwest to the south, owing to higher topography in the north compared to the south. This region falls within Nigeria's tropical savannah belt, which experiences two distinct climates: a rainy season and a dry season. [30].

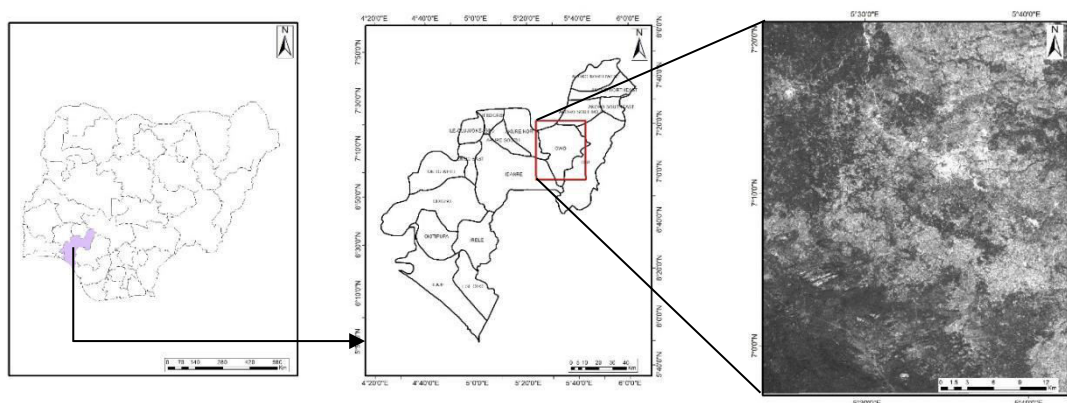


Fig. 1. Map showing the study area

III. GEOLOGICAL SETTINGS

Owo is situated in the Pan-African mobile belt, positioned between West Africa and the Congo Craton, according to sources [31, 32]. Nigeria's geology is characterized by a mixture of sedimentary and crystalline rocks. Gneiss-quartzite complexes make up the Precambrian basement rocks in Nigeria, which are thought to be between 2700 and 2000 million years old. Furthermore, there is a schist belt that stretches in a NE-SW direction, mainly located in the western region of the country. Additionally, there are granitoid plutons from the older granite group, which date back to the Late Proterozoic to Early Phanerozoic period, approximately 750-450 million years ago. The primary types of rocks in the study area include amphibolites, migmatite gneisses, granites, and pegmatites, as cited in sources [33-35].

IV. RESEARCH DATA

The study primarily used a subset of data from the panchromatic spectral band (Band 8) of the Landsat-7 ETM+ data set, with a particular scene path (190) and row (50). The panchromatic band is geo-referenced to the UTM coordinate system, specifically Zone 32 North.

V. METHODOLOGY

The Landsat-7 ETM+ scene that covered the research area was used as a source to subset the image. Afterward, the image underwent edge enhancement techniques and a Directional Filter to improve its quality. The LINE algorithm was then applied to further enhance the image and extract lineament features. Geospatial analysis and the creation of final lineament maps were conducted using Geographic Information Systems software.

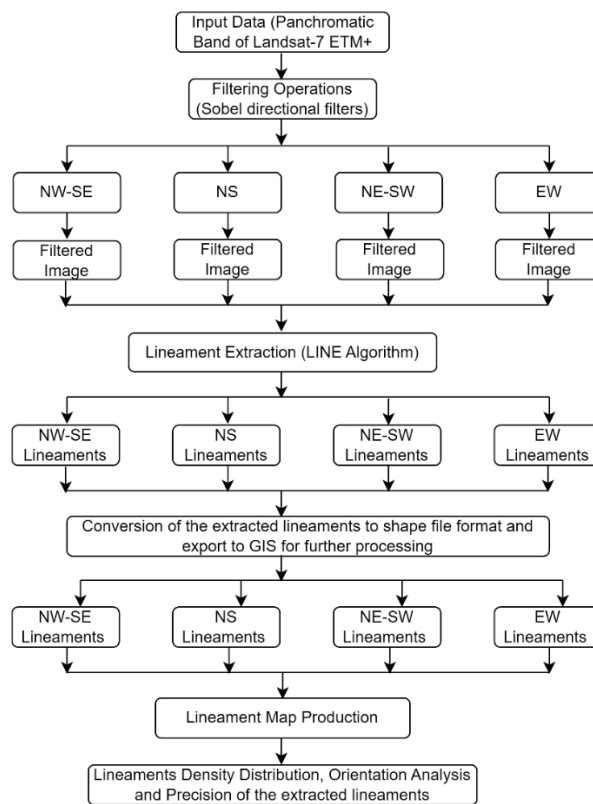


Fig. 2. Methodology (Work Flow)

