LINEAMENT EXTRACTION AND ANALYSIS USING REMOTE SENSING IN NORD-GHOUBBET GEOTHERMAL FIELD, DJIBOUTI

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ABSTRACT

Remote sensing is useful at the pre-feasibility stages of geothermal exploration. Lineament study is one of the most important assets for geothermal resource exploration. Several surface manifestations, in particular, fumaroles occur in Nord-Ghoubbet geothermal field and have not yet been examined by lineament extraction. Therefore, this study aims to quantify the spatial density of lineament and examine a correlation between surface geothermal manifestations and lineament distribution by remote sensing techniques for the Nord-Ghoubbet geothermal area as a preliminary investigation. Lineament extraction was performed manually in this study. For manual lineament extractions, the shaded relief technique (the lineaments were extracted from 6 different azimuth angles (0° 45°, 90°, 180°, 200°and 315°), the filtering operation (based on a directional edge detection by different directions (NS, EW, NW, NE)), and image processing (False-color composite (FCC), a combination of band ratio methods, and principal component analysis (PCA)) were used to guarantee an impartial mapping of all lineaments in the study area. All manual lineament extractions were performed using QGIS. All lineaments obtained were overlain into a single shape file. After duplicate lineaments were removed, the final manual lineament map was created. This was accompanied by some lineament evaluation techniques such as lineament density and orientation to extract additional lineament information. NW-SE trend, one of the main trends extracted here, is the general orientation of the faults in the study area. Conversely, N-S and WNW-ESE to E-W trends were less pronounced in the study area. The results of lineaments density were extracted manually. The analyses showed that the fumaroles are mainly located in high and medium density areas, suggesting that the structures may control the surface manifestation distribution.

1. INTRODUCTION

The Nord-Ghoubbet area is in the western part of the Gulf the Tadjourah and the central part of the Republic of Djibouti, on the northern side of the bay of Ghoubbet Al Kharab, between Lake Asal and the Gulf of Tadjourah. The issue of geothermal prospects in Djibouti are permeability and salinity, but according to the previous research (BRGM 1982; CERD 2011)(JICA et al. 2015)**,** the Nord-Ghoubbet area is characterized as one of the major geothermal potential areas in Djibouti by structure well developed and good reservoir fluid condition (low salinity). Lineaments are defined as mappable linear polygon features, which differ markedly from models of adjacent features and likely reflect subterranean phenomena(O'leary et al., 1976). The lineament highlights whether the subsurface effect is valid if the origin of the lineament is controlled by geological structures such as faults and fractures. The structures are the main factor that controlled the distribution of surface manifestation and it can be recognized by lineament analysis. The area with intense faults and fractures has a high probability of surface manifestation occurrence. For that, it is essential to study the lineament as a pre-feasibility study. The lineament extraction was conducted manually by different extraction techniques (Shaded relief, Filtering operation, Image processing). The relationship between surface manifestation distribution and lineament is important to find out the geothermal potential area for further investigation. This study aims to apply remote sensing techniques for lineament analysis at the geothermal site of Nord-Ghoubbet. In order to achieve this aim, two general objectives were set: the preparation of lineament map (both by visual interpretation of Shuttle Radar Topography Mission (SRTM) images, by filtering operation and image processing), and a comparison of those techniques to highlight the best suitable techniques of the study area and implementation of some lineament evaluation techniques such as density, length and orientation for extracting additional lineament information. At final, a spatial relationship of surface geothermal manifestations with lineament distribution extracted in this study.

