

ARTICLE

LIST ALGORITHM: LINEAMENT IDENTIFICATION AND STOCKWORKS TARGETING WITHIN ASTER SATELLITE IMAGE

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ABSTRACT

Background: Now-a-days, remote sensing has been widely used in the field of geology. The application of remotely sensed data for lineament interpretation in mineralogical environment is demonstrated here. Lineament investigation is classified based on the geological properties, and lineament parameters like its position, direction. Satellite images (or) Aerial images are used now-a-days to discriminate the lineaments based on the spatial variations in orientation and density. The main purpose of this work is to identify lineaments and target stockworks from the ASTER satellite image which contributes to understand about the geological faults over the study area. **Methods:** The major work for the extraction of lineaments and its intersections is implemented using the following steps: A) selection of the suitable band from the ASTER satellite image for lineament extraction and the following geospatial analysis. B) applying image preprocessing methods to denoise and enhance the contrast, edge information of lineaments C) Identifying the lineaments using the proposed Lineament Identification and Stockworks Targeting (LIST) algorithm D) Analyzing the following geospatial aspects: lineament length, density and stockworks. **Results:** The proposed LIST algorithm solved many of the existing problems encountered while analyzing lineaments and the result of LIST is compared with Mask based clustering and Fuzzy C Means clustering techniques which is mostly used by other researchers. LIST algorithm concentrates more on micro lineaments and stockworks area which has the higher potential for minerals existence. A total of 699 lineaments with total length of 17,561kms are extracted using LIST which is comparatively higher than the other two methods discussed here. **Conclusion:** the geospatial analysis result shows that the identification of geological lineaments over wide area is possible and detailed information for the purpose of exploring minerals and its prospective zones can be obtained using the proposed LIST algorithm. The knowledge of lineaments can be applied to the terrain surfaces to map/monitor the road networks, drainage density networks, and alignment of vegetation.

INTRODUCTION

The alignment of faults and fractures were analysed during the 19th century in Great Britain. Hobbs initiated the work [1] on "lineaments of the Atlantic border regions". He defined lineaments as "significant lines in the Earth's surface" and stated that "an essential lineaments as the top of ridges or boundaries of elevated areas, drainage lines, coastlines and limits of geological formation of petrographic rocks or vegetation line of crops" and then the definition is rephrased as that "significant lines in the landscape which reveal the hidden architecture". Most of the authors classified the lineaments based on its width, length and contrast.

Identifying lineaments from the satellite image [2, 3] can be done using two steps. At first, selecting suitable band for processing, applying edge enhancement methods, then extracting lineaments using GIS software. Various automatic tools and software's are used since only one software tool is not sufficient to process all the steps of analysis. Most of the studies utilised the following software tools. LINDEN [3], PCI Geomatica [4-6] software extracts lineaments using edge detection, thresholding and curve extraction steps. But this kind of extraction may detect non geologic lineaments (e.g.) manmade linear structures like road, pipelines and drainage networks etc., LINE module, ArcGIS, ArcMap, GEOrient [7, 8]. "PhotoLin" tool [9] is developed exclusively for IBM compatible PCs to extract lineaments from aerial, satellite and topographic images. For that, the given image is binarized, segmented using threshold to locate the features of interest and then the thinning algorithm is applied to generate the lineament map. Tonal / Contrast based methods are applied to differentiate lineaments. In Segment Tracing Algorithm lineaments are extracted based on the local variance of grey level and connect two line elements of same orientation. The main advantage of this method is that the capability to track continuous valleys and its shadows which look like two parallel lines in the lineament map of the study area.

An adaptive anisotropic kernel method [10] estimates the lineament density and distribution by adjusting the smoothing kernel based on the local spatial distribution, and then the global thresholding is applied to segment the density image. Whenever the number of objects is large, the natural way of counting the object is by using pointing (or) dotting the objects. Likewise, the spatial arrangement of the dots provides wealthy additional information on density analysis. Counting by detection method localises individual object instances in the image. Locating and counting the overlapping objects becomes trivial and hard. Instead of solving the hard problems of overlapping, Counting by regression method considers the global characteristics (histograms of image features) to detect the number of objects and this method cannot consider other information like the location and the population of the objects. Counting by segmentation methods [11, 12] combines both the methods which segment the image objects into separate clusters and then regresses from the global properties of each group to the overall number of objects in it. Various classification algorithms and its combinations are used to categorize the land use areas from the satellite image [13, 14].