DIRECTION-BASED FILTER

Through the use of Sobel directional filters, specifically 3x3 types, lineaments in the study were extracted. It is interesting to note that these filters, as demonstrated by [21], produced impressive results by optimizing the enhancement. This optimization significantly improved the discrimination of lineaments, making it easier to map them in the study area. In our analysis, we applied each convolution matrix of the Sobel filter using the PCI Geomatica software (Fig. 2). The filters were specifically designed for the directions NW-SE, NS, NE-SW, and EW, highlighting lineaments in these respective directions. To capture lineaments comprehensively, the Sobel filter was applied in four directions, as detailed in (Table 1) [36, 37].

Table 1: Four principal directions of Sobel filter utilized in this study.

NW-SE			NS			NE-SW			EW		
0	1	2	-1	0	1	-2	-1	0	-1	-2	-1
-1	0	1	-2	0	2	-1	0	1	0	0	0
-2	-1	0	-1	0	1	0	1	2	-1	2	1

Table 2: Values of suggested parameters

Parameters	Suggested Parameters Values
RADI	5
GTHR	75
LTHR	10
FTHR	2
ATHR	20
DTHR	1

VI. RESULTS

DIRECTIONAL SOBEL FILTERS

In order to improve the image for lineament extraction, Sobel's directional filters were used in four distinct directions: NE-SW, E-W, N-S, and NW-SE (as shown in Fig. 3). This was done by using the convolution matrices of the directional filters in each of these directions.

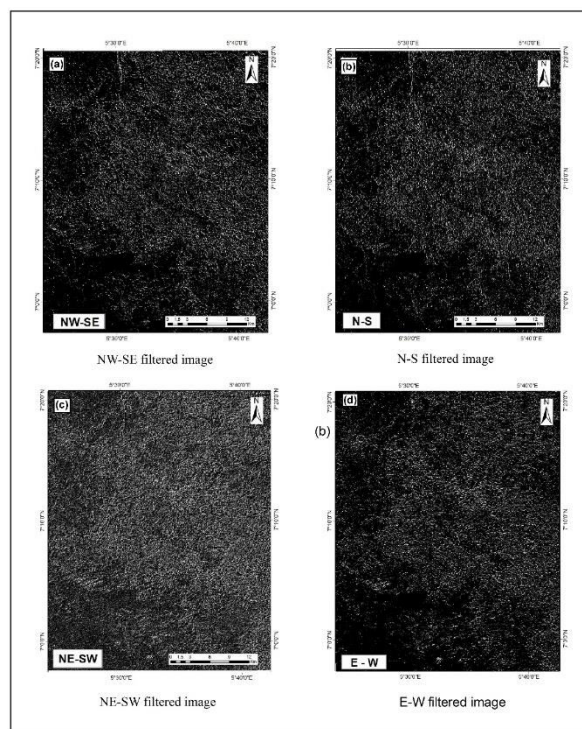


Fig. 3. Filtered images derived from Sobel's directional filters in the four directions on band 8 Image of the Landsat 7 ETM+.

LINEAMENT MAPS

After the process of validation, the lineament maps shown in Fig. 4 were generated. Four different orientations—NW-SE, NS, NE-SW, and EW—were used to automatically extract these lineaments. With a total of 5650 lineaments, Table 3 lists the different lineaments for each direction. A total of 2180206.90 m consisting of these extracted lineaments have lengths between 285.01 m and 1331.72 m. The lengths are 0.39 km, 0.38 km, 0.38 km, and 0.39 km, respectively, for the NW-SE, NS, NE-SW, and EW directions. According to the four tectonic directions, there are 26.25% (1483 lineaments) in the east-west (EW) direction, 25.29% (1423 lineaments) in the north-south (NS) direction, 24.34% (1375 lineaments) in the northwest-southeast (NW-SE) direction, and 24.12% (1363 lineaments) in the northeast-southwest (NE-SW) direction (Table 3).