2. GEOLOGICAL CONTEXT

The study area is located at the triple junction among the Nubian plate (Northeast), the Somali plate (Southeast) and the Arabian plate. This triple junction forms the convergence area of the three rifts, called the Afar Depression (Figure 1). The Red Sea (oceanic rift) defines the Arabian plate of Africa, the Gulf of Aden (oceanic rift) extends from the Indian Ocean to the Red Sea, and the East African rift (rift) is the frontier between Nubian and Somalia rifts and extends up to Tanzania. The recent geological history of this region is the result of the spread of the Gulf of Aden ridge (the Gulf of Aden is a young oceanic crust) resulting in the formation of a series of disjointed rift segments in which tectonic deformation and magmatic activity are still active. This ridge seems to end abruptly to the west on the coast of Africa. However, a narrow Gulf extends landward, the Gulf of Tadjourah is enclosed within the Republic of Djibouti recognized as a portion of the oceanic rift in the prolongation of the Gulf of Aden (Gaulier and Huchon 1991). The western part of this oceanic axis is the famous Asal rift (Francheteau et al. 1976). The rift of Asal-Ghoubbet is one of the youngest and most western segments of this ridge. It constitutes the onshore extension of the Tadjourah Rift (Manighetti et al. 1998 and Daoud et al. 2011). Nord-Ghoubbet area is one of the major geothermal potential areas in Djibouti and is located near the NW-SE trending axial volcanic range of the Asal-Ghoubbet rift which has a high enthalpy geothermal prospect (Mohamed Houmed, Omar Haga, and Varet 2012). This site was characterized by different tectonic patterns affected by several fault systems, noted normal faults with NW-SE direction (Asal rift)(Courtillot, Tapponnier, and Varet 1974), N-S (transform faults) (Courtillot, Tapponnier, and Varet 1974), and NNW-SSE (the opening of Tadjourah Gulf direction) (Figure 2)(O. Richard and J.Varet 1981). The surface manifestation, in particular, fumaroles are clear phenomena to show the fairly active tectonics in the study area. The older formation hosting a geothermal reservoir is characterized by Dalha basalt (4 to 8 Ma) and overlaying recent gulf basalt (formed during the early stage of penetration of Aden ridge, through the Gulf of Tadjourah at 4 to 2 Ma).

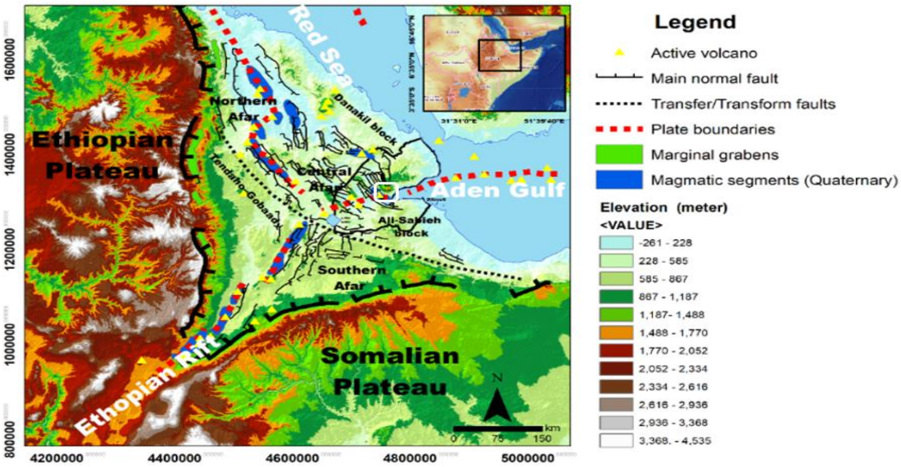


Figure 1: Digital elevation model of the Afar triangle area (data from the Shuttle Radar Topography Mission, SRTM; resolution 90 m.), White Square indicates the study area.

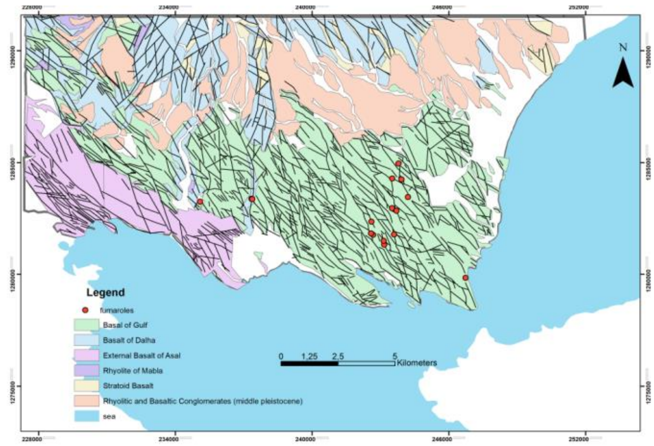


Figure 2: Geological map with faults patterns distribution (Gasse, Richard, and Ruegg 1985)**.**

The Nord-Ghoubbet area acts as a block and stops the extension of Tadjourah Gulf to the landward and change the direction to NW-SE in 0.9 Ma (Asal rift) (Mohamed Houmed, Omar Haga, and Varet 2012). This tectonic evolution and variations indicate that the active faults are resulting from the transform system linking Ghoubbet with the Gulf of Tadjourah ridge but it also results from the fast rotation of this brittle block (Manighetti et al. 2001). Numerous fumaroles affecting the whole block, testify to the leakage of the geothermal reservoir due to the active tectonics of the site. The fracture network in Nord-Ghoubbet was well developed.

