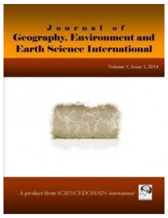

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# Spatial Analysis of Lineaments and Their Tectonic Significance Using Landsat Imagery in Alarasah Area-Southeastern Central Yemen

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Author HSA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors SAA and JI managed the analyses of the study. Author SAG managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

Remote Sensing data are being used in solving various earth related problems by digital image processing in a computer. Detection of the geological linear features contributes significantly towards the understanding of structural scenario of the area. The purpose of this study was to identify lineaments on Alarasah area, Shabwah Province, Southeastern central Yemen, with the aid of Satellite images. Therefore, automated and manual methods were applied to extract lineaments from Satellite images. In general, automated extraction does not work properly to identify the faults or fault zones present in the area, the problem faced is related to the length and the pattern of the faults. For this reason, it has been decided to use the manually extracted lineaments for further analysis. The manual method is believed to extract the lineaments showing similarity with geological lineaments/faults present in the area. The resultant lineament map is tested with the fault map of the area compiled from the literature and geological map. Good relationship was observed

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between lineaments extracted from Satellite images and the geological structure in the study area. The final lineament map generated for the study area will help to identify potential zonation of hydrocarbon resources.

*Keywords: Lineaments; tectonic significance; geological faults; Yemen; remote sensing and digital image processing.*

## 1. INTRODUCTION

Lineaments are defined as mappable linear features of the earth's surface which differ distinctly from the patterns of adjacent features and presumably reflect subsurface phenomena [1,2,3]. Linear and curvilinear feature on the earth's surface were named as 'lineaments' by Hobbs [4], who recognized the existence of linear geomorphic features and interpreted them as surface expressions that represent the zones of weakness or structural displacement of the earth's crust [5]. In the later part of the twentieth century the literature has helped fundamentally in understanding the morphology and genesis of the lineaments, geoscientists acknowledged the view that the lineaments are surface indications of faults; fractures; continental margins and submarine ridges [6,7]. The study of lineaments provides us the opportunity of assessment of the hydrogeology, volcanic structures, tectonics and rich prospects of minerals in the concerned areas [8,9,10,11,12]. Lineaments extraction from satellite imagery has been treated by several authors among them [13,14,15]. The purpose of this study was to apply the Remote Sensing techniques for identifying surface lineaments in Alarasah Area-Southeastern Central Yemen (Situated between 47º 00' - 47º 30' Longitude and 14º 40 – 15º 00 Latitude); Fig. 1. The scope includes preparation of lineaments map by visual image interpretation (manually extracted) and automated extraction techniques; this has been shown possible relationships between lineaments and known geologic structures in the study area.