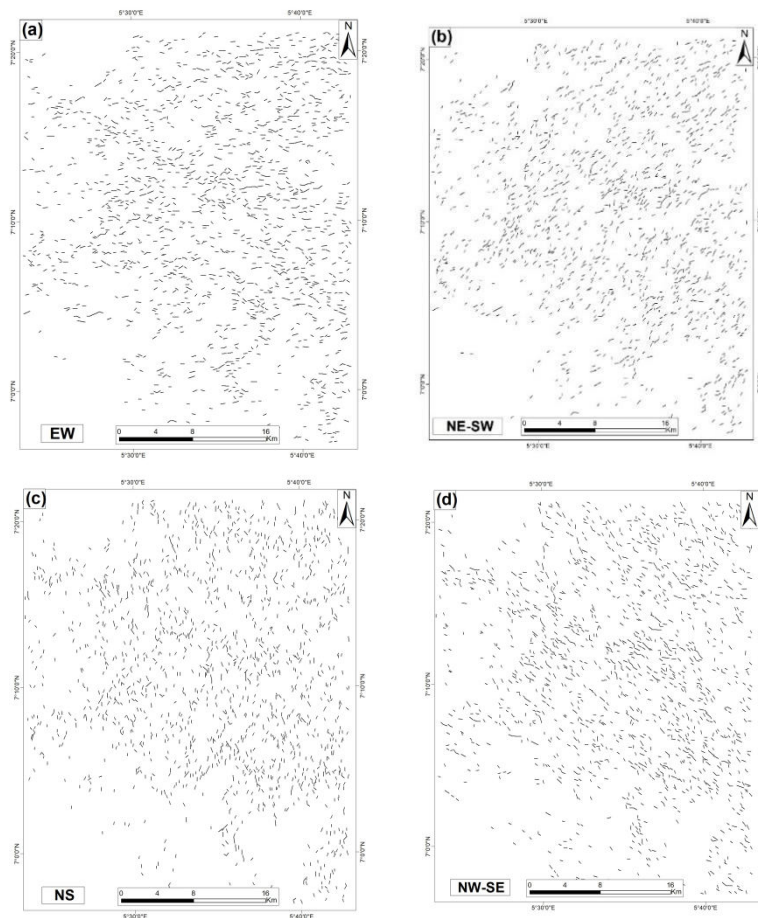


Fig. 4. Extracted lineaments in the four directions of (a) EW, (b) NE-SW, (c) N-S, and (d) NW-SE.

Table 3: Number of lineaments by direction, Lineament lengths by direction and lineaments precision parameters

Directions	Number of Lineaments	Min. Length (m)	Max length (m)	Average Lengths (m)	Average Length (Km)	Standard Deviation. (Km)	Confidence Interval		R-mag
							Value	percentage	
NW-SE	1375	285	1249.46	391.58	0.39	0.311	2.5 °	0.71	0.71
NS	1429	285	1049.05	377.45	0.38	0.307	2.4 °	0.72	0.72
NE-SW	1363	285	1331.72	383.07	0.38	0.312	2.4 °	0.73	0.73
EW	1483	285	1175.09	391.29	0.39	0.313	2.3 °	0.73	0.73
Combined	5650	285	1331.72	385.88	0.39	-	-	-	-

ORIENTATION ANALYSIS OF THE EXTRACTED LINEAMENTS

The results of the lineaments' orientation analysis, which was carried out using a rose diagram, are shown in Fig. 8. The rose diagram reveals the frequency of lineaments for every 10-degree interval, highlighting the prominent trends in their directions. The analysis indicates that the lineaments are primarily oriented in the EW direction (26.25%), followed closely by the NS direction (25.29%). Additionally, significant percentages were observed for the NW-SE direction (24.34%) and the NE-SW direction (24.12%).

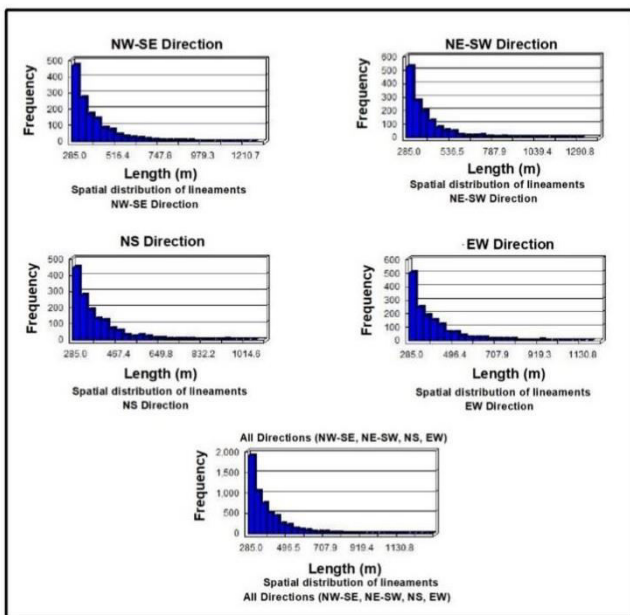


Fig. 5.