KEY WORDS

Lineament, Stockworks, LIST, ASTER Satellite, Afar depression

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Fracture Network Evaluation Program (FraNEP)[15] is developed to analyse various parameters of lineament such as lineament density, intensity, and length using scanline sampling and window sampling. FracSim 3D software package analyses the fracture lengths with the help of image histograms. The LINDENS tool estimates the lineament density. Some of the lineament analysis works [16, 17] focused on tectonic and geochemical estimation which determines the orientation of fault and fractures. Canny algorithm [18] with different window size extracts lineaments and its alteration zones. Evaluation of density and frequency of lineaments helps to update the fault / geological map of the study area. From the detailed review of these works results the following limitations and challenges exists. They are:

- Lineament exhibits different brightness and contrasts on its sides because of poor illumination.
- Global scale segmentation cannot be able to detect the micro lineaments.
- Discontinuity in the linear pattern even in the same fault occurs if edge detection is poor.
- Extraction of stockworks is hard; if the lineament object is over / under segmented.
- Difficult to update geologic lineament maps by field observations. Lack of up-to-date lineament maps.

The main objective of the current research work is to provide a Lineament and Stockworks extraction system. For that, a new algorithm named LIST (Lineament Identification and Stockworks Targeting) is proposed here to solve the above-listed problems which are encountered while analyzing lineaments. Finally visual interpretation of manually extracted lineaments [19] with the geologic map of Ethiopia and also the automatically extracted lineaments can be done to update the geologic lineament maps of an area. Macro, moderate and micro lineaments and its geospatial results along with the field evidence reveal firm evidence of geologic/tectonic scenario.

MATERIALS AND METHODS

ASTER image dataset

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery of 30-m resolution [20] gives better results while analysing lineaments when compared to IRS 1D imagery because of improved spatial resolution. To classify the geologic lineaments from the High-resolution Multispectral image, ASTER satellite image is used. ASTER is a multispectral imager which covers a wide spectral region of the electromagnetic spectrum from the Visible Near Infra-Red (VNIR) to the Thermal Infra-Red (TIR). Recent years, the use of ASTER data in mineral prospecting application is increased because of it is freely available on the internet, the image covers a broad area (approx. 60 sq.kms), and different integral bands are highly sensitive to alteration minerals (i.e.) minerals known to surround target minerals. Lithologic and mineralogical units on the surface can be accurately mapped with this satellite image. 15m resolution of VNIR data is one of the best resolutions among all the multispectral satellite data available commercially.

Description of study area

The Afar is one of the northeastern states of Ethiopia [21]. The Afar Depression is an area of lowland plains split by fault blocks and dotted with shield volcanoes. It is the lowest valley region in Ethiopia and one of the lowest in Africa. Afar depression is surrounded by southern Red Sea rift on its northern side. In the eastern part, the Gulf of Aden Rift is spread through the Gulf of Tajura. The Ethiopian Plateau is located in the west. The Somalian Plateau covers the southern region. The Danakil Depression extends to its Northeast, and the south-east is Ali-Sabieh block. Southwest extension continues through the Main Ethiopian Rift to the East African Rift System. It is widely a desert scrubland with shallow salty lakes and long chains of volcanoes.

Geology of the study area

The geology and tectonics of the Afar Depression [22] is a plate tectonic triple junction where the spreading ridges that are forming the Red Sea and the Gulf of Aden emerge on land and meet the East African Rift. The Afar Depression is one of two places on Earth where a mid-ocean ridge can be studied on land, the other being Iceland. The Afar is slowly being pulled apart at a rate of 1-2 cm per year. This geologic feature is one of earth's great active volcanic areas [23]. Due to this volcanic activity the floor of the depression is composed of lava, mostly basalt. The continuous process of volcanism results in the occurrence of major minerals including potash, sulphur, salt, bentonite, and gypsum. Most of the region's mineral potential is found in Afar state. The overall structural trend across the Afar Depression is for the older larger border faults to be abandoned and for active faulting to be concentrated along narrow zones within the centre of wider rift systems. This is due to the decrease in the strength of the lithosphere with increasing strain rates. ASTER image of Afar region for this work was acquired on March 7, 2002, is located near 12.2 degrees north latitude and 41.9 degrees east longitude, and covers an area of 57 x 61.7 km (approximately 3500 sq.kms).