3. METHODOLOGY

The methodology of this research consists of the extraction of lineament features manually, for that, the methodology is composed of four successive steps (figure 3).

1) Selection of adequate satellite image with less cloud possible, (In this research Landsat 8 and SRTM image was selected) and the suitable band for manual lineament and geospatial analyses (orientation and density evaluation).
2) The second step will be the applying of image processing, created a shaded relief of SRTM image respected different azimuth angles using QGIS and for Landsat 8 some band ratios (BR), principal comparing analyses (PCA) and False-color composite was built following by filtering operation of band panchromatic of Landsat 8 to enhance the edge detection with different direction (NS, EW, NW, NE) using Envi 5.2 software.
3) The third step consists of the manual extraction process using QGIS software.
4) Step four is the evaluation of lineament extracted by combining all techniques to overcome a final lineament map following by constructed rose diagram using Rockwork software for orientation analysis, and lineament density created by ArcGIS software to evaluate the geospatial distribution of lineament to relate with surface manifestation distribution.

The data used in this research is a subset of the region of interest (ROI) who is the Nord-Ghoubbet geothermal field, this subset of Landsat 8 (VNIR (Near Infrared), SWIR (Short-wave Infrared) and panchromatic spectral band) data set (Row 52/path 170) dated 21 March 2017 (Table 1). Digital elevation image using shaded Relief is an SRTM image. For the SRTM image, the sun elevation was fixed 45° and the azimuth angle will be the variable content in this research (six azimuth angles was used a noted (0°, 45°, 90°, 180°, 200°, and 315°)). The image processing technique consists of a principal analysis, Band ratio and false-color composite. False-colour composite 7 in Red, 5 as Blue and 3 as Green channels (RGB), Band ratio 4/2 and principal component 1 was built and used.

Table 1: Landsat 8

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)		
Bands	**Wavelength (micrometers)**	**Ground Sampling Distance (meter per pixel)**
Band 1 – Coastal aerosol	0.43 - 0.45	30
Band 2 – Blue	0.45 - 0.51	30
Band 3 – Green	0.53 - 0.59	30
Band 4 – visible Red	0.64 - 0.67	30
Band 5 – Near Infrared (NIR)	0.85 - 0.88	30
Band 6 – SWIR 1	1.57 - 1.65	30
Band 7 – SWIR 2	2.11 - 2.29	30
Band 8 – Panchromatic	0.50 - 0.68	15
Band 9 – Cirrus	1.36 - 1.38	30
Band 10 – Thermal Infrared (TIRS) 1	10.60 - 11.19	100*30
Band 11 – Thermal Infrared (TIRS) 2	11.50 - 12.51	100*30
* TIRS bands are acquired at 100 meter resolution, but are resampled to 30 meter in delivered data product		

The filtering operation procedure was used in different directional filters a noted (NS, EW, NW, NE). Band panchromatic was utilized in this step because this band is favoured of lineament analysis of its improved spatial resolution (15 meters). Those four filtered images have been produced by Envi 5.2 software. In general, this research undergoing two main phases. The first step is the compilation of the literature review in aspects of different lineament analysis techniques. The second step consists of all the routing of the process implemented to overcome the objective of this research. All manual lineament extractions, density analysis and length calculation are performed on GIS software (QGIS and ArcGIS). The image enhancement (image processing, filtering operation) has proceeded in Envi 5.2 software and the rose diagram was performed in Rockwork software.

