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Mapping of Lineaments for Groundwater Targeting and Sustainable Water Resource Management in Hard Rock Hydrogeological Environment Using RS- GIS

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Additional information is available at the end of the chapter

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1. Introduction

Lineament definition and history

Numerous definitions of the term 'lineament' are given in the literature and various attributes are sometimes linked to the term - such as 'geologic lineament', 'tectonic lineament', 'photo lineament' or 'geophysical lineament' - either describing the assumed origin of the linear feature or sometimes the data source from which it has been derived. Some researchers also use the term 'fracture trace' or 'photo linear' as an alternative term. The work by Lattman and Parizek (1964) is commonly regarded as pioneering work in groundwater exploration; they mapped linear features (fracture traces) on stereo-pairs of aerial photographs in carbonate terrain in the eastern United States and subsequently showed the correlation between well productivity and distance to the identified features.

Lineament mapping was used long before this work in other geological applications and the first usage of the term lineament in geology is probably from a paper by Hobbs (1904, 1912), who defined lineaments as significant lines of landscape caused by joints and faults, revealing the architecture of the rock basement. This was later used by O' Leary et al. (1976) as a basis for developed definitions. Lineaments have been defined as extended mappable linear or curvilinear features of a surface whose parts align in straight or nearly straight relationships that may be the expression of folds, fractures or faults in the subsurface. These features are

mappable at various scales, from local to continental, and can be utilized in mineral, oil and gas, and groundwater exploration studies.

Linear features on the Earth's surface have attracted the attention of geologists for many years. This interest has grown most rapidly in geological studies since the introduction of aerial photographs and satellite images. At the beginning, to the middle of the twentieth century, several geologists recognized the existence and significance of linear geomorphic features that were the surface expression of zones of weakness or structural displacement in the crust of the Earth.

Studies revealed a close relationship between lineaments and groundwater flow and yield (Mabee et al., 1994; Magowe and Carr, 1999; Fernandes and Rudolph, 2001). Generally lineaments are underlain by zones of localized weathering and increased permeability and porosity. Meanwhile, some researchers studied relationships between groundwater productivity and the number of lineaments within specifically designated areas or lineament density rather than the lineament itself (Hardcastle, 1995). Therefore, mapping of lineaments closely related to groundwater occurrence and yield is essential to groundwater surveys, development and management. In the last two decades remote sensing and GIS have been widely used for preparation of different types of thematic layers and their integration for different purposes.

This research work focuses on developing the remote sensing and Geographic Information Systems (GIS) methodology for regional groundwater potential evaluation. The objectives of this study are to (i) produce a regional structural lineament map of the study area from remotely sensed data, (ii) determine the hydro geological implication of the lineaments by integrating them with the available ancillary data (Digital Elevation Model [DEM] and geological map), (iii) analyse the lineament trend distribution of the study area using rose diagrams, lineament density maps and lineament intersection maps.

2. Description of study area

The Vaigai sub-basin extends over approximately 849 km² and lies between 09° 30' 00" and 10° 00' 00" N latitudes and 77° 15' 10" and 77° 45' 00" E longitudes in the western part of Tamilnadu, India. It originates at the altitude of 1661m in the Western Ghats of Tamilnadu in the Theni district (Figure 1). The basin is generally hot and dry except during the winter season. The maximum and minimum temperature for the basin is 40.7 °C and 16.0 °C. The area receives an average annual rainfall of about 384 mm. The surface runoff goes to stream as instant flow. Rainfall is the direct recharge source and the irrigation return flow is the indirect source of groundwater in the Vaigai sub-basin. The study area depends mainly on the north-east monsoon rains which are brought by the troughs of low pressure established in the Bay of Bengal. Most of the farmers depend on the groundwater for their irrigational needs. There are a few tanks across these drainages, however, most of these remain dry.