Geospatial analysis

Several researchers have conducted lineament length and density studies. Lineament density analysis can be done to identify or locate the weathered zone and also helps to find out the ground water potential area, landslides, and so forth. Lengthy lineaments are the zones having higher permeability and porosity [24]. Lineament density map is generated to describe the distribution of lineaments in a two-dimensional

plot. The image is split into equal sized polygons. The number of lineaments in each polygon is taken into account which shows the concentration of lineaments over the study area. The result of this analysis helps to know the densely populated lineaments area in the image. A new type of fractal plot is developed based on the fractal nature of lineaments. Optimized lineament density map is generated with the help of Optimal Cell Dimension (OCD) which depicts the point of intersection of two lines on the plot. A statistical analysis is being carried out to count lineaments and its intersection regions within the cell dimension. This results various density maps.

Methodology used

In this work, lineament extraction process comprises the following four steps: (i) image preprocessing (ii) lineament identification (iii) stockworks extraction and (iv) lineament / stockworks density map generation.

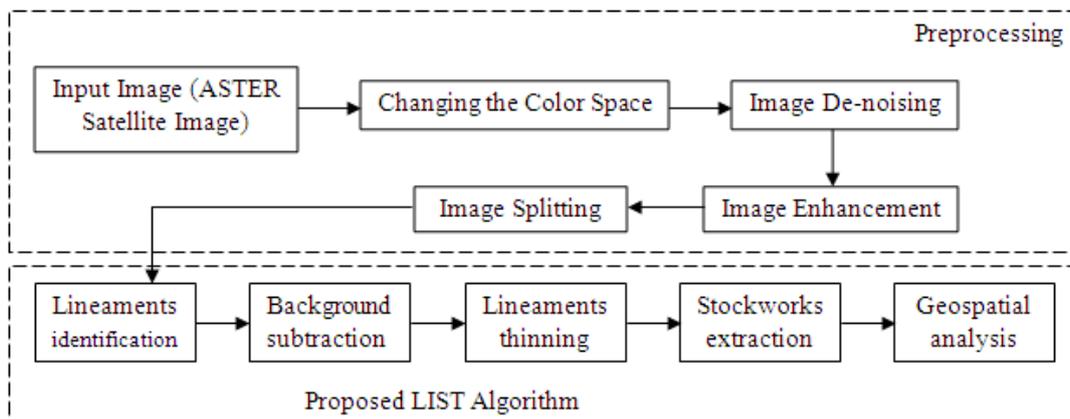


Fig. 1: Workflow diagram

Changing the colour space

Whenever an observer is moved further away from a scene, an illusion produced by the visual system is a mixing of colours. Initially, the viewer notices the difference between those colours; because these colours activate two different sensors in the retina. However, if the object is away from the scene, then these two colours activates the same sensor present in the retina, this enables the observer to see only one colour which composed of varying real colours in the scene. CIE L*a*b* (CIELAB) is a colour space specified by the International Commission on Illumination. It is the device independent colour space which denotes all the colours visible to the human eye. In this colour system, "L" shows the colour lightness, "A" describes the colours in between red/magenta and green, and "B" shows the colours in between yellow and blue

Denoising

The isotropic undecimated wavelet transform is suitable for planetary imaging. It decomposes the image into different scales. IUWT introduces a multi-resolution algorithm for detecting bright spots. To keep the important response of the filter to the desired feature, the denoising technique [25] uses hard thresholding value. Finally, the newly selected coefficient allows us to combine multiscale information to detect the spots. However, its performance is slightly poor in case of low-quality images, at that time, soft thresholding is used; instead of hard thresholding.

Contrast enhancement

One of the effective ways to enhance the image is by equalising the histogram values of the image. Histogram equalisation methods enhance the image fully i.e. it does not consider the contrast and brightness (intensity) values present in the image. It creates an undesirable effect while post processing the image. Brightness preserving dynamic fuzzy histogram equalisation [BPDFHE] technique equalises the image histogram by distributing the grey values present in the valley portions of the histogram. It clearly shows that no remapping of the histogram peaks takes place. This method is used in both grayscale and colour images.

- Compute and partition the histogram based on the "local maxima" value. To reduce the approximation errors, second order derivative is calculated from the fuzzy histogram.
- Global Histogram Equalization method is used to equalise every partitioned histogram dynamically based on the highest and lowest intensity values contained in the partitioned histogram.
- Normalising the brightness of the image.

Image splitting

Splitting the image is termed as the process of dividing the image into equal sized blocks. The basic structure is non-overlapping square blocks of size m x m. To identify the micro lineaments, this condition is applied to split the image, and after processing, the blocks of equal size are merged to form a whole image. If the block differs in size, the merging process terminates, and no further merge is possible.