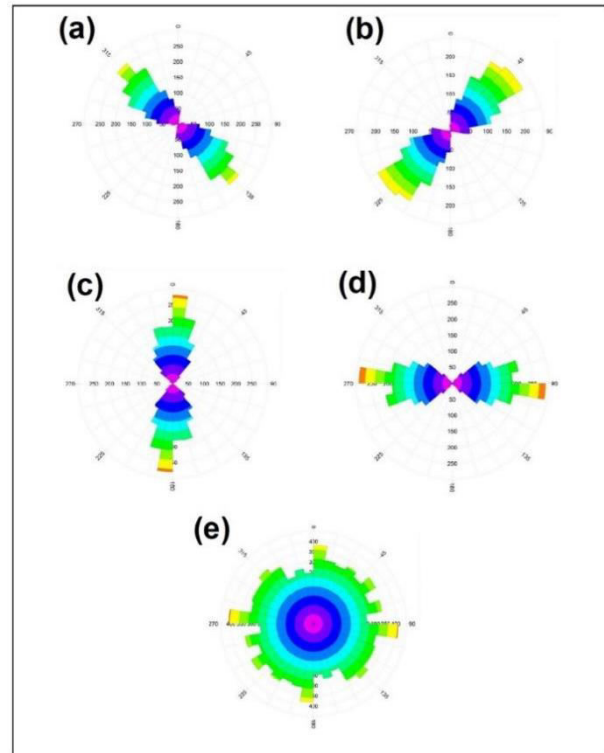


Fig. 6.

Fig. 5. Frequency distribution and fundamental statistics of the extracted lineaments; Fig. 6. Rose diagram showing all the lineament trends over the study area (a) NW-SE, (b) NE-SW, (c) N-S, (d) E-W and (e) All directions

DENSITY DISTRIBUTION OF THE LINEAMENTS

The extracted lineaments' spatial distribution is shown in the study area's lineament density map, which also shows variations in lineament intensity. Fig. 6 illustrates this observation. The map encompasses the entire study area and showcases how lineaments are distributed. Upon analyzing different parts of the lineaments' density, it is apparent that 80% of the Owo area is comprised of medium and high-density classes. Another 10% of the study area corresponds to the low-density class, mainly found in Okeluse, Ago-Asolo, Olasanmoye, Ago-Oyinbo, and Araromi. Additionally, in Owo locality, there are areas with exceptionally high lineaments density, as depicted in Fig. 7.

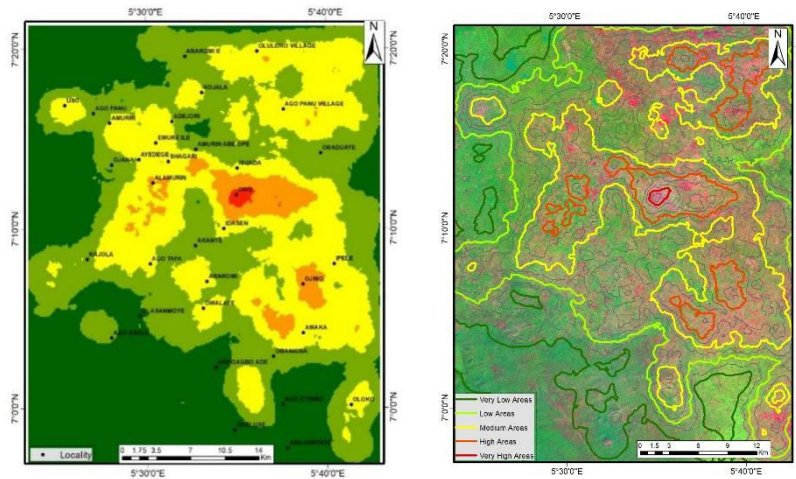


Fig. 7. Lineaments Density map of the overall lineament

INTENSITY OF LINEAMENTS

Based on Fig. 8, the graph displaying the distribution of lineament density indicates a wide spectrum of lineaments ranging from 0 to above 5. The formation of a hollow channel within the area depends on the degree of rock fracturing, which is represented by lineament density [38]. Fig. 8 displays four profiles (A-B, C-D, E-F, G-H) drawn at different intervals from east to west on the lineament density map. Profile C-D shows higher density values (>5), primarily located in the central portion of the study area. On the other hand, profiles A-B, E-F, and G-H exhibit density values greater than 3, indicating a high level of rock fracturing in the region.

