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# Lithological, structural and hydrothermal alteration mapping utilizing remote sensing datasets: a case study around Um Salim area, Egypt

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**Abstract.** Remote sensing datasets have introduced remarkable advancements in mapping rock units, structural elements, and hydrothermal alteration zones. This study applied Landsat Operational Land Imager (OLI) multispectral dataset in discriminating the intricate basement of Um Salim area, Central Eastern Desert (CED), Egypt. Moreover, a panchromatic 15m pixel size band is implemented to extract the study area's linear structural features. Several image processing methods including False Color Combination (FCC), Band Ratio (BR), Optimum Index Factor (OIF), and Density slicing were utilized in lithological and alteration mapping. The widely used, LINE module of the PCI Geomatica is applied for lineament extraction. Results reasonably discriminate the complicated rock units using selected composites depending on OIF results. A photo-geological map is constructed and shows greater coincidence with recently published maps. Lineaments map and its density revealed the preponderance of NE-SW and WNW-ESE structural trends. The spatial relationship between the resultant hydrothermally-altered zones and the detected structural features strongly recommends further detailed examination for ore deposits within the study area besides manifesting the efficiency of the utilized data and methods.

## 1. Introduction

Geological mapping is considered an indispensable issue for several fields and applications i.e. mineral exploration, landslides, mining, geomorphology, flash flooding,...etc. Recently, remote sensing datasets serve as a cheap, efficient, time and effort-saving method when compared with conventional ways of field mapping, this could be easily manifested especially for inaccessible large areas[1,2]. Landsat data has been widely utilized for discriminating rock units, deciphering lineaments, and disclosing hydrothermal alteration [3–5]. Nowadays and by the availability of several image processing techniques that can enhance specific targets from Landsat data, the latter is still used in several applications especially the latest series (Landsat 8) that has better spectral characteristics compared to the earlier missions[6–8]. Thus, this study implemented Landsat Operational Land Imager (OLI) for demarcation of lithological boundaries, delineation structural elements, and assigning hydrothermal alteration zones, which could be a direct indicator for metallogenic areas within the study area. Specific alteration minerals cannot be accurately detected using Landsat data, however, the predominance of clay minerals, sulfide, iron oxides, carbonate, hydroxyl-bearing and



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silicates could be highlighted. In our study and generally, for images acquired simultaneously and utilizing the same sensor, most image fusion techniques deliver efficient results (single-sensor, single-date fusion) [9]. The widely known Hue, Saturation, and Value (HSV) sharpening method is implemented for enhancing the spatial resolution of multispectral images to panchromatic resolution (15 m), retaining the spectral information. This, in turn, could better visualize the rock units within the study area. In this study, the best RGB combinations for lithological discrimination will be assigned using the Optimum Index Factor (OIF) method. Then, specific band ratios will be applied depending on the spectral characteristics of the utilized bands aiming to enhance lithological units and three types of hydrothermal alteration (Ferrugination, Ferromagnesian, and OH-bearing minerals) within the study area. Furthermore, the study will test all the VNIR and SWIR bands of Landsat data in their potency in extracting linear features compared to panchromatic band efficiency.

## 2. Study area and geological setting

The study area constitutes a part of the Arabian Nubian Shield (ANS) and is located at the extreme southern part of the Central Eastern Desert, eastward to the well-known Barramiya area, as shown in figure 1. It is mainly occupied by crystalline Precambrian basement rocks besides Phanerozoic Nubian sandstone at the southwestern corner. The main rock units in the study area are ophiolitic serpentinite (Ser), ophiolitic metagabbro, ophiolitic mélangé (Mel), island arc metavolcanics (MV), metagabbro-diorite complex (MG), granitic rocks, and Phanerozoic Nubian Sandstone (NSS) as shown in the geologic map [10].