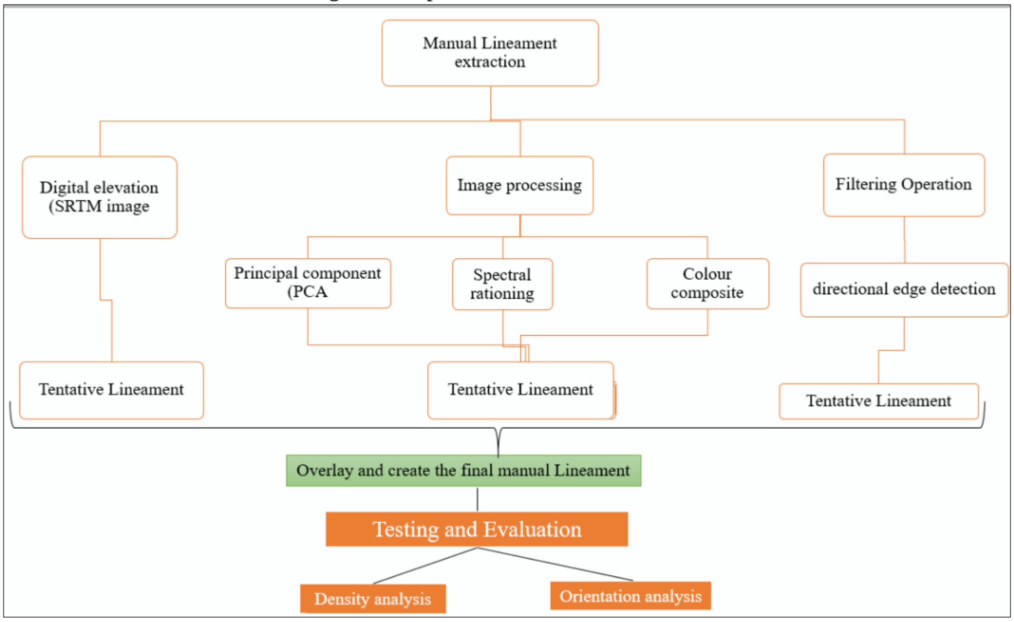


Figure 3: Flow chart of Methodology

4. RESULTS AND DISCUSSION

Lineaments are topographic features that are of great use in the exploration of resources such as groundwater, hydrocarbons, minerals and geothermal energy, and some Geohazard (landslide etc....) (Guild 1974). By manual lineament technical extraction, lineaments are extracted from the satellite image and Digital Elevation Model (DEM) using visual interpretation. Lineaments generally appear as straight lines or "edges", in all cases contributing to differences in tone in the surface material. Manually, several features that help to identify lineaments are such as topographic features including straight valleys and continuous escarpments, straight rocky limits, systematic river offset and alignment of vegetation. The lineaments extracted according to the SRTM image was used at six different azimuth angles (0 °, 45 °, 90 °,180°, 200°, and 315°) to ensure an unbiased mapping of all lineaments in the study area. Therefore, overlay all lineaments obtained from these six different azimuths into a single shapefile. d. Lineaments extracted from each of the six azimuth angles considered from the 0 °, 45 °, 90 °,180°, 200°, and 315° and the final lineament output generated by compiling the lineaments from these six azimuth angles are shown in Figures 4 and 5, respectively.

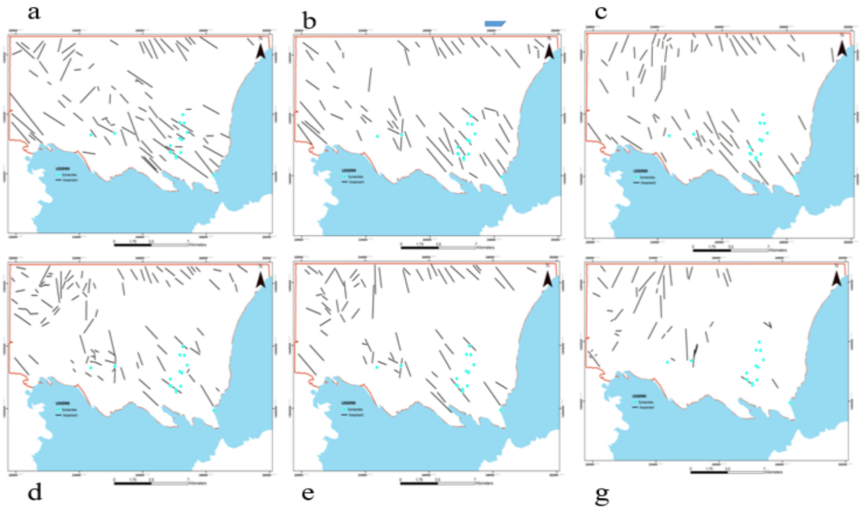


Figure 4: Lineaments traced from the SRTM of different azimuth angles. Alphabets are used to indicate different azimuth directions from which maps are derived. a) 0° azimuth angle. b) 45° azimuth angle. c) 90° azimuth angle. d) 180° azimuth angle. e) 200° azimuth angle. g) 315° azimuth angle.