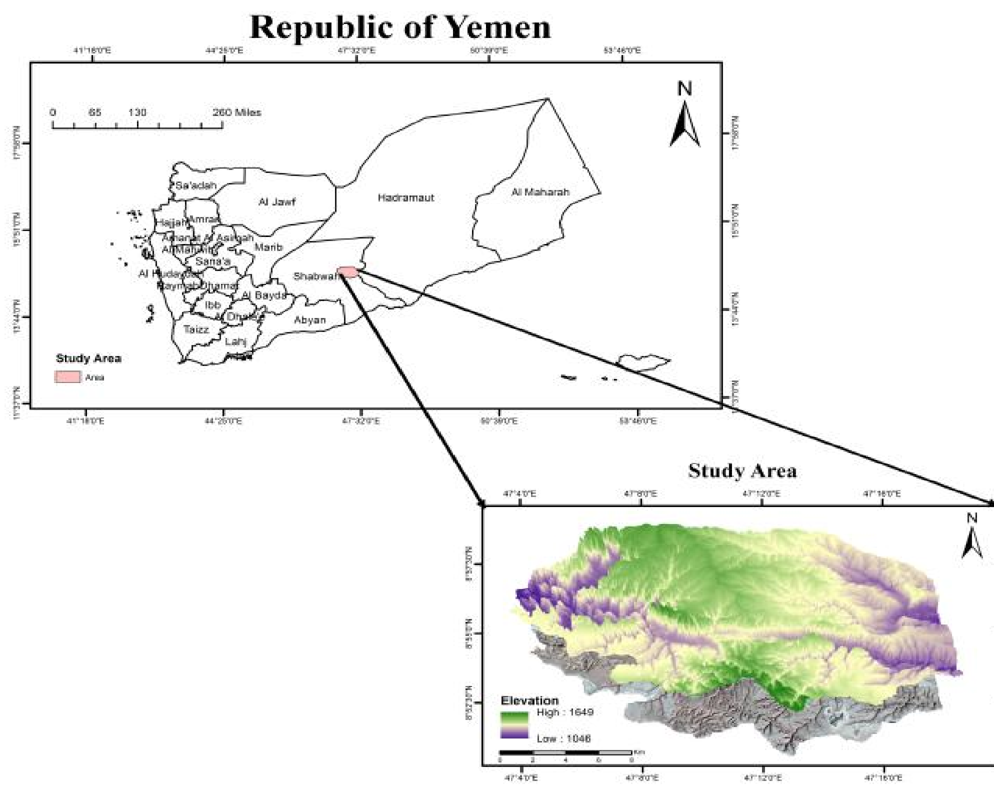



**Fig. 1. Location map of the study area**

## 2. GEOLOGICAL SETTING

Geologically, Yemen situated in the southwestern edge of the Arabian Peninsula bordering the extensional realms of the southern Red Sea and the Gulf of Aden. Yemen Geology is linked to the regional geology of the Arabian Peninsula, in which the basement complex is a part of the Arabian Shield in a larger geologic framework of the Arabian – Nubian Shield. Geology of Yemen ranging from Precambrian basement rocks to recent sediments and comprises metamorphic rocks which formed during the Archean-Proterozoic time, transected by a failed Jurassic rift system related to the break-up of the super continent of Gondwanaland and a Tertiary to recent geological history determined by the propagation of Indian ocean Ridge which triggered the opening of Gulf of Aden-Red Sea rift [16]. The study area is located in the south-eastern part of Marib-Shabwah Graben. Marib-Shabwah Graben is formed part of an extensive rift system developed across much of Yemen and northern Somalia during the late Jurassic. The Graben is northwest-southeast trending and bounded by two major normal faults and it has a complex block faulted floor rising up from marginal sub-basins towards a central axial basement high [17]. According to the geological map sheet of Alarasah area (D-38-47.1987), the Study area is covered by Mesozoic-Cenozoic sedimentary successions; these rocks are represented by three units: Tawilah Group, Hadramawt group, and Shihr group. Tawilah group composed of sandstones dated as Early Cretaceous and it locally occurs below a thin alluvial stratum. It is exposed throughout the western part of the study area. Hadramawt group is represented by Paleocene of Umm Er Radhumah formation, Jawl Member and Lower Eocene of Jiza' Formation. The Umm Er Radhumah formation is marked by nodular limestones in alteration with marly-chalky limestones; it covers large parts of the study area. Jawl member covers huge parts of the study area, according to Beydoun et al. [18] Jawl member was originally separated from the topmost beds of Umm Er Radhumah formation to form a discrete unit above the massive nodular part, dolomitic limestones which form the top of the escarpments at the edge of the coastal area between Al Mahfid in the west, the Balhaf basin and the Hajar sector of the Sab'atayn basin in the central part through the Mukalla-Jahi high and into the Say'un-Masilah basin in the east. The Jeza' formation is conformably underlain by Umm Er Radhumah formation, the contact being at the well-bedded dolomitic limestone of the Jawl Member at the top of the Umm Er Radhumah, or the massive limestone below that member, and the Jiza formation above. Jiza' formation consists of variegated argillaceous shale in alteration with marls and nodular limestones [18]. The Shihr group is represented by Conglomerate of Irqah formation which dated as Miocene-Pliocene [18] and exposed in small part in the Eastern ward of the study area. Quaternary deposits of recent sediments cover almost western ward of the study area. These sediments are composed of unconsolidated and loose such as gravel sand and silt produced by the dumping of sediments along the Wadi banks during floods. These sequences were already defined by Beydoun [19]. Fig. 2 shows the geological map of study area.

## 3. METHODOLOGY

The study of this paper is completed in two major methods: the first method is a compilation of literature related to various aspects of lineament analysis; the second method involves lineament extraction from satellite images. The data used in this study are: Published geological map of Alarasah area (sheet no D-38-47, at scale 1:100,000) prepared by (Department of Geology and Mineral Exploration/Aden), Landsat ETM image 30m resolution and SRTM 30m resolution (The Shuttle Radar Topography Mission) both are downloaded from the Global Land Cover Facility (GLCF) website. During this study four different software packages are used to achieve the purpose of the study since there is no single software that will process all steps in the analyses; these are ERDAS IMAGINE 2014, ARC GIS 10.1, PCI Geomatica 2013 and Rockworks 15 Software. All the study are office work and no field work are made during the study.

### 3.1 Fault Digitized from Geological Map

The fault map of the study area was prepared via digitized faults from the geological map for Alarasah area (with scale of 1:100,000). A total 41 faults from this map were identified with maximum length 27.40 km and total length is 202.9 km; resultant map and its basic statistics are given in Figs. 3 and 4 respectively.