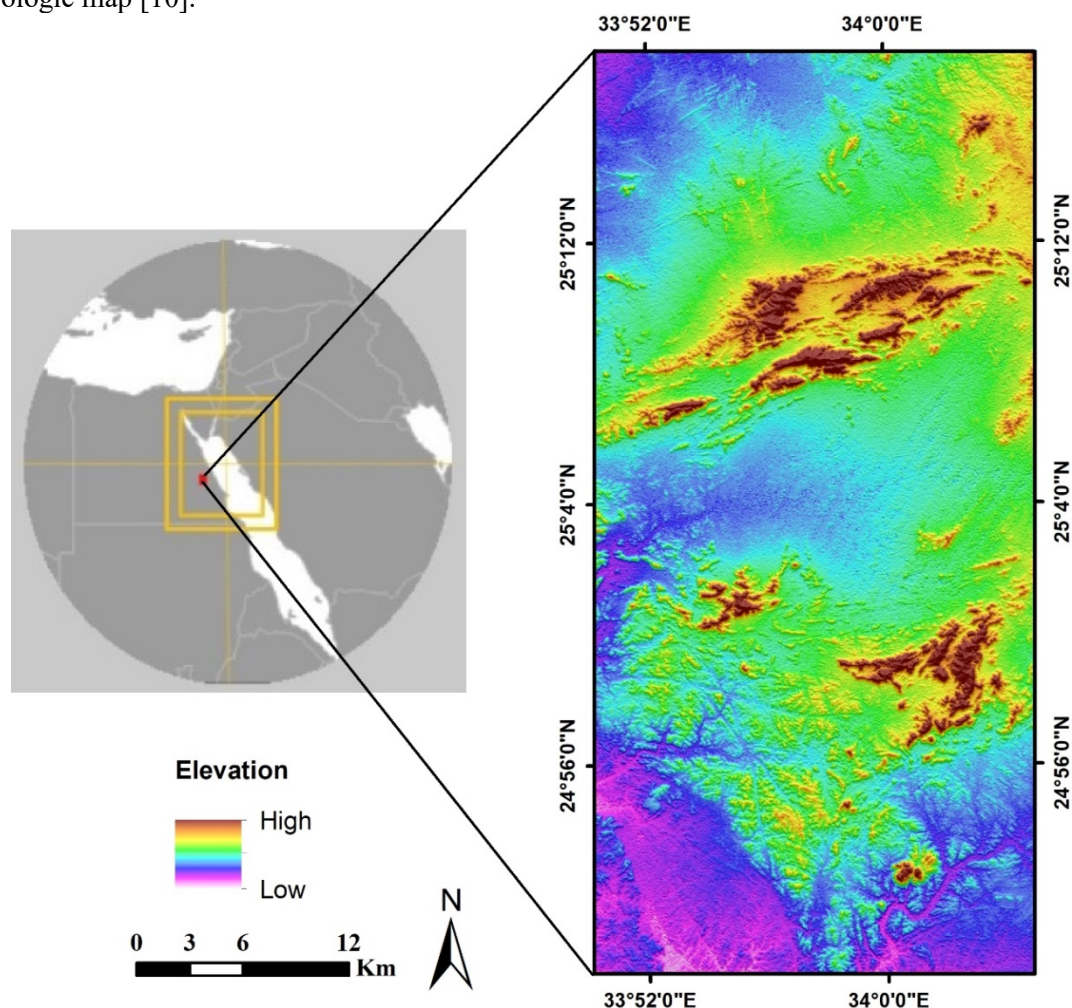


**Figure 1.** (a) Location of the study area (small red rectangle); and (b) 12.5 m pixel size ALOS PALSAR DEM of the study area.

### 3. Materials and Methods

#### Materials

Besides its wide coverage scenes (185 x180 km), non-cost availability and compared to the previous sensors of Landsat series, an eminent improvement is evident in terms of spectral resolution, and radiometric resolution (16 bits) [11], Landsat-8 is the most preferred for many researchers in various applications. A cloud-free Landsat 8 scene (LC81740432019298LGN00), covering the study area, was obtained through USGS. Landsat 8 mission has two sensors, OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) to acquire spectral data in the Visible and Near-Infrared (VNIR), Short-Wave Infrared (SWIR), and TIR regions [12]. OLI data are recorded in nine spectral bands as shown in Table 1, while TIRS data give information in only two bands. TIRS data are excluded from this study.