- Split the input image into equal sized square blocks/grids.
- Before extracting the lineaments, the line support regions (i.e. clusters having the same intensity which depicts lineaments) are formed. Find the magnitude of the image and the direction of all the lineaments to avoid the boundary effect of each grid while joining the grids after processing.
- Local search of coherent components is characterized using two parameters: intensity and shape. The intensity similarity between the candidate pixel and its neighbourhood values are analysed. Thus the starting and ending point coordinates of the lineaments are detected

LIST (Lineament Identification and Stockworks Targeting)

Lineament Identification

- Eigenvectors can be used to formulate the lineaments of various angle projections from the grid image. In this step, scatter matrix is formed to check whether the pixel contributes to form a lineament or not and this represents the spatial relationship between the neighbouring pixels in an image.

$$sm = \begin{pmatrix} sm_{11} & sm_{12} \\ sm_{21} & sm_{22} \end{pmatrix}$$

- Consider 'm' is the number of pixels in the line, (A_i, B_i) is the coordinates of the i^{th} pixel on the line. Eight neighbourhood elements and 24 neighbourhood elements of an image are analysed to detect the lines efficiently.

$$A_m = \begin{bmatrix} -1, -1 & -1, 0 & -1, 1 \\ 0, -1 & & 0, 1 \\ 1, -1 & 1, 0 & 1, 1 \end{bmatrix}$$

$$B_m = \begin{bmatrix} -2, -2 & -2, -1 & -2, 0 & -2, 1 & -2, 2 \\ -1, -2 & -1, -1 & -1, 0 & -1, 1 & -1, 2 \\ 0, -2 & 0, -1 & & 0, 1 & 0, 2 \\ 1, -2 & 1, -1 & 1, 0 & 1, 1 & 1, 2 \\ 2, -2 & 2, -1 & 2, 0 & 2, 1 & 2, 2 \end{bmatrix}$$

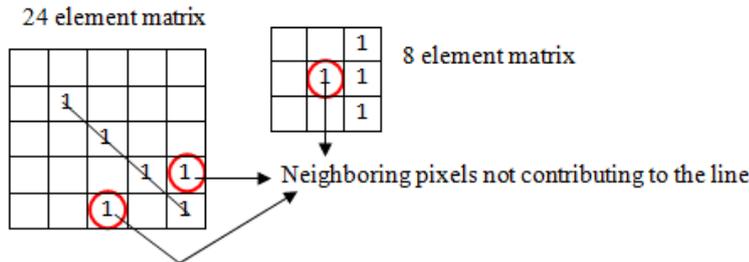


Fig. 2: Eight element matrix and twenty four element matrix.

- Now, the coordinate of the i^{th} pixel on the line is termed as

$$sm_{11} = \frac{1}{2} \sum_{i=1,n} (A_i - A_m)^2 \quad sm_{22} = \frac{1}{2} \sum_{i=1,n} (B_i - B_m)^2$$

- Resultant large eigenvalue k_1 and small eigenvalue k_2 of scatter matrix is formulated as

$$k_1 = \frac{1}{2} \left[sm_{11} + sm_{22} + \sqrt{(sm_{11} - sm_{22})^2 + 4sm_{11}^2} \right]$$

$$k_2 = \frac{1}{2} \left[sm_{11} + sm_{22} - \sqrt{(sm_{11} - sm_{22})^2 + 4sm_{22}^2} \right]$$

- Calculate the lineament length and the number of lineaments.
 - Classify the lineaments based on its length. In this work, lineaments are categorised into
 - Micro lineaments - lineament length less than 1 km
 - Moderate lineaments - lineament length greater than 1 km and less than 2 km.s
 - Macro lineaments - lineament length greater than 2 km.s
- ```

function Length_Analysis (input image, the length of the lineament)
if lineament length < threshold level
 Set colour code for micro lineament and increment its count
else if lineament length > threshold level
 Set colour code for macro lineament and increment its count
else
 Set color code for moderate lineament and increment its count
end

```

- Lineaments may fall/extend on more than one block. All the blocks are merged to extract the total lineaments of the geological area. This can be done by repeating the steps 3 to 7

**Background subtraction & lineament thinning**

- Background subtraction is a common approach is used to detect the object of interest in the foreground thus the background information is not needed for processing. After image preprocessing, object localisation is required for further processing. In this work, lineaments detected from the original image are highlighted alone by suppressing the background of the image.
- Subtract the background image from the lineaments detected image and increase the intensity of the lineaments image for further processing

$$B(x,y) = \frac{1}{N} \sum [L_i(x,y) - L_j(x,y)]$$

- Where N is the number of pixels in the image used as a scaling factor. L<sub>i</sub> and L<sub>j</sub> are the images before and after lineament extraction
- The relationship between the lineament pixel and its neighbourhood varies the lineament width while increasing the intensity after background subtraction which leads to the false stockworks mapping. This can be avoided by applying the morphological thinning operation on the extracted lineaments image.