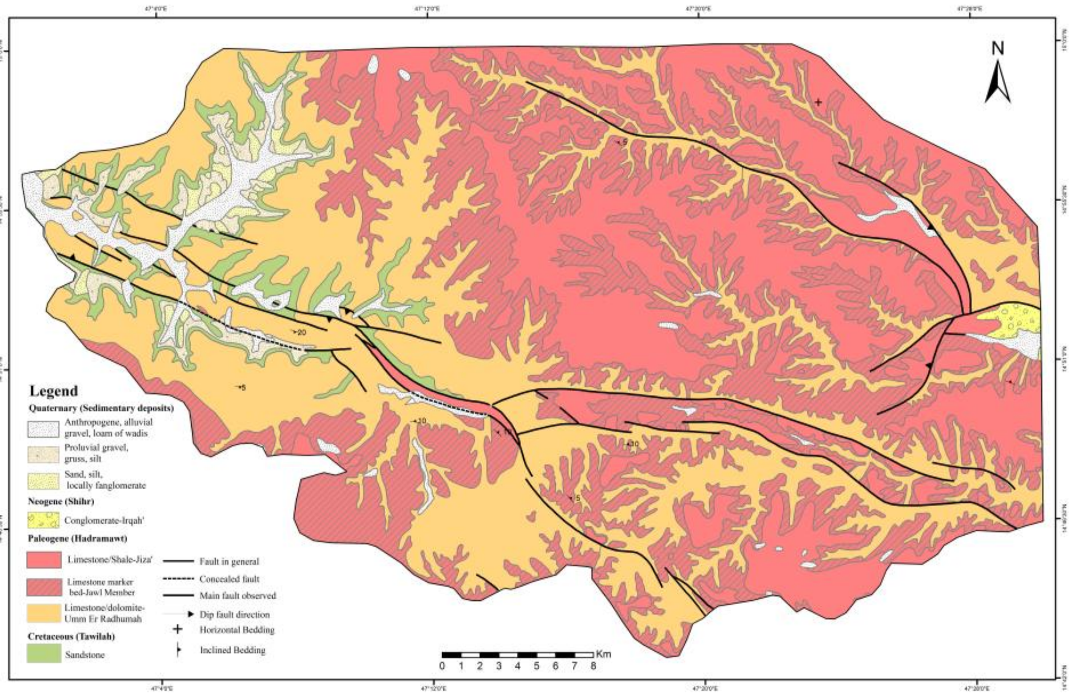



**Fig. 2. Geological map of the study area**

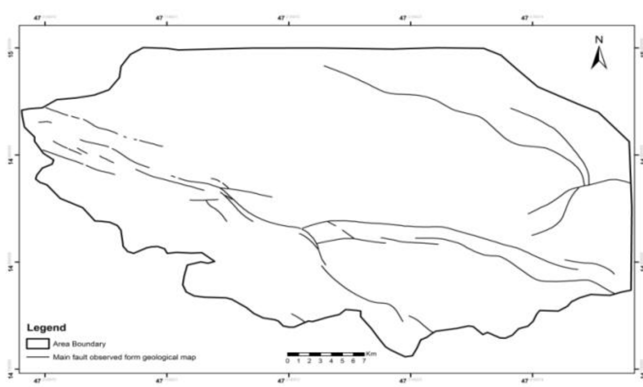
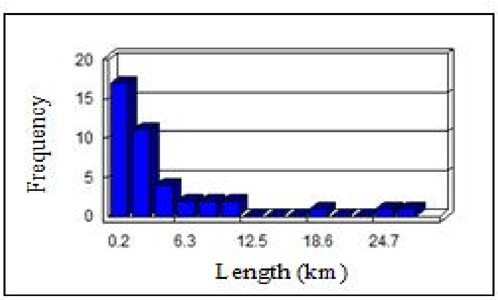



**Fig. 3. Fault map of the study area**




| | |
|---|---|
| Count | 41 |
| Minimum Length (km) | 0.231 |
| Maximum Length (km) | 27.40 |
| Sum (km) | 202.9 |
| Mean (km) | 4.950 |
| Standard Deviation | 6.199 |

**Fig. 4. Basic statistics of fault map observed from geological map of the study area.**

### 3.2 Lineament Extraction from Satellite Image

From the literature, we can conclude that lineaments usually occur as edges with tonal differences in satellite images. There are two common methods for the delineation and extraction of lineaments from the satellite images:

- **Manual lineament extraction or (visual interpretation)**: In this method, the lineaments are extracted by image processing techniques. Usually, the lineaments appear on satellite images as straight lines or "edges"; this is contributed by the tonal differences within the surface material. Edge enhancement leads to image sharpening in which the geometric details of an image may be modified and enhanced [20]. Lineaments are delineating from satellite images based on number of general geomorphological features such as aligned ridges and valleys, displacement of ridge lines, scarp faces and river passages, straight channel drainage and channel segments, straight rock boundaries, breaks in crystalline rock masses and aligned surface features depression [21,22]. The straight valley is the most helpful feature as a primary identification criterion in image processing for lineaments because a satellite image has no direct information on the topography of the area [23]. Manual method has good advantage of faults detection; and the user's experience can lead him to distinguish true geological lineaments from non-geological features such as roads, railway lines, power-cables, canals and crop-field boundaries, with experience and skills of the operator these features will be deleted from the interpretation [24,25,26,27]. There are several image enhancement techniques that can contribute to manual lineament extraction, one of them was used in this paper for preparation of manual lineament extraction map, as one method is enough to detect all the lineaments because low variation in the nature of the surface material in the study area; this method is Color Composite, lineaments were digitized manually, a map was prepared for this method. Details of this map will be given in the following:

#### 3.2.1 Colour composite

Digital images are typically displayed as additive color composites using the three primary colors: red, green and blue (RGB) [28]. For increasing the amount of information that can be visually interpreted from the data; different spectral bands of ETM data have been selected and combined together in RGB colour system to make color composite images. After examine each every three combinations bands; the best visual quality is obtained with ETM bands 3 (Red), 4 (Green) and 1 (Blue). This image produces for manual extraction of lineaments from the study area. Fig. 5 shows the image combination of ETM bands 5, 4 and 3; in this method for digitizing lineament, those linear features which correspond to roads were neglected. After visually interpreted for the colour composite image; a total of 988 lineaments were extracted manually; maximum length of the lineaments extracted in this method is 7.93 km.; the result map and its frequency distribution are shown in Figs. 6 and 7.

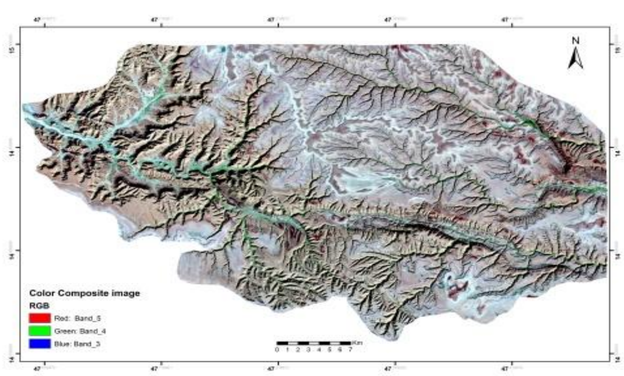



**Fig. 5. Color composite of band 5, 4 and 3 (RGB)**

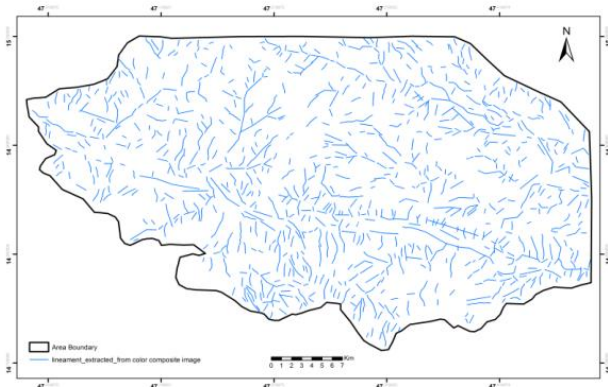
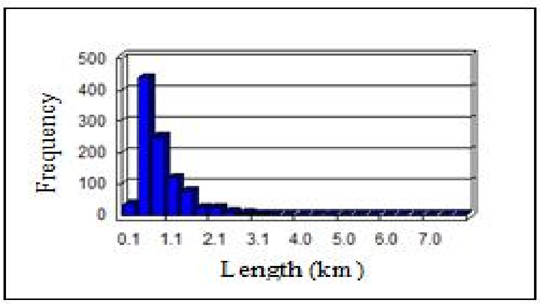


**Fig. 6. Lineament extracted from color composite**




| | |
|---|---|
| Count | 988 |
| Minimum Length (km) | 0.11 |
| Maximum Length (km) | 7.93 |
| Sum (km) | 930.3 |
| Mean (km) | 0.94 |
| Standard Deviation | 0.542 |

**Fig. 7. Frequency distribution of Lineament result of color composite.**

- **Automatic lineament extraction:**

Lineaments are extracted automatically or digitally from satellite image based on edge enhancement and filtering techniques using algorithms and computer software [21,22,26,29,30,31,32,33]. The principle of this method is to detect adjacent pixels which abruptly change in grey level by the use of a differential operation [23,34]. Different algorithms are provided by software for automatically extraction of lineaments; three common of these algorithms are Hough transform, Haar transform and Segment tracing algorithm [3,26]. The Hough transform is most commonly used in edge linking for line extraction; the main advantages of the Hough transform are that its ability to extract linear features even in areas with pixel gaps or pixel absence and also its insensitivity to noise [32]. Hough transform is designed to detect the collinear sets of edge pixels in imagery by mapping these pixels into a parameter space [29]. Haar transform: is use for extraction of linear patterns in the image; it also provides a transform domain in which a type of differential energy is concentrated in local regions [35]. This transform has been used for image enhancement due to its low and high-frequency components [26]. Segment Tracing Algorithm (STA): it has been developed by Koike et al. [23], the principal of STA is automatically detect a linear of pixels as vector elements by examine local variance of the gray level in a digital images and to connect retained line elements along their expected directions [27,34]. There are many advantages to the automatically extraction of lineaments; the main of these advantages are: its ability to extract the lineaments which are not in recognized by the human nicked eyes; the processing operations are taking less time comparing to manually extraction; and it also produce uniform approach to different images [36]. Also Sarp [3] compared the accuracy that achieved by the manually and automatically lineament extraction and