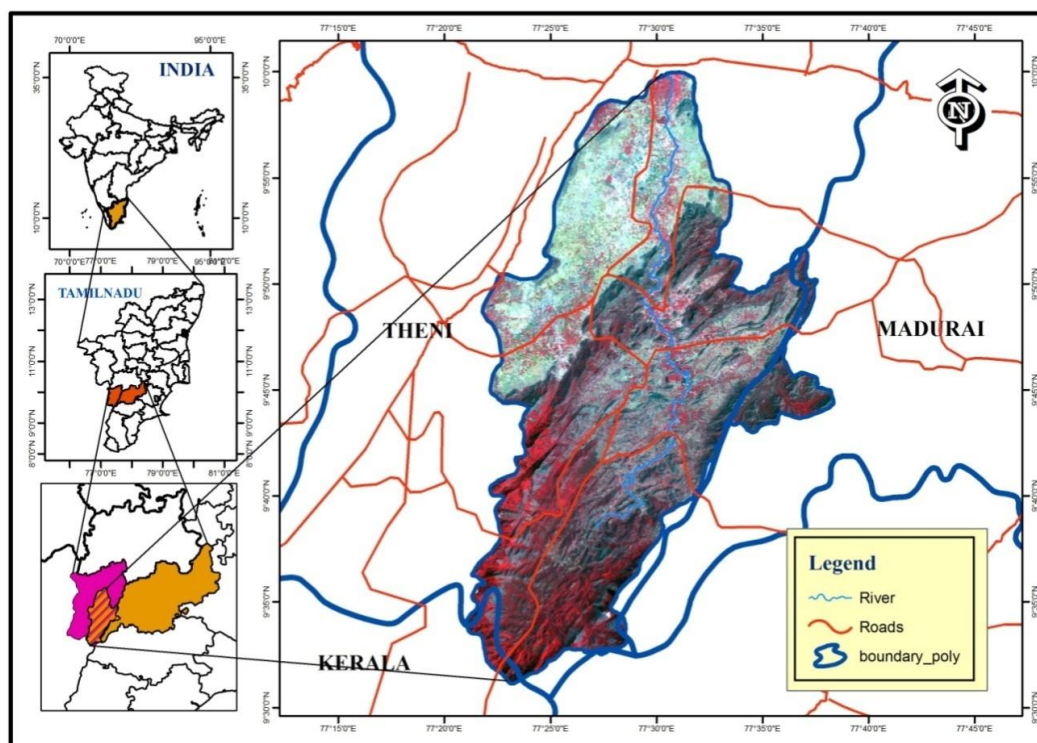


Figure 1. Location of the study area with ASTER 30m DEM

3. Methodology

The Indian Remote Sensing Satellite (IRS) ID, Linear Image Self-Scanning (LISS) III of geo-coded False Colour Composites (FCC), generated from the bands 2, 3 and 4 on 1:50,000 scale was used for the present study. The application of higher-resolution 30- m Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) imagery yielded better results in lineament interpretation compared to IRS 1D imagery due to improved spatial resolution. Lineament mapping is normally undertaken based on geomorphological features such as aligned ridges and valleys, displacement of ridge lines, scarp faces and river passages, straight drainage channel segments, pronounced breaks in crystalline rock masses and aligned surface depression. For the study area, the main interest was topographically negative lineaments, which may represent joints, faults and probably shear zones (Juhari and Ibrahim 1997; Koch and Mather 1997; Solomon and Ghebreab 2006). To eliminate the non-geological elements, such as paths, roads, power cables and field boundaries in the study area, geographical maps and field checking were undertaken using the method suggested by Yassaghi (2006).

3.1. Geology

Eleven geologic features were identified and mapped by the Geological Survey of India, shown in Figure 2.