The utilized bands are georeferenced to WGS-84, UTM zone 36 N, atmospherically corrected by implementing Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) preprocessing method using the Environment for Visualizing Images (ENVI) software version 5.6 (developed by L3Harris.com).

**Table 1:** Characteristics of Landsat 8 data.

| bands | Central Wavelength ( $\mu\text{m}$ ) | Spatial Resolution (m) |
|-------|--------------------------------------|------------------------|
| 1     | 0.442                                | 30                     |
| 2     | 0.483                                | 30                     |
| 3     | 0.561                                | 30                     |
| 4     | 0.654                                | 30                     |
| 5     | 0.864                                | 30                     |
| 6     | 1.609                                | 30                     |
| 7     | 2.203                                | 30                     |
| 8     | 0.598                                | 15                     |
| 9     | 1.373                                | 30                     |
| 10    | 10.90                                | 100                    |
| 11    | 12.00                                | 100                    |

#### Methods

Optimum Index Factor (OIF), False Color combinations (FCCs), Density Slicing (DS), and Band Ratios (BRs) are the main utilized techniques for distinguishing rock units and alteration zones. OIF is a statistical way (depends mainly on standard deviation and variance between bands) for highlighting the best combinations (from multispectral datasets) valid for lithological classifications [13–15]. OIF method quantitatively estimates the scene statistics to avoid redundancy and save time and efforts exerted in the visual selection of the efficient RGB combination[16,17].

Then these results are HSV pan-sharpened and displayed as FCCs in successive RGB order. BR is a frequently used method in classifying rock units, detecting hydrothermal alteration, and mineral exploration. As the name suggests, BR is a division of digital numbers value (DNs) of two different bands in the sensor array. Specific BRs are assigned for detecting ferrugination, ferromagnesian, and OH-bearing hydrothermal alterations depending on spectral characteristics of the utilized bands and the alteration type, then and using density slicing technique, each type of hydrothermal alteration is separated and mapped.

Structural mapping is performed via LINE module algorithm of PCI Geomatica software. This algorithm firstly detect the edges then constitutes the lines by connecting these edges[18–21]. A comprehensive lineament analysis was outlined via testing all VNIR and SWIR bands. Parameters for the lineament extraction process are specified as 10, 50, 30, 3, 15, and 20 for

filter radius, Edge Gradient Threshold, Curve Length Threshold, Line Fitting Threshold, Angular Difference Threshold, and Linking Distance Threshold, respectively.

#### 4. Results and Discussion

##### Lithological and hydrothermal alteration mapping

By evaluation of the information amount and correlation of bands composites, OIF analysis generally suggests a combination of visible, NIR, and SWIR for enhancing lithologies as shown in table 2. The resultant six combinations were built (in RGB, 761, 721, 762, 751, 731, and 752) however not all of them obviously discriminate rock units of the study area. This could be attributed to the summation of standard deviations and correlation coefficients for both numerator and denominator in OIF calculation[14]. However, some of the OIF results could be described as optimum band combination as shown for FCC 761 (figure 2a), and FCC 751 (figure 2b), respectively in RGB. These bands are selected as the best combinations for lithological mapping of the study area. Moreover, results show how informative is the seventh band and the higher variance for bands 7 and 1 (smallest correlation with the other bands) is manifested (as shown by table 2), consequently, any FCC encompassing bands 7 and 1 will result in higher OIF and thus reasonable discrimination in this study.

**Table 2:** OIF Index Highest Ranking

|    |    |    |              |
|----|----|----|--------------|
| b1 | b6 | b7 | <b>72.16</b> |
| b1 | b2 | b7 | <b>72.14</b> |
| b2 | b6 | b7 | <b>71.55</b> |
| b1 | b5 | b7 | <b>71.25</b> |
| b1 | b3 | b7 | <b>70.86</b> |
| b2 | b5 | b7 | <b>70.70</b> |