$$A \oplus B = \max_{\{j,k \in B\}} \{a[m-j, n-k] + b[j,k]\}$$

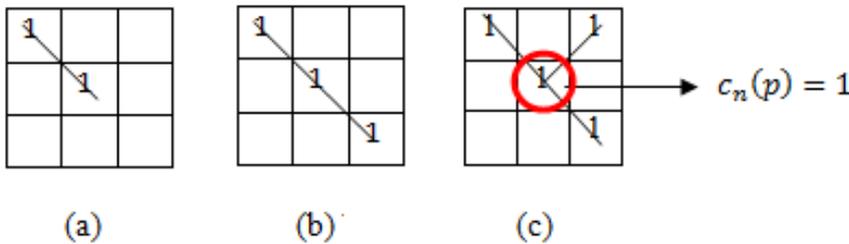
where, A - Input image & B - Structural element

**Stockworks extraction**

- Set the cross point pixel as the cumulative successive difference between a pair of adjacent pixel belongs to 8 neighbourhood of point p.

$$c_n(p) = \frac{1}{2} \sum_{i=1}^8 |val(p_i \text{ mod } 8) - val(p_{i-1})|$$

- Where p<sub>0</sub>, p<sub>1</sub> and p<sub>2</sub> are the pixels belonging to 8 neighbourhood of p. If the centre candidate pixel has only one one valued neighbour, then the pixel is a cross point termination pixel, and if the centre candidate pixel has three one valued neighbour, then the pixel is said to be a cross point pixel. If the centre candidate pixel has two one valued neighbour, it is the usual pixel not termed as the cross point.



**Fig. 3:** (a) Lineament termination (b) usual line and (c) stockworks.

To map the density feature of the stockworks and the lineaments, the spectral similarity measure is calculated by measuring the angle between the spectral value of two samples k<sub>i</sub> and k<sub>j</sub>. This is insensitive to illumination effect because the angle between the two vectors is constant according to the length of the vector.

$$\Delta k = \arccos \left( \frac{k_i \cdot k_j}{|k_i| \cdot |k_j|} \right)$$

To calculate the angle deviation of the spectral values, the Gaussian function is defined as

$$F(\Delta k) = \exp \left[ \frac{-1}{2} \left( \frac{\Delta k}{\sigma \Delta k} \right)^2 \right]$$

$$|k| = \left( \frac{(|k_i| - |k_j|)}{\max(|k_i| - |k_j|)} \right) \quad \forall [0..1]$$

For similarity prediction,

$$k(w_i, w_j) = \max\{k_1[\Delta k], k_2[\Delta k]\} \quad \forall [0..1]$$

This highlights the spatially disjoint and spectrally similar areas in the given satellite image

## RESULT & DISCUSSION

Geological lineaments are the faults, fractures and folds on the ground surface. The geospatial analysis of these lineaments and the stockworks were carried out in this work. This algorithm generates blocks that divides the study area and locate the lineaments from each block and also find the length and the density of the lineaments on those blocks. It also maps the stockworks and its density regions. [Fig.4(a)] shows the original input image of a part of afar region and 50 parts of the same region images are also taken into account for detecting lineaments and stockworks. Then the identified lineaments on those locations are superimposed on the input image after several processing steps and finally stockworks are extracted [Fig.4(b)] from the image. [Fig.5(a)] shows the geospatial analysis output of LIST algorithm. In that analysis, [Fig.5(b)], [Fig.5(c)] and [Fig.5(d)] shows various categories of lineaments based on its length - Macro lineaments, Moderate lineaments and Micro lineaments. [Fig.5(e)] depicts stockworks density map and [Fig.5(f)] depicts lineament density map, the density of the lineaments is categorized into three classes by different colors patterns. The denser the area of the lineaments seems to be the best prospective zone for mineralization. Likewise, various kinds of density regions of stockworks are generated to describe the varying quantity of minerals located on that area.