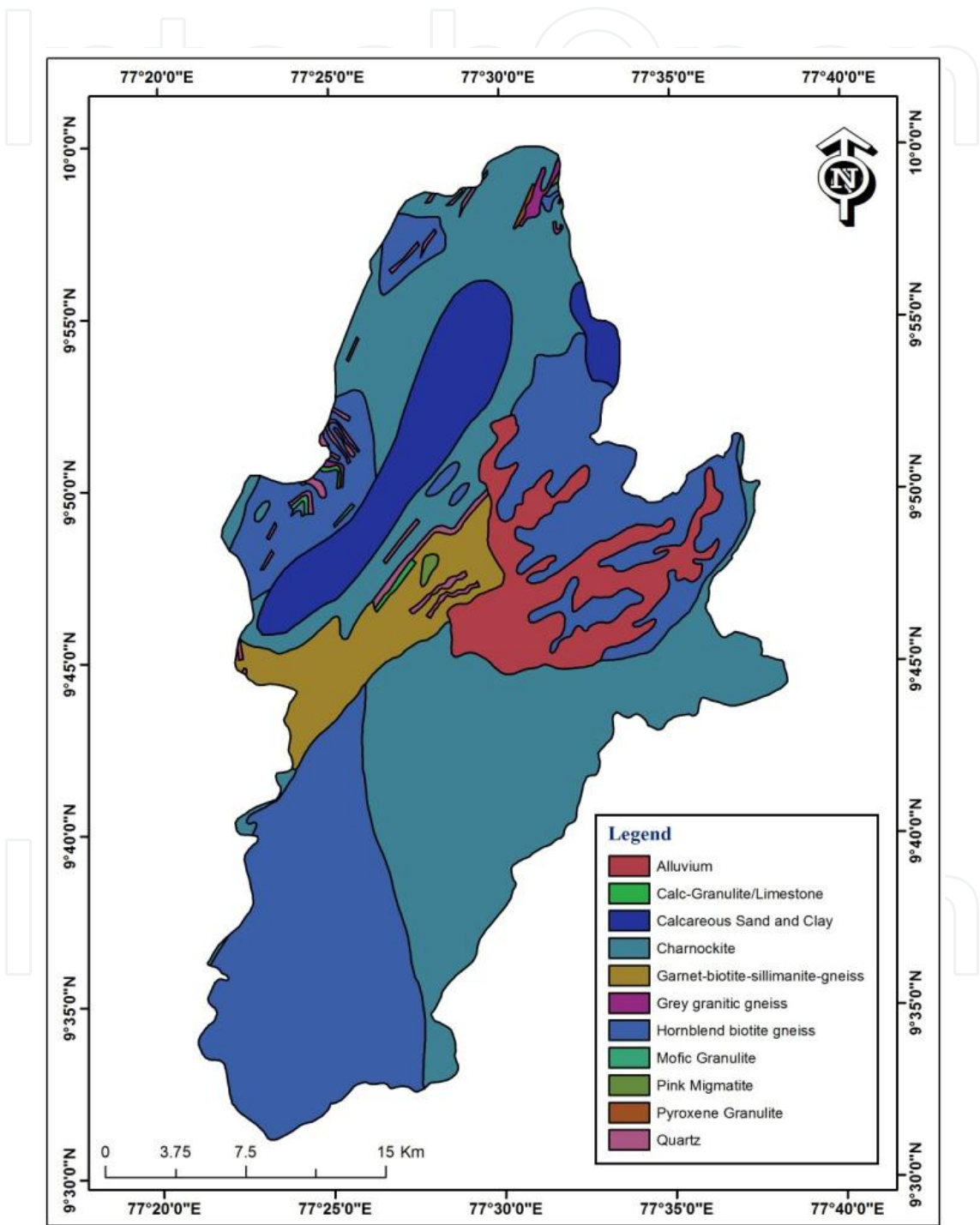


Figure 2. Geology of the study area

3.2. Lineament analysis

The mapped structural lineaments were mapped and analysed using the lineament density (LD), lineament frequency (LF) and lineament intersection (LI) parameters. The results of the analysis are presented as the lineament map, lineament density map, rose diagram, lineament frequency map and lineament intersection map (Figures 3, 4, 5, 6 & 7) respectively.