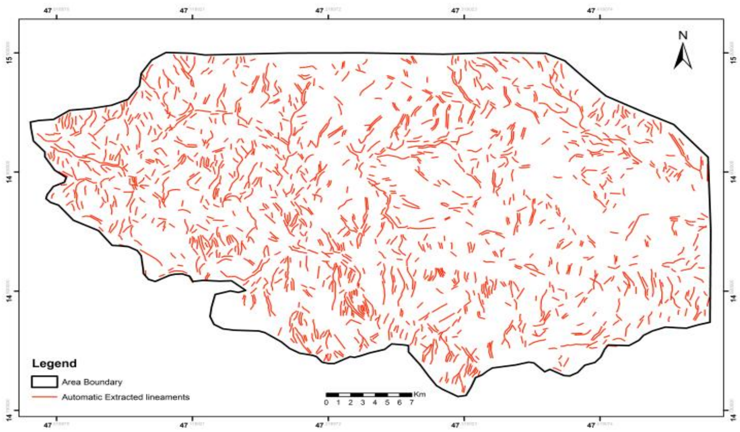
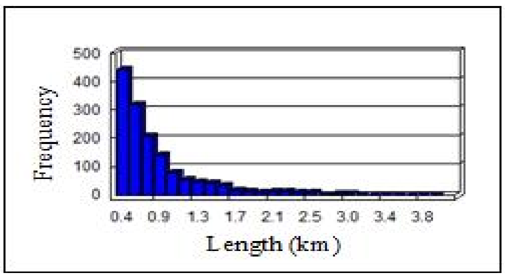



**Fig. 8. Map of automatically extracted lineament**




| | |
|---|---|
| Count | 1441 |
| Minimum Length (km) | 0.446 |
| Maximum Length (km) | 3.969 |
| Sum (km) | 1236.76 |
| Mean (km) | 0.858 |
| Standard Deviation | 0.455 |

**Fig. 9. Frequency and basic statistics of automatically lineament map**

found that the accuracy of the automated extraction in identifying faults was much lower than with manual interpretation. Lineaments are extracted automatically in this paper from Landsat ETM image; band 7 with a spatial resolution 30*30 meter was selected for this purpose; according to Sabins [37] band 7 is useful for discrimination of lineaments and other geological features such as minerals and rocks types and is also sensitive to vegetation moisture content. The extraction process was carried out by using the only used software for lineament extraction; PCI Geomatica Analytical Software. The automatically extracted lineament map and its basic statistics are shown in Figs. 13 and 14, a total number of 1441 lineaments were identified from the map of lineament extracted automatically in the study area; with total length 1236.76, and the maximum length is 3.969 km.

## 4. RESULTS AND DISCUSSION

In order to extract further information on the distribution and the nature of lineaments; extracted lineaments on both manually and automatically methods have been evaluated and analyzed, then comparing with the major observed faults on the geological map. Several studies in remote sensing literature have been focused on lineament analysis such as Sesören, 1984; he studied the geological and geomorphological features on Netherlands, he identified lineaments from Landsat MSS imagery and compared with real faults on the alluvial plains [38]. The most common methods applied for lineaments analysis are: lineament density maps [39] and Rose diagram [8,17] also intersection density of lineament is useful for characterizing the spatial patterns of lineaments [40]. In this paper, three processes of lineament evaluation are applied: 1.Density analysis, 2.Intersection density analysis, and 3.Orientation analysis.

## 4.1 Density Analysis

Distribution of lineament is characterized by a density map for summarizing and verifying existing lineaments [23]. Lineament density analysis is applied to calculate the frequency of the lineaments per unit area; this map can be produced based on counting the pixels of line elements in a small window and assigning these values to the center pixel in the window in true geographic coordinates [23]. Lineament density maps for the study area will show the concentrations of the lineaments over the area Figs. 10 and 11. It appears from both maps that there are several fault zones in the area; the resulting lineament density map shows dominantly increased density towards the south and northeastern parts of the area; faults can be distinguished into the main fault which extends in NW-SE, N-S direction, and roughly fault set extend in NE-SW. In the southern part of the area, there is a high concentration of lineaments with an irregular pattern on both density maps; that seems to be the result of high effectively of the faulting processes in the area. In the northeastern part of the area, fault zone is observed to be NW-SE direction. In the western part of the area, there is cluster of faults especially in automatic lineament density map; it has several sets trending in almost N-S direction.