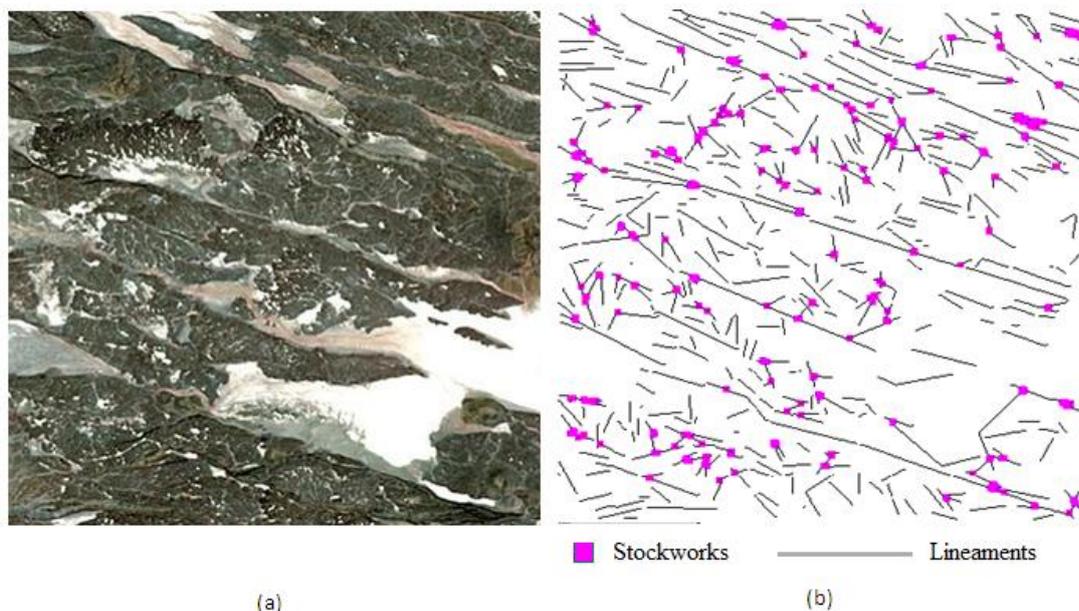


Fig. 4: (a) Original input image of afar region (b) Lineaments & stockworks extraction using LIST algorithm.

Table 1: Geospatial analysis – lineaments length analysis

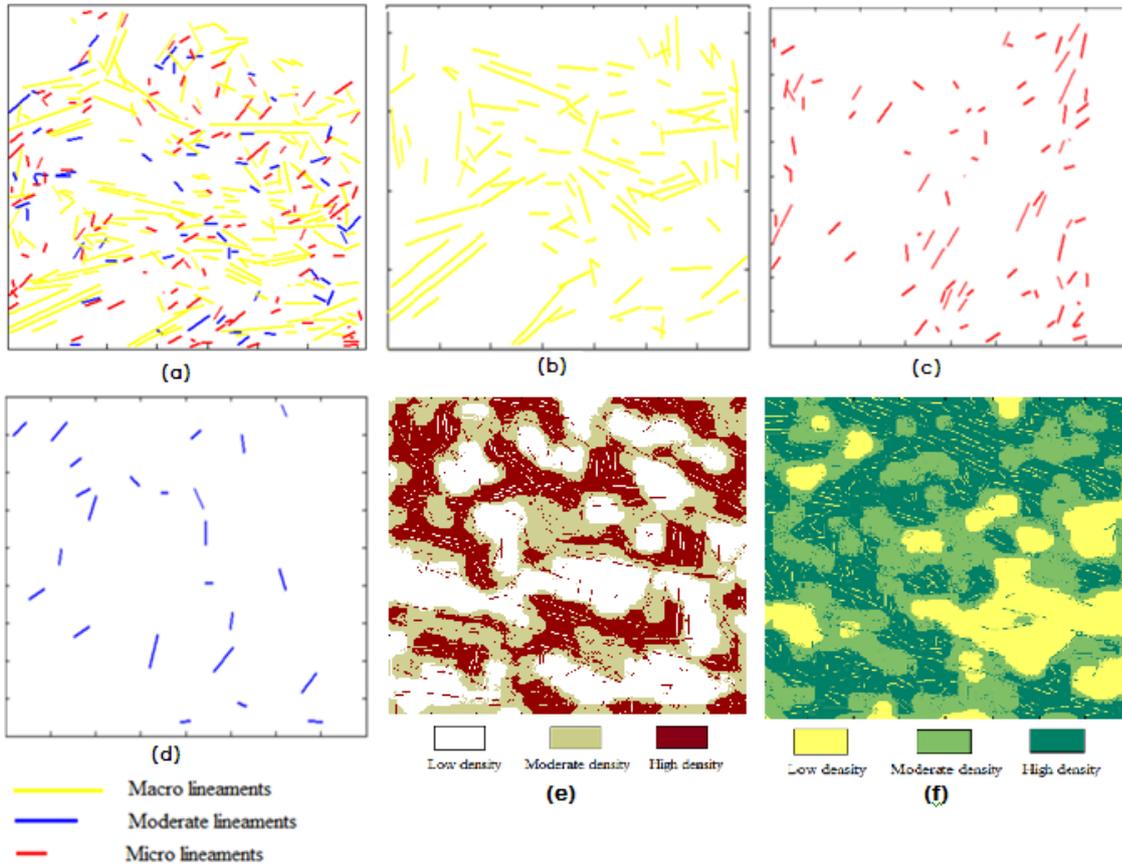
| Methods | Micro lineaments | Moderate lineaments | Macro lineaments | Total no. of lineaments |
|---------|------------------|---------------------|------------------|-------------------------|
| MBC     | 106              | 7                   | 17               | 130                     |
| FCM     | 224              | 143                 | 278              | 645                     |
| LIST    | 391              | 107                 | 201              | 699                     |