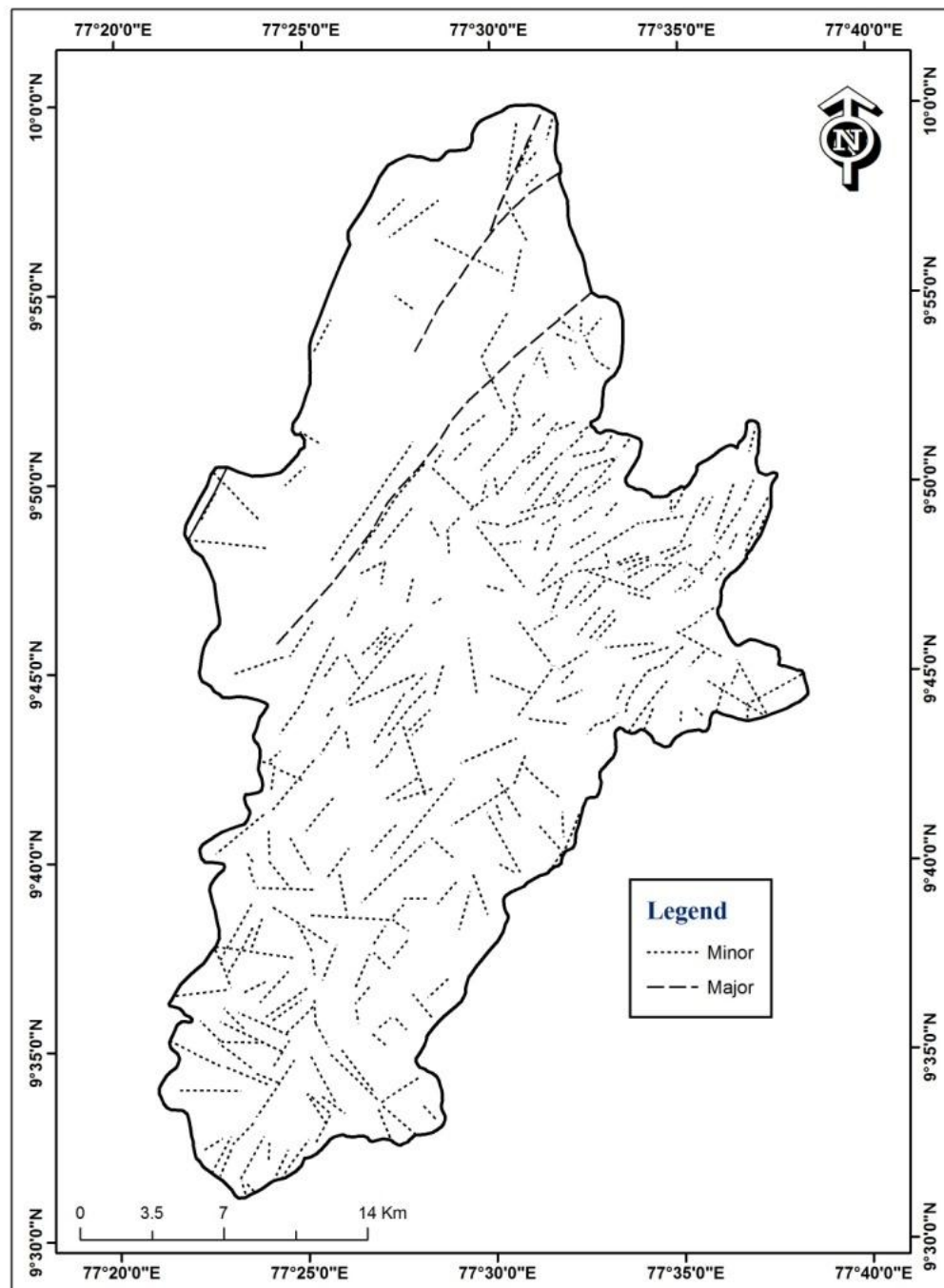


Figure 3. Lineament map of the study area

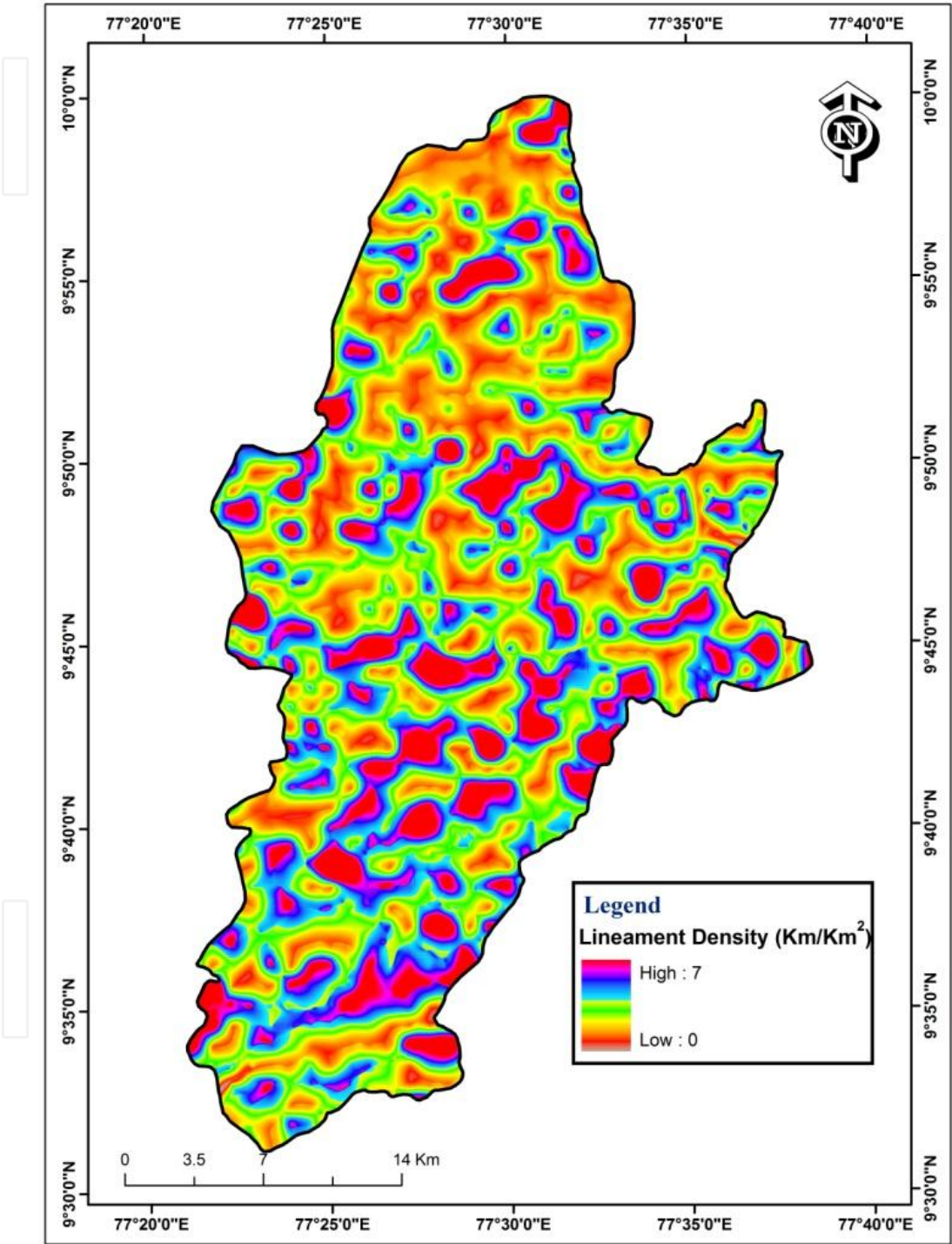


Figure 4. Lineament density of the study area

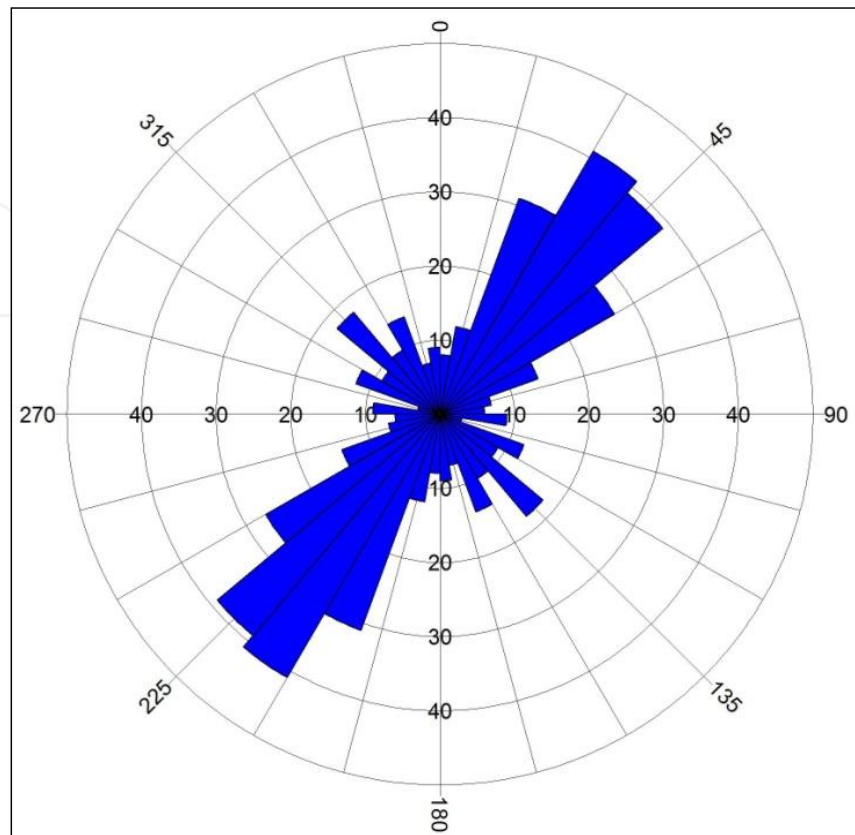


Figure 5. Lineament rose plot in the study area

4. Results and discussion

4.1. Frequency and spatial location of the fractures

The lineament and frequency map (Fig. 3 and Fig. 6) shows that the lineaments/fracture distribution is hardly homogeneous. The lineament density variation map (Fig. 6) shows the lineament numbers to be in the range of 0 and 7. The majority of the fractures are located on lithologies that correspond to the term “hard rocks”, which generally refers to igneous and metamorphic rocks (Krasny 1996, 2002). Therefore, the discussed character represents an initial indication for the unified tectonic and hydrogeologic behaviour of the hard rock environment. The majority of the lineaments/fractures are located on the Hornblende biotite gneiss and minority of the lineaments/fractures are located on the Pink Migmatite (Table 1).

4.2. Orientation of the lineaments

The orientation of the lineaments is analysed by constructing rose diagrams (Fig.5). Even though these diagrams are not length-weighted, they can indicate on each occasion what the