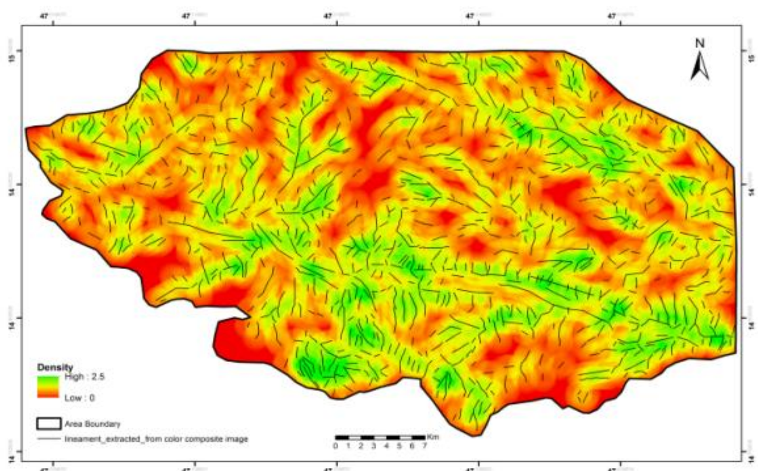



**Fig. 10. Density map of lineaments extracted manually**

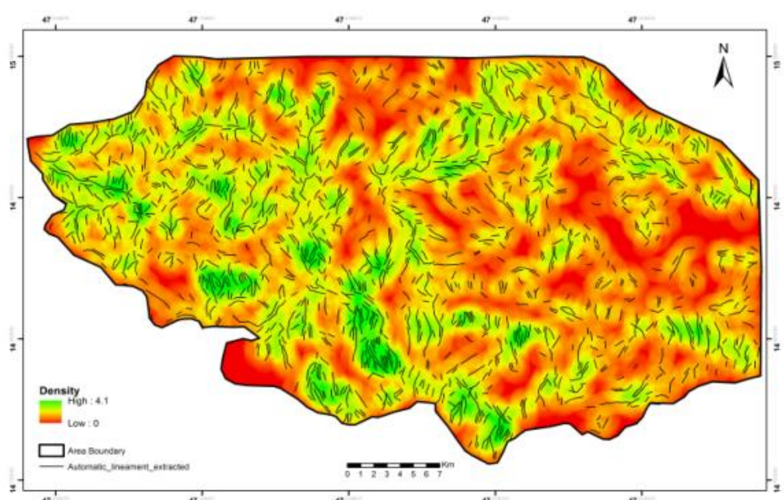



**Fig. 11. Density map of lineament extracted automatically**

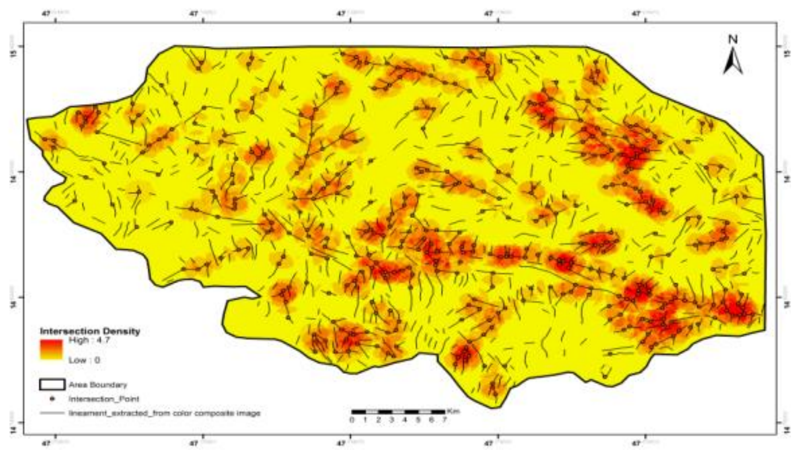



**Fig. 12. Lineament intersection density map**

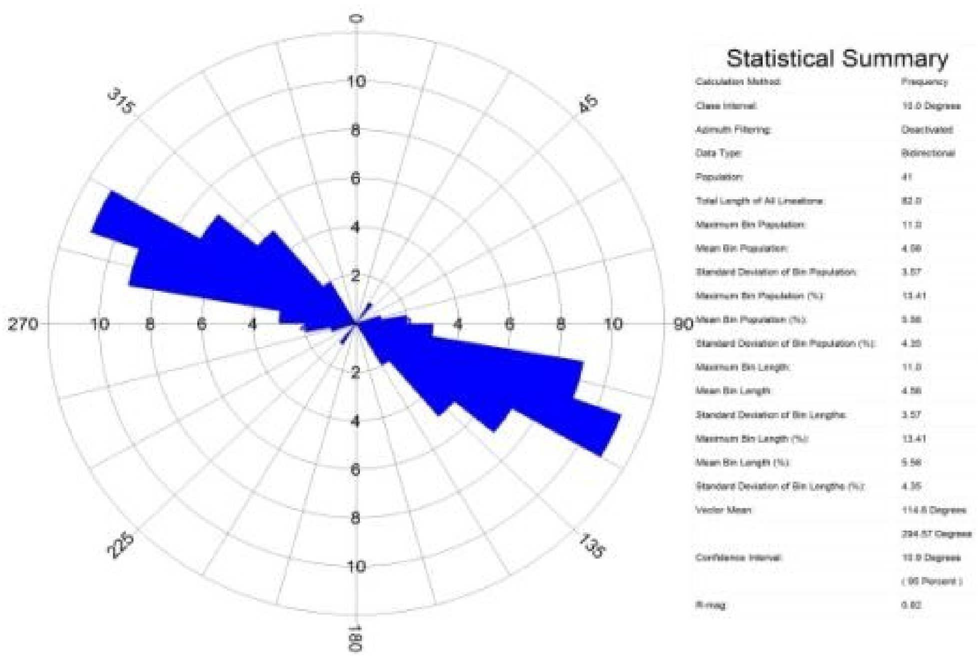



**Fig. 13. Rose diagram showing the main trends for the observed faults**

### 4.2 Intersection Density Analysis

The lineament intersection analyses give an idea about the frequency of intersections which occur in each every unit grid cell; the purpose of using intersection density map is to estimate the areas of diversity lineament orientations [3]. Wherever the lineaments do not intersect; the result map will represent a plain map, which means the lineaments are parallel to sub-parallel in this area or shortest in length. The lineament intersection map has been generated by counting the number of lineament intersections per unit area. Fig. 12 shows the lineament density map and manually extracted lineament intersection; after comparing the intersection points with density map it has been indicated that in certain parts of the area the density map different from the intersection density. For example in the northwestern part of the study area density map is high, the intersection density is low; that's means in this part most of the lineaments are parallel to each other, they do not intersect. In some areas in southern part of the area; intersection density show high values coincide with density map.