Band ratio is considered an efficient technique in geological mapping[22–25], thus 20 BRs were created. Six of them display greater lithological discrimination and structural explication. These combinations are (RGB 4/7 6/7 2/5, RGB 6/7 2/3 4/5, RGB 7/1 5/2 4/3, RGB 7/3 7/2 6/2, RGB 1/3 4/5 6/7, and RGB 2/5 4/7 6/7). In the first composite (figure 2c), serpentinite (Ser) appears in a very light yellow color, metavolcanics (MV) have a green color, dark blue color for gabbroic rocks (MG), bright bluish to violet color for syntectonic granites (SGr), and reddish-brown color for the contact separating basement rocks from Phanerozoic Nubian sandstone (NSS) at the southwestern corner of the study area. Whereas in the second band ratio (figure 2d) composite (RGB 6/7 2/3 4/5) metavolcanics appear in strong red color, serpentinites as pink color, ophiolitic metagabbro is displayed in bright green color, metagabbro diorite in dusky green, and a very bright cyan color representing syntectonic granites is displayed at the central and northern part of the study area. Although, SGr is weathered and has very low elevation but still distinguished from the surrounding wadi deposits. Structural trends could be deciphered via the discriminated controlled dikes that appeared at the southeastern corner of the study area and the aligned valleys at the southwestern part of the area (figure 2d and e). These results reasonably harmonized with the previous geological map (figure 2f).

Hydrothermal alteration mapping is performed by using three main band ratios depending on the spectral ranges of the utilized bands and the type of alteration required to be detected. Ferrugination is detected by applying Visible BR of b4/b2, Ferromagnesian minerals via NIR b5/ SWIR b6 BR, and OH-bearing minerals through 6/7 SWIR BR. Then, pixels indicating each type of alteration are separated via the density slicing technique. Results show a predominance of ferrugination at the southwestern corner and through metavolcanics located to the south of Wadi Dungash. Logically, ferromagnesian minerals are spatially related to ophiolitic serpentinites. OH-bearing minerals are mainly concentrated at the central part of the study area, distributed through serpentinites, ophiolitic metagabbro, and sporadically represented through some metavolcanic rocks, as shown in figure 3 a and b. It should be emphasized that several previous studies recommended the implemented

techniques for other applications and in other areas. For example, the studies of [16,17] utilized the OIF technique in urban landuse / cover mapping using Landsat data. Coinciding with our research, several previous studies utilized FCCs, and BRs in lithological discrimination (e.g. [8,21,26–28]).