most dominant directions of the fractures are. This analysis is very critical for the study of groundwater flow, as in most cases the orientation of the fractures is identical to the orientation of the preferential flow path.

The faults rose plot indicates two sets of orientation classes. The main two classes have NE and SW strike, while others have NW and SE strike. The uniformity of fracture orientation becomes an additional indication for the hydrogeologic regime.

No	Description	Frequency	Percent (%)	Length (Km)	Percent (%)
1	Hornblend biotite gneiss	163	44.05	221.68	45.51
2	Charnockite	104	28.11	158.27	32.49
3	Alluvium	54	14.59	57.81	11.87
4	Garnet-biotite-sillimanite-gneiss	26	7.03	28.60	5.87
5	Calcareous Sand and Clay	7	1.89	14.17	2.91
6	Quartz	11	2.97	3.17	0.65
7	Pyroxene granulite	1	0.27	1.43	0.29
8	Grey granitic gneiss	2	0.54	1.16	0.24
9	Calc-granulite/Limestone	1	0.27	0.55	0.11
10	Pink migmatite	1	0.27	0.28	0.06
Total		370	100.00	487.13	100.00

Table 1. Total length of lineaments in each geological feature

4.3. Size of the lineaments

Fracture dimensions (aperture and apparent aperture) are very difficult to define and the depth of the apertures makes the measurements even more complicated. Nevertheless, length measurements can be taken relatively easily and they are also significant, since a fracture with a greater length affects the groundwater flow in a more dominant way than those of smaller length. The calculated total length of lineament/fracture per unit area in each lithology are shown in Table 1.

4.4. Density of the lineaments

The purpose of the fracture density analysis is to calculate frequency of the fractures per unit area. With this analysis a map has been produced showing concentrations of the lineaments over the study area (Fig. 4). The map in Figure 3 shows that very high density is observed in areas of Hornblende biotite gneiss and Charnockite (7 Km/ Sq.km²), indicates the high degree of hydraulic interconnection between the above lithologic units as surface water circulates through these discontinuities. This is verified in the next consideration (degree of fractures intersection). On the other hand, very low density is observed in calcareous sand and clay (1

Km/ Sq.km²), and quartz in areas where combination of more lithological features dominate. This verifies that these lithologies are affected by tectonic activity.