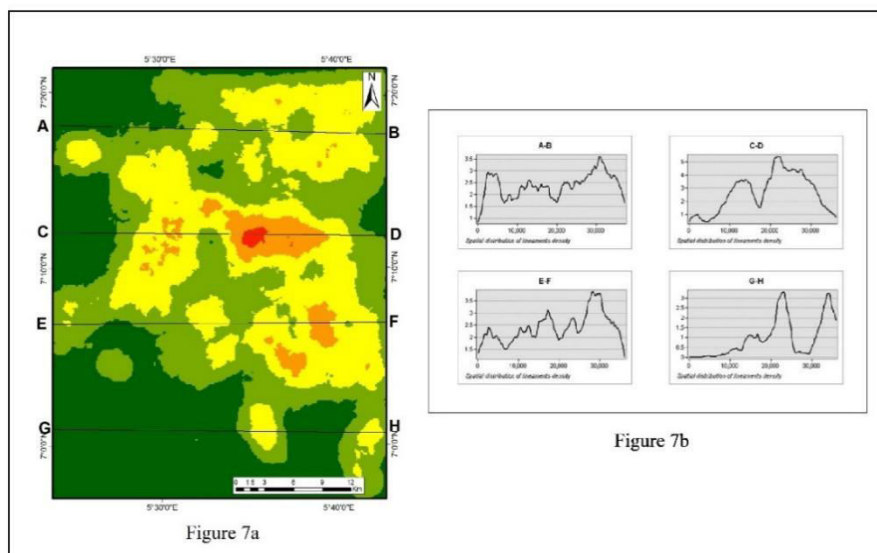


Fig. 8. Lineaments density map showing density profile sections 7a and lineaments profile showing the spatial distribution of lineaments density 7b

PRECISION EVALUATION OF THE EXTRACTED LINEAMENTS

According to the rose diagram, the standard deviations of the lineament lengths are 0.311 Km, 0.307 Km, 0.312 Km, and 0.313 Km for the NW-SE, NS, NE-SW, and EW directions respectively. These values are very close to the average lengths of lineaments in the same directions, which are 0.39 Km, 0.38 Km, 0.38 Km, and 0.39 Km. This suggests that the distribution of lineament lengths on the rose diagram is weak. The R-mag parameter values for the NW-SE, NS, NE-SW, and EW directions, which measure the evidence of the distribution, are 0.71, 0.72, 0.73, and 0.73 respectively. These values are close to one and indicate a close relationship between the standard deviations and the average lengths

of the lineaments, indicating low spread of the extracted lineaments. This statement affirms that there is a negative correlation between the dispersion index and lineament lengths. The lineaments extracted in all four directions have confidence thresholds set at 95%, which denotes a 5% margin of error in the extraction process accuracy. This acceptable degree of error is used as proof that the LINE algorithm was correctly used to extract the lineaments.

VII. CONCLUSION

1) The LINE algorithm implementation demonstrates a systematic scientific approach by assessing important parameters for enhancing the quality of input imagery (RADI) and distinguishing lineaments (GTRH, LTHR, and FTHR). The algorithm also utilizes the canny edge detection algorithm.

2) A total of 5650 lineaments were identified in this study, with lengths ranging from 285 m to 1331.72 m. The combined length of these lineaments amounted to 2180206.90 m. The most common directions observed were NW-SE (24.34 percent), NS (25.29 percent), NE-SW (24.12 percent), and EW (26.25 percent). Analysis revealed that the central and north-eastern regions of the study area exhibited a higher concentration of lineaments with values exceeding five (>5). The LINE algorithm implementation shows a methodical scientific approach by evaluating crucial factors for improving the quality of input imagery (RADI) and differentiating lineaments (GTRH, LTHR, and FTHR). Additionally, the algorithm makes use of the canny edge detection approach.

3) Notable localities within the high lineament density regions include Owo, Uso, Alampur, Odeya, Ojimo, and Ago-Panu. These areas, composed of migmatite, quartzite schist, and undifferentiated granite gneiss, exhibit an elevated density of lineaments. The identification of these regions with a dense lineament network suggests a significant degree of rock fracturing, which indicates favorable conditions for groundwater resources. The research findings highlight the valuable role of integrating remote sensing (RS) and geographic information systems (GIS) with automatic lineament extraction techniques in the planning and development of groundwater exploration strategies.

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