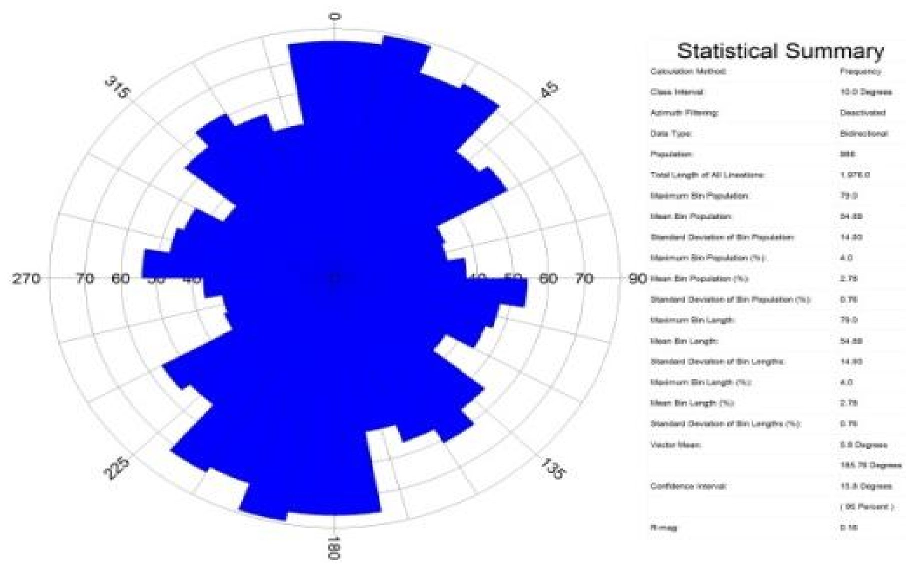



**Fig. 14. Rose diagram prepared from manually extracted lineament**

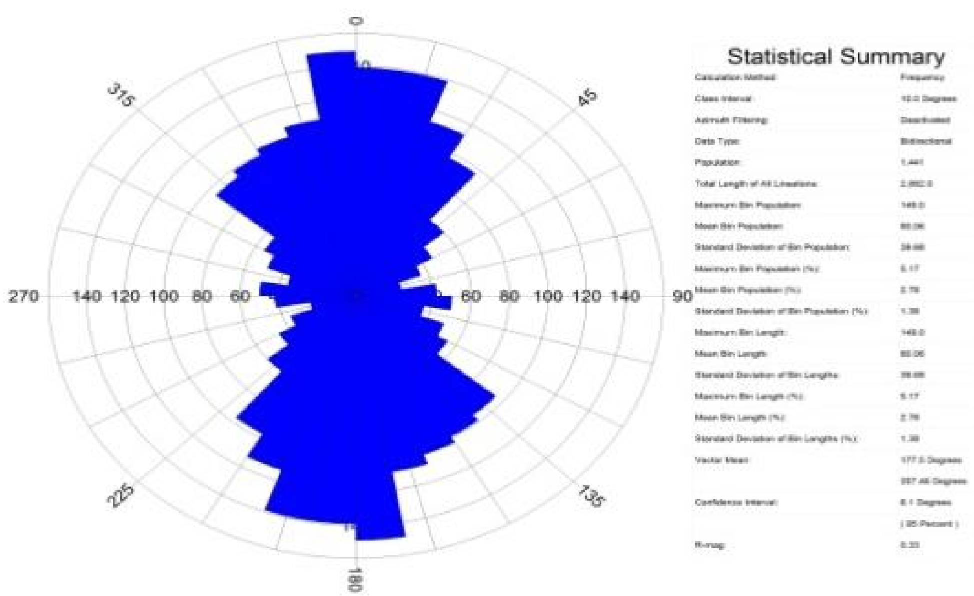



**Fig. 15. Rose diagram prepared from automatically extracted lineament**

### 4.3 Orientation Analysis

Lineaments are the type of fractures that are oriented in different directions; in addition to the view of individual lineament orientation at a given point, it is possible to combine the various orientations in all directions into a single rose diagram with angles ranging from 1to180 degrees [41]. Rose diagrams are used to analyze the distribution of lineaments based on the contribution of its frequency to the orientation trend. In this paper rose diagrams are generated by counting each line as an element; despite its length (short or long); the process was done with the helping of RockWorks.v15 Software. In this paper; the orientation of lineaments on both extracted lineaments map compared with the previous published faults map of the study area. Three different diagrams in trends Figs. 13, 14 and 15 have been summarized as following observations:

1. Rose diagrams of identified lineaments and digitized faults are noticed with different ranges in four principal directions (NW-SE, N-S, NE-SW, and E-W); the most dominance trends in the directions are NW-SE, N-S, and NE-SW.
2. Also from rose diagram we can find the WNW-ESE trending lineaments as shown in Fig. 13 can be relate to the Najd fault system in the Arabian Shield.
3. The orientations of major observed faults show dominance trends in NW-SE directions; with azimuth ranging approximately $280^0$-$320^0$.
4. Manually and automatically extracted lineaments map indicates a similarity in directions; and heterogeneous with real faults observed in the geological map, the orientation in manually extracted lineaments show three sets dominant orientation which are North-South, Northeast-Southwest and roughly East-West, minor lineaments trend in the direction of main faults in the area (Northwest-Southeast); and roughly East-West Fig. 14; automatically extracted lineament show three different sets in the: Northeast-Southwest, North-South and Northwest-Southeast directions.