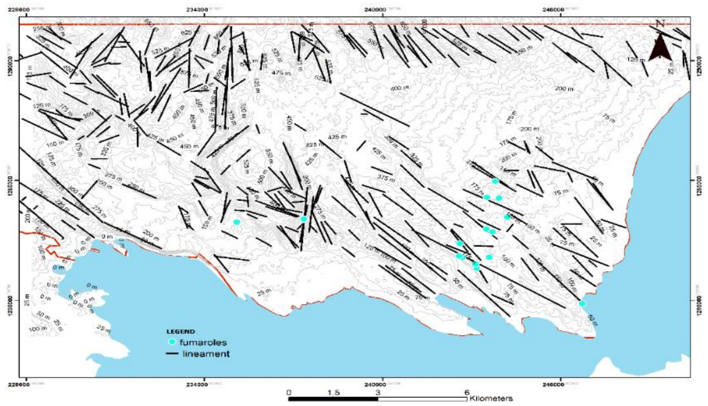


Figure 5: Lineament maps generated by different Azimuth angles

One of the characteristic features of the satellite images is a parameter called spatial frequency which is defined as the number of changes in brightness value per unit distance for any particular part of an image (Jensen 1996). Filtering operations are used to emphasize or deemphasize spatial frequency in the image (Sarp 2005). This frequency can be attributed to the presence of the lineaments in the area. In other words, the filtering operation will sharpen the boundary that exists between adjacent units.

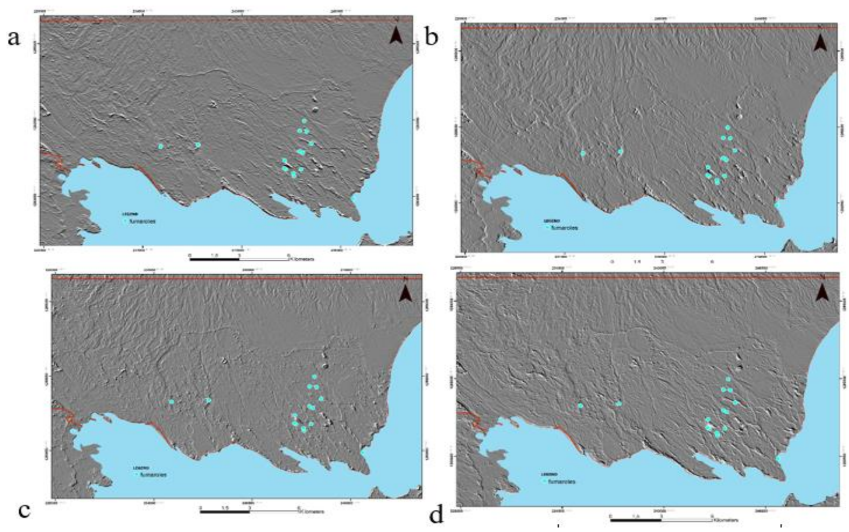


Figure 6: Directional edge detection a) E-W, b) NE-SW, c) NW-SE and d) NS directions.

In this study, directional filters (edge detection filters) are designed to enhance linear features such as roads, streams, faults, etc. The filters can be designed to enhance features that are oriented in specific directions. The following direction, E-W, NE-SW, NW-SE and N-S directions are used in this step (Figure 6).

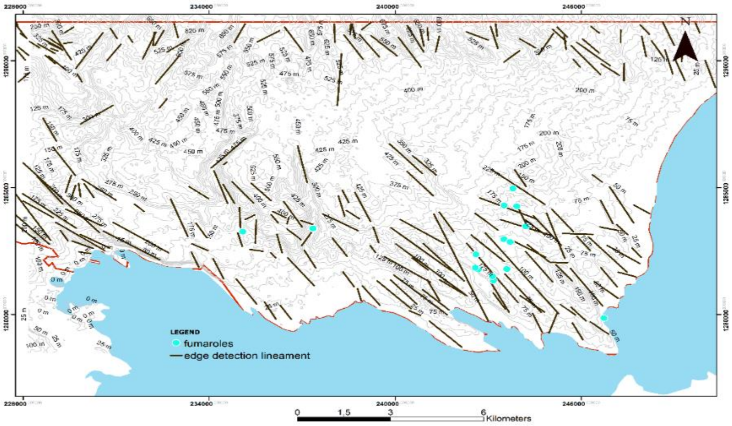


Figure 7: Combining the lineament maps generated by directional edge detection.

In image processing, three techniques were used: Principal Component Analysis (PCA), Spectral rationing and Color composite. PCA is an image transformation technique based on the processing of multi-band data sets that can be used to reduce the dimensionality in the data and compress as much of the information in the original bands into fewer bands (Sarp 2005). In this study, PCA was applied in seven-band (band 1, 2, 3, 4, 5, 6 and 7) and PC1 was chosen according to the highest eigenvalue (Table 2).