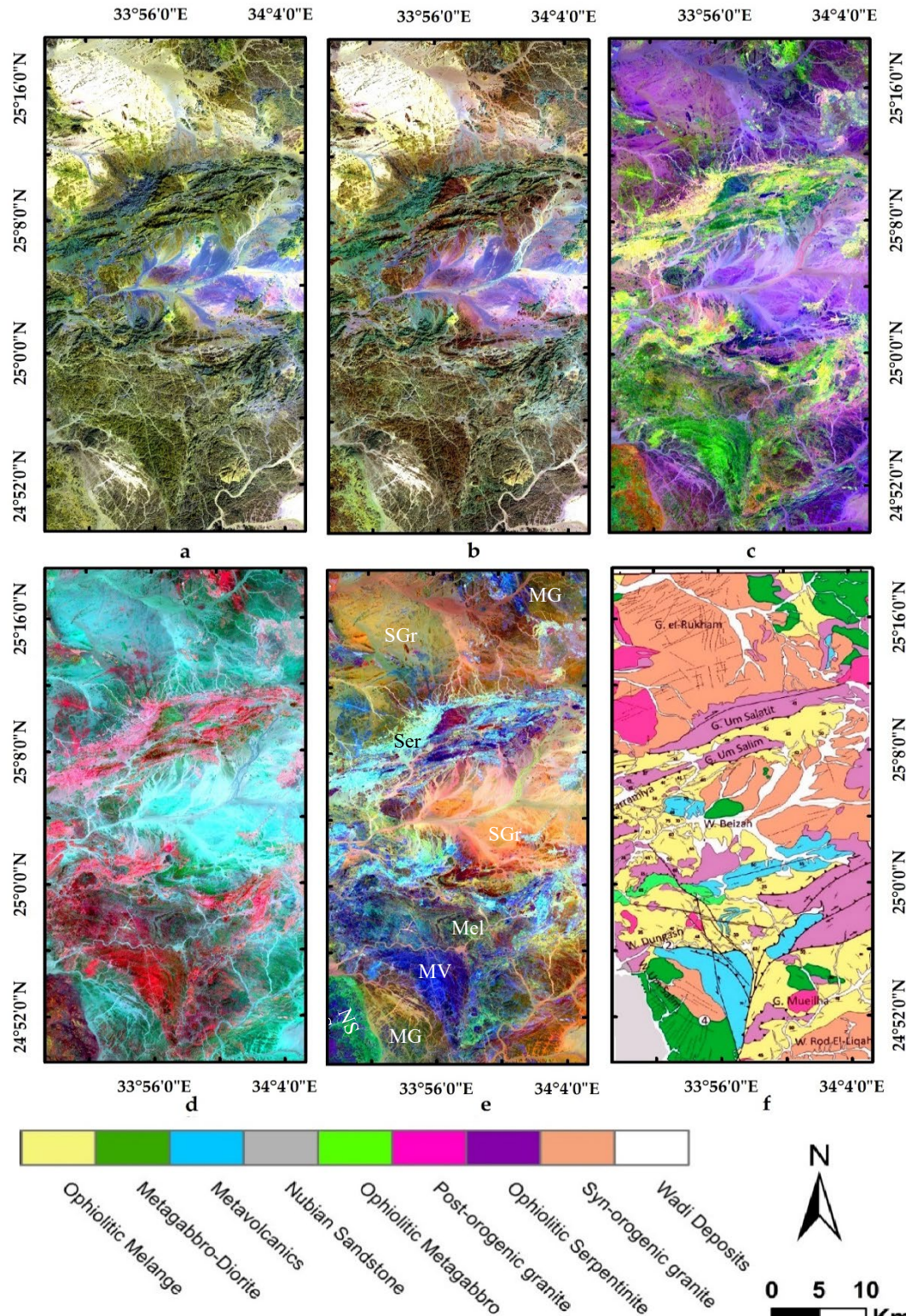


**Figure 2.** FCCs of (a) RGB 761 and (b) RGB 751. BRs of (c) RGB 4/7, 6/7, 2/5, (d) RGB 6/7, 2/3, 4/5 and (e) RGB 2/5, 4/7, 6/7. (f) Geological map for comparison, after [10].