5. The dominance direction of the main observed faults in the area do not correspond with the main direction in both extracted lineaments map only with minor trends; the reason is that a fault can be represented by a number of lineaments with the same direction and/or with different direction due to the forces effective by tectonic activity.
6. Majority of the surface linear features in the area are oriented in two directions: Northwest-Southeast and Northeast-Southwest.
7. In the north east of the Marib Shabwah graben, the orientation of linear feature is trended towards west-north-west related to Najd fault system, as shown in Fig. 13.

## 5. CONCLUSION

Various lineament maps were prepared for the study area in order to compare the linear features with the main fault lines in the area. This also paper focused on the analysis of lineaments using remote sensing techniques. It has been demonstrated the capability of Landsat satellite image (ETM) in lineament extraction by seeing the valuable results comparing with the major faults from the geological map of the study area. The high concentration of lineaments on both extracted lineaments map indicates that the area suffered highly distortion structures; as it realizes on the geological literature map for the study area. Extracted lineaments from satellite image for the study area are useful to explain the structural features; the diversity in intersection density, especially around the observed fault zones, indicates that there are different tectonic phases in the area. Lineament analysis also clarifies that the area really affected by several structural trends some of them not previously identified in literature faults map e.g. NE-SW; as it appears on both extracted lineament map. The WNW-ESE striking system in the study area (in Fig. 13) is related to the pre-existing of primary and secondary faulting in the Najd fault system in the Arabian Shield. The origin of these two lineaments system is related to the northwest-southeast trending of Marib Shabwah Graben and the Rifting Gulf of Aden and Red Sea. The concentration of North-South trending lineaments on both extracted lineament maps is the most noteworthy findings on this study; which mean its perpendicular and nearly perpendicular to the major observed fault zone on the area, these lineaments seems to correlate a possibility of basement hinge zone at the depth on the area.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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