Table 2: Principal component analysis of Landsat 8 of Nord-Ghoubbet area

Eigenvector	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7	Eigenvalue (%)
PC1	0.999912	0.01302	0.00256	-0.00017	-0.000436	0.000643	-0.000241	97.097
PC2	-0.013116	0.999125	0.038049	-0.001605	-0.007803	0.008083	-0.001005	2.378
PC3	-0.002059	-0.03803	0.998056	-0.043181	-0.011876	-0.020681	-0.000097	0.337
PC4	-0.000046	0.000253	-0.043507	-0.998852	0.006293	-0.018157	0.005701	0.115
PC5	0.000451	0.009399	0.006974	0.010541	0.96604	-0.257585	0.012996	0.035
PC6	0.000481	0.006678	-0.022092	0.016901	-0.257627	-0.965821	0.00075	0.035
PC7	-0.000222	-0.000875	-0.00031	-0.00554	0.012407	-0.004182	-0.999898	0

Rationed images are useful for discriminating spectral variations in an image that are masked by the brightness variations. The aim is to highlight the spectral differences that are unique to the material being mapped. Band ratio (BR) is defined by the numerator divided by the denominator. The color composite is a method where the spectral response of the minerals indicates a maximum in their reflectance. FCC images are produced for manual lineament extraction because they increase the interpretability of the data. For that, band 7, 5, 3 combinations in RGB channels respectively were used and made it easier to identify linear patterns of vegetation, geologic formation boundaries, river channels and geologically weak zones. The results of the process are shown in Figure 8.

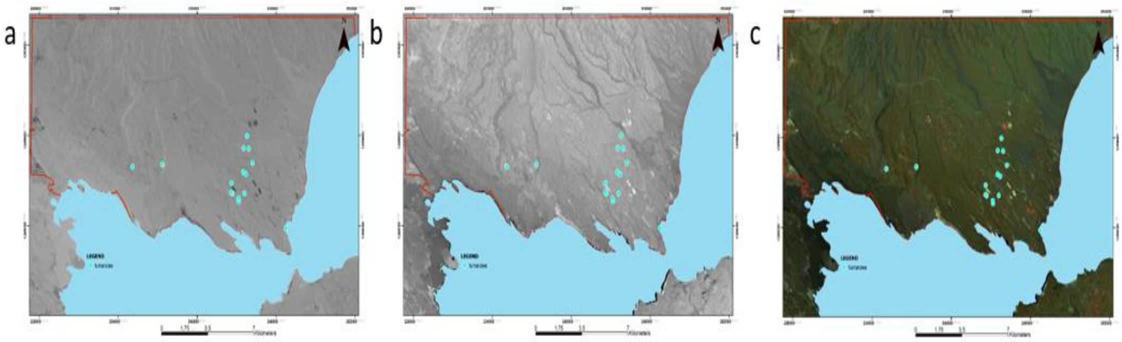


Figure 8: a) Principal component 1 (PC1), b) Band ratio 4/2, c) False-color composite (753) in RGB

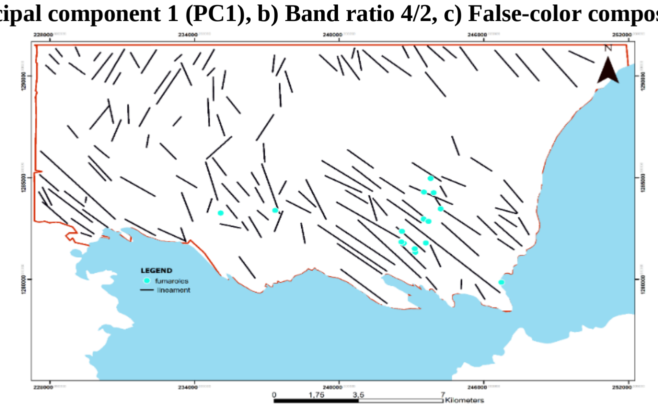


Figure 9: combining the lineament maps generated by different image processing (A noted FCC, BR, and PCA)

The evaluation was based on the orientation analysis using the rose diagram, density lineament and the length of lineament. A rose diagram is a circular histogram plot that displays the directional data and frequency of each class. The rose diagram was plotted in rockwork using the linear algorithm under the utility function. In general, a rose diagram was used to analyze the orientation of lineaments, faults and fractures. The density of faults and lineaments refers to the total number of faults per unit area, therefore the areas with more faults or lineaments per unit area are considered as high-density areas, while those with fewer faults and lineaments per unit area are considered as low-density areas of faults and lineaments. Density analysis was calculated using the line density option under the Spatial Analyst tool in ArcGIS software. The software simply counts the number of lines per unit area. Areas with a high number of lineaments per unit area were identified as high-density areas followed by medium and low-density areas.