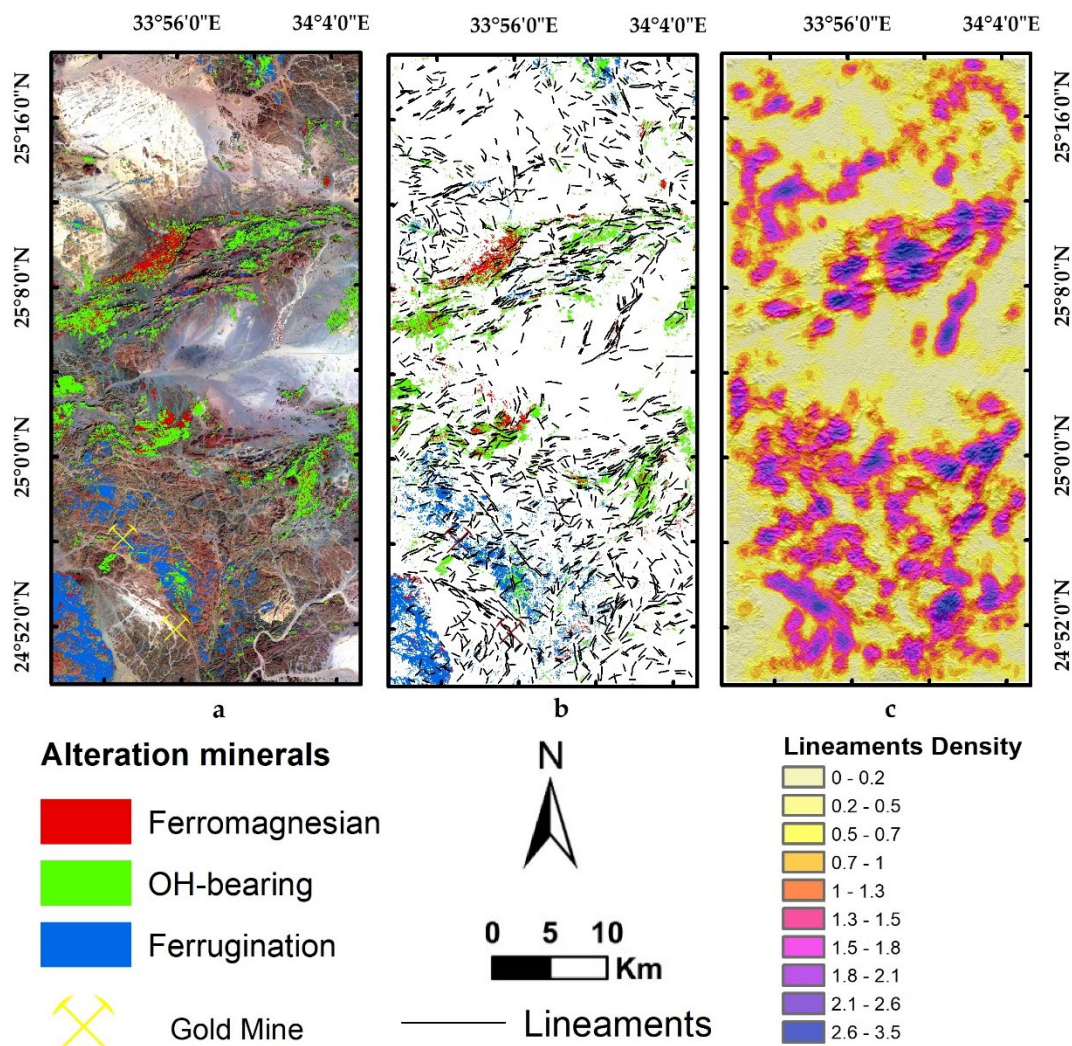


**Figure 3.** Hydrothermal alteration results dropped over (a) FCCs of RGB 642, showing spatial proximity to ancient gold mines (Dungash and samut) (b) automatically-extracted lineaments from panchromatic band 8. (c) Lineaments density map showing reasonable coincidence (of moderately to high density regions) with the distribution of alteration zones.

#### 4.1.1. Structural mapping and Results Integration

A comprehensive lineament extraction analysis was performed for each band of Landsat data separately aiming to detect the best VNIR and SWIR bands able to extract linear features. For 30 m resolution data, the best VNIR band was b4 by extracting 789 lines whereas b6 extracts 784 lines as the higher number for SWIR bands. Due to its higher spatial resolution (15 m), band 8 results in 2951 lines (figure 3b). Consequently, b8 results were adopted as a structural map of the study area. A lineament density map was created to display highly dissected areas and their spatial relationship to hydrothermally altered zones.