Table 2: Geospatial analysis – lineaments length classification and its contribution (in percentage)

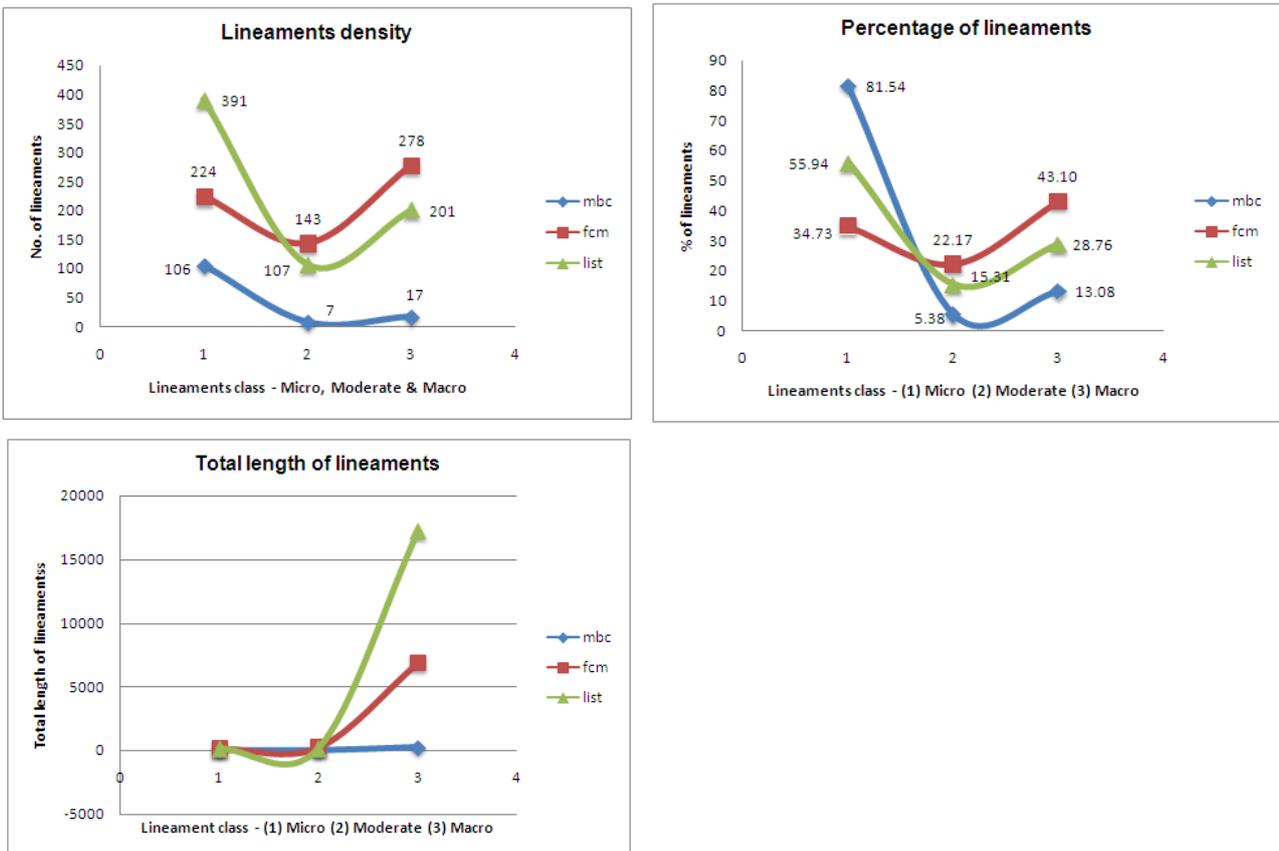
| Methods | Micro lineaments | Moderate lineaments | Macro lineaments |
|---------|------------------|---------------------|------------------|
| MBC     | 81.53%           | 5.38%               | 13.07%           |
| FCM     | 34.72%           | 22.17%              | 43.10%           |
| LIST    | 55.93%           | 15.30%              | 28.75%           |