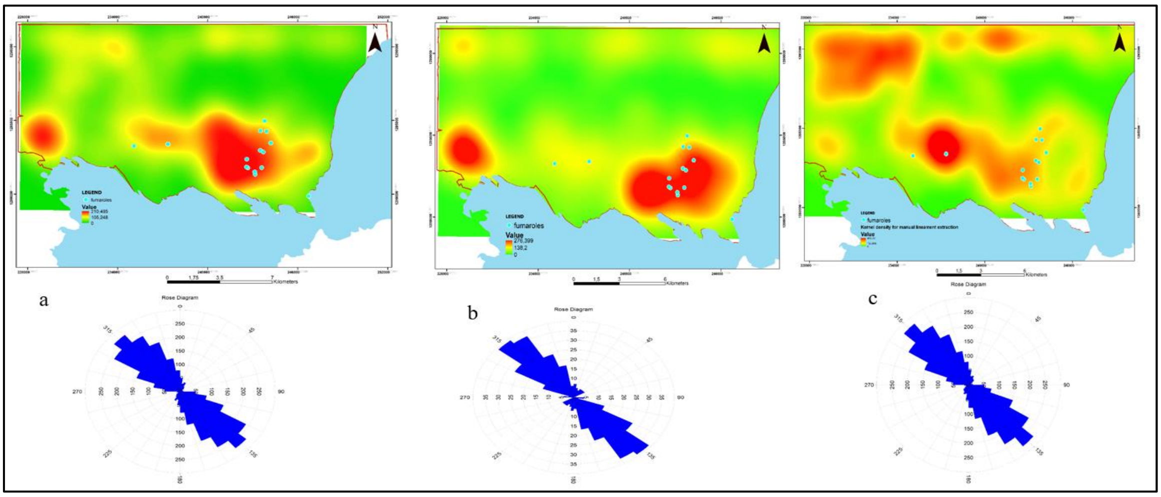


Figure 10: Lineament density map showing high, medium and low-density zones. Rose diagram presenting the overall directions of lineament extracted by different techniques, a) image processing, b) filtering operation and c) Shaded relief (SRTM) lineament extraction

A total of 418 lineaments are manually identified using shaded relief techniques (Figure 5). The minimum length of lineament found in this technique is 29 meters and the maximum length is 6097 meters. The total length of all lineaments is 283999 meters in this analysis. Furthermore, the number of lineaments is more than those obtained in the filtering operations and image processing. The shaded relief (Digital elevation) shows the highest total lineament and the minimum length, in addition to the highest maximum length and the highest total lineament (Table 3). This technique is the most suitable in this study area to extract manually the lineament. The fumaroles are in the high and medium density area and the orientation of lineaments using the rose diagrams are NW prominent and less pronounced direction such as NS, EW, and NNE. The results of orientation and lineament density show almost the same results as the other techniques

Table 3: Different manual lineament extraction techniques evaluation

Manual Lineament Extraction	Total Lineament extracted	Minimum length (m)	Maximum length (m)	Total length (m)	Fumarole distribution	Lineament Orientation
Digital elevation	418	29.43	6097.16	283999.51	High and medium lineament density	NW and less pronounced fault as NS, EW and NE
Filtering Operation	276	125.13	4570,25	199640.76	High and medium lineament density	NW and less pronounced fault as NS, EW. NE are more pronounced than the other lineament extraction
Image processing	210	257.33	5309.75	173984.48	High and medium lineament density	NW and less pronounced fault as NS, EW and NE

The final manual lineament was generated based on the overlain of the lineament created of three techniques discuss later (figure 11). As of this release, duplicate lineaments have been removed and the final manual lineament map was created. The total number of manual lineament extraction is 904. The maximum lineament length detected is approximately 6097 meters and it is the maximum length of shaded relief techniques lineament extracted.