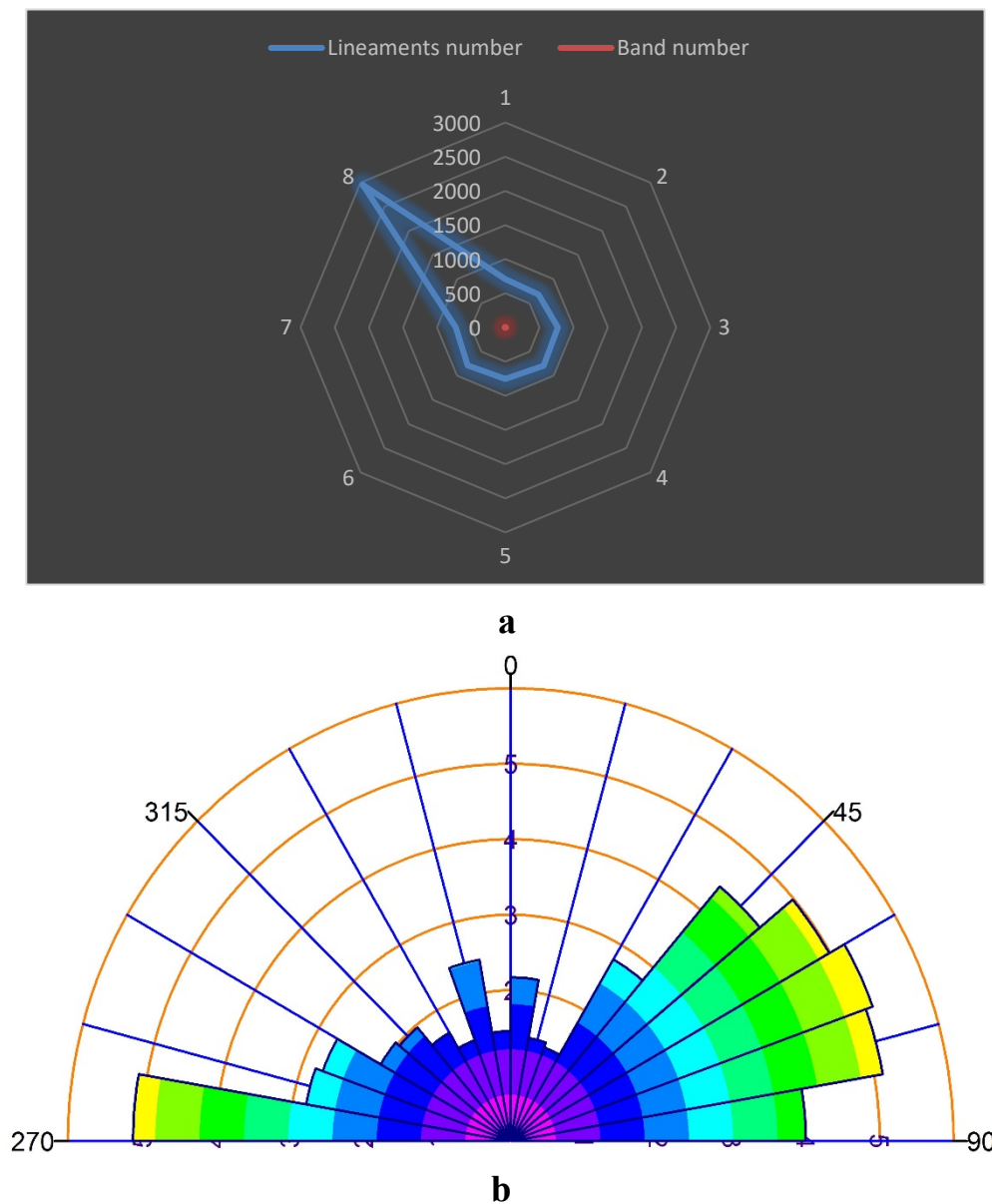


**Figure 4.** (a) Notability of panchromatic band 8 (approximately 3000 lines) over the other bands (less than 1000) in extracting lineaments, manifesting spatial resolution effect in the process (b) Rose diagram exhibiting predominance of NE-SW and WNW-ESE structural trends.

A reasonable coincidence was reported, where most of the alteration areas are located within medium to high-density regions, this, in turn, raises our expectation of the presence of structurally-controlled mineral deposits within the study area other than the well-known ancient gold mines (Dungash and Samut). The latter, by their locations, already emphasize our results as they are closely located to highly or moderately dissected and altered zones. Figure 4a strongly emphasizes the effect of spatial resolution in increasing the numbers of extracted lineaments. Trend analysis was performed and revealed that the dominant trends are NE-SW and WNW-ESE however all the other structural trends are represented (figure 4b).

## 5. Conclusions

The study concludes the following points:

- 1- Remote sensing datasets efficiently perform geological and structural mapping of complex terrains and their results are reasonably coincide with the costly field mapping methods,
- 2- OIF is a good technique in selecting bands to be combined for enhancing specific targets,
- 3- A combination of visible, NIR, and SWIR bands is generally recommended for enhancing rock units in arid regions
- 4- Band ratio technique is potent in discriminating rocks and alteration zones depending on the utilized data characteristics,
- 5- Cross linking structural, lithological and hydrothermal alteration data is considered an efficient, time and cost saving technique for mineral exploration

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