Table 3: Geospatial analysis – Lineaments length classification and its total length

| Methods | Micro lineaments | Moderate lineaments | Macro lineaments | Total length of lineaments |
|---------|------------------|---------------------|------------------|----------------------------|
| MBC     | 26.51            | 9.68                | 269.86           | 306.05                     |
| FCM     | 121.62           | 206.02              | 6902.67          | 7230.31                    |
| LIST    | 162.66           | 158.997             | 17240.33         | 17561.99                   |



**Fig. 5:** (a) Geospatial analysis by proposed LIST algorithm. Length analysis: (b) Macro lineaments (c) Micro lineaments (d) Moderate lineaments. Density analysis: (e) Stockworks density (f) Lineaments density



**Fig. 6:** Lineament density analysis and length analysis

A total of 699 lineaments are mapped in the afar depression region and its surroundings using the proposed LIST algorithm – a manual extraction technique. The total length of lineament is 17561kms. From the visual interpretation, all the lineaments mapped in the region have its orientation towards NE-SW direction. This detailed analysis of lineaments length is consistent with the published geological survey map of Ethiopia. Lineament density analysis is also done to calculate the frequency of lineaments based on its length. Micro lineaments extracted using LIST algorithm contributes 55% of overall lineaments. Mask based clustering (MBC) and Fuzzy C Means (FCM) algorithm contributes 81% and 34%. These two methods are applied in afar depression image results 130 and 645 lineaments with a total length of 306 and 7230kms respectively. This difference is caused by different methods of mapping on regional and local scale and also some of the lineaments are missing due to under segmentation and over segmentation problem. In this work, stockworks density map is also generated to strengthen the lineament density analysis. Areas with higher micro lineaments density and higher stockworks density are the main prospective zones for mineralization. In conclusion, the geospatial analysis result shows that the identification of geological lineaments over wide area is possible and detailed information for the purpose of exploring minerals and its prospective zones can be obtained using the proposed LIST algorithm.

## CONCLUSION

Remote sensing (Image processing) and GIS (modelling) techniques is very much helpful to map the geologic lineaments. In particular, the flow of minerals in hard formations is mainly controlled by the lineaments corresponds to the faults, fractures and stockworks. This work concentrates on extracting both the lineaments and stockworks. The complexity lies while detecting the lineaments due to poorly illuminated image, global scale segmentation, and discontinuity in lineament patterns. In this work, all these problems are solved effectively. CIE L\*a\*b\* color space and Brightness Preserving Dynamic Fuzzy Histogram Equalisation technique eliminates the poor illumination effect and enhances the image for further processing. Then the image is splitted into equal sized grids to locate micro lineaments. 24-element matrix and 8-element matrix are used to detect line segments by considering its contribution of neighbour pixel values; to avoid discontinuity in linear patterns using the proposed LIST algorithm. It also targets the stockworks easily. This gives better results when compared to the existing methods of lineament segmentation. Lineament density map and stockworks density map are also generated from this work.

## FUTURE ENHANCEMENTS

Mineralogical application of remote sensing helps to identify the large scale lineaments, which in turn helps to understand the geologic structures / topologies of an area. Different combination of sensors mounted on the satellite / aircraft is used to facilitate accurate mapping of lineaments. The research work will be enhanced for the following applications in future. Modernization and Globalisation are some of the cause for the occurrence of natural hazards. Many events such as earthquakes, landslides, floods can be dangerous to people. Geologists may predict these events well in advance to avoid damages to the property and life of the people, with the help of the geological map / lineaments map prepared with the knowledge of past activity and earth's surface. This effort will help in the hazards susceptibility analysis. Vulnerability mapping of these areas will increase the Resilience of Communities.

The current framework can be extended to deal with the factors of geology, such as tectonics, geophysics, geochemistry to map, interpret and classify the minerals from the prospective zones. The knowledge of lineaments can be applied to those terrain surfaces to map/monitor the road networks, drainage density networks, alignment of vegetation, etc. and the effect of the change in these networks. A more precise determination of ground water is mainly controlled by the low permeability areas such as rock types, landforms, geological structures, soil, land use etc. hydro geological and geophysical methods are used to generate the groundwater prospect zone which is essential to delineate groundwater reservoir.

## CONFLICT OF INTEREST

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article

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## FINANCIAL DISCLOSURE

The author declares that he has no relevant or material financial interests that relate to the research described in this paper.

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