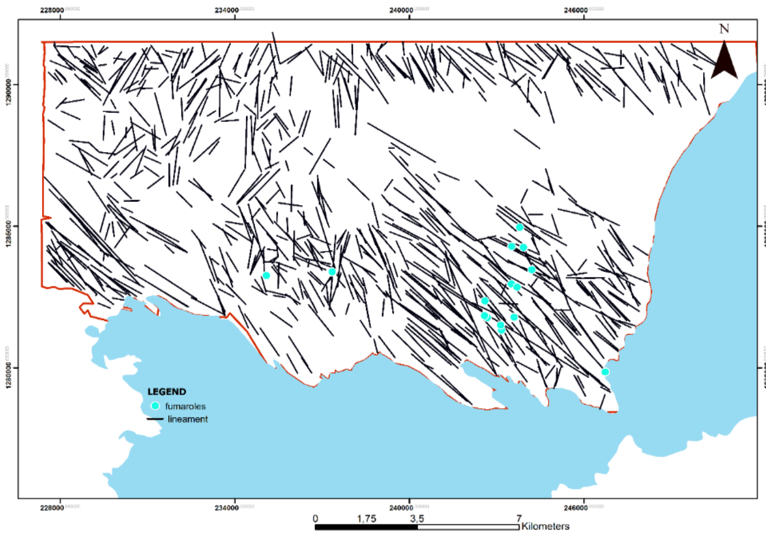
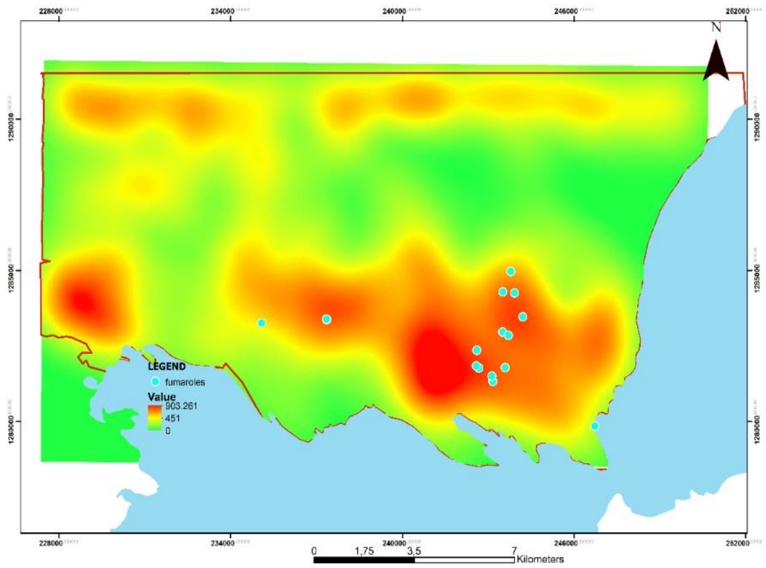


Figure 11: Final manual lineament maps generated by combining those different techniques, digital elevation, filtering operation and image processing respectively.

The orientation of the final lineaments extracted using the rose diagrams shows as the main direction NW trend and less pronounced lineament direction as NS, EW and NE. Those finding directions tie in the tectonic patterns in Nord-Ghoubbet geothermal areas. The main tectonics trends effect in the study areas are the Asal-Ghoubbet rifting (NW-SE direction is the rifting trend), following by Makarrasou transform faults correspond NS trend, and WNW-ESE to EW correspond the opening of Tadjourah Gulf direction.

a) 

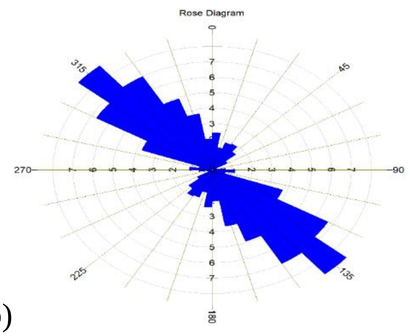
b) 

Figure 12: a) Fault density map showing high, medium and low-density zones and b) Rosette diagram is presenting the overall directions

5. CONCLUSION

The manual lineament extracted in this study was used a digital elevation model (SRTM topographic data with a spatial resolution of 90 meters), filtering operations (edge direction detection using different directions edge detection such as NS, NW, NE, EW) and the image processing (PCA, BR, FCC). The lineaments maps and the final lineament map were created based on these three different methods. The lineament extracted by digital model elevation was the most suitable of this area according to the evaluation techniques (density, direction evaluation, length of lineament and number of lineament). The results from the rose diagram showed that one main NW-SE (direction of rift Asal-Ghoubbet) in the general orientation of the faults in the study area and less pronounced fault as N-S (Makarassou fault transform direction) and WWN-SSE to EW (the opening of Tadjourah Gulf direction) and those directions agreed with the faults patterns trend in the study areas. The density analysis showed that the geothermal fumaroles are mainly located in high and medium lineament density that can suggest the surface manifestation are controlled by faults. The areas with high-density lineament with surface manifestation distribution would be estimated as a potential area for further geothermal investigations.

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