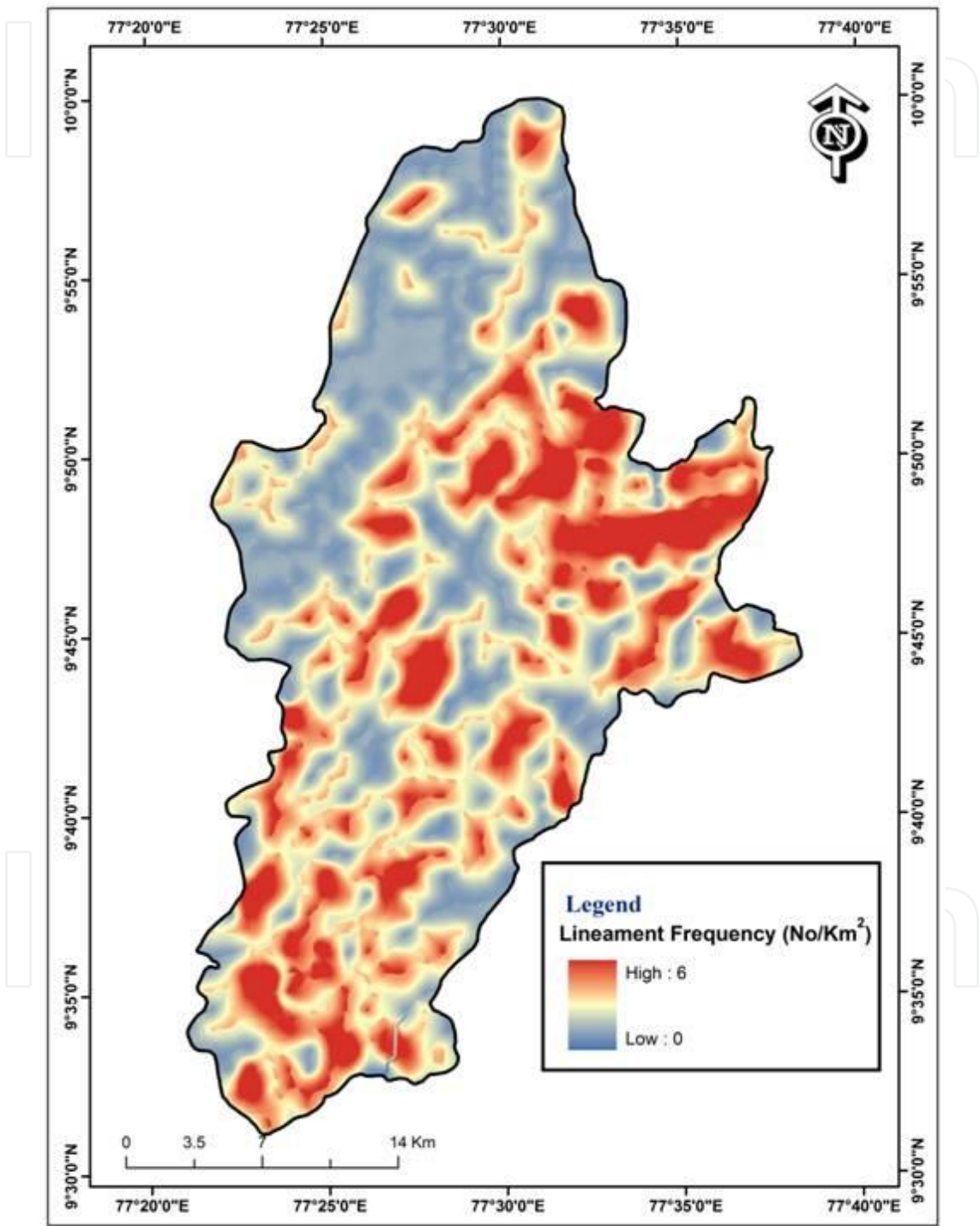


Figure 6. Lineament frequency of the study area

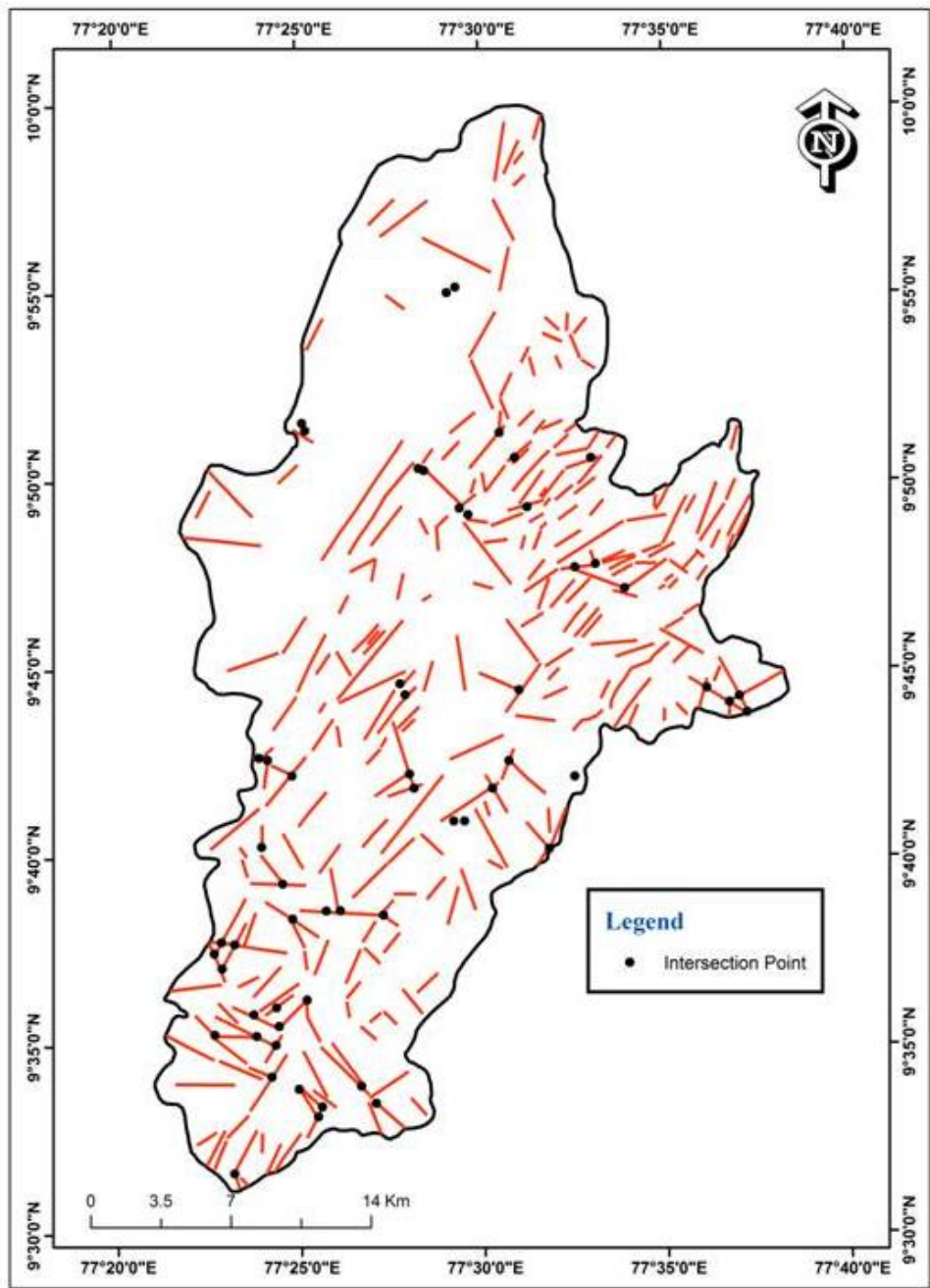


Figure 7. Lineament intersection of the study area

4.5. Degree of lineaments intersection

The density of lineaments along with the degree of lineament intersection determine the degree of anisotropy of groundwater flow in the fracture network, as in environments with a high

degree of interconnection where groundwater flow is smoother and more uniform. Fracture intersection density is a map showing the frequency of intersections that occur in a unit area. The purpose of using intersection density maps is to estimate the areas of diverse fracture orientations. If the fractures do not intersect in an area, the resultant map will be represented by a plain map with almost no density contours and the fractures are almost parallel or sub-parallel in an area. The lineament intersection map of the study area (Fig. 7) indicates high and very high intersection in the same areas where there is very high density of lineaments. The zones of high lineament intersection over the study area are feasible zones for groundwater potential evaluation.

5. Conclusions

Groundwater studies on hard formations often require extraction of data from images and remote sensing, and GIS. Due to insufficient data, maps of lineament and structural elements are important tools that may reveal points of groundwater recharge and discharge, flow and development. In particular, groundwater occurrences in hard formations are mainly controlled by the lineaments corresponding to fractures, joints and faults. Furthermore, the distribution of lineament is closely related to groundwater discharge points and their concentration.

Remote sensing has proved to be a useful tool in lineament identification and mapping. This study demonstrates the application of remotely sensed data for lineament interpretation in a hard rock hydrogeological environment. A Digital Elevation Model (DEM) was generated to improve the interpretation. The lineament analysis has been effectively done in a GIS environment. Thematic maps, such as lineament frequency, lineament density and lineament intersection, were prepared using the interpolation technique.

The results from the study show that the remote sensing technique is capable of extracting lineament trends in an inaccessible tropical forest. The study has led to the delineation of areas where groundwater occurrences are most promising for sustainable supply, suggesting where further geophysical surveys can be concentrated. It is therefore suggested that the high lineament intersection and density should be combed with detailed geoelectrical surveys for quantitative evaluation of the groundwater potential of the study area. Properly sited wells in drought-stricken areas could change the lives of many and the remote-sensing analysts and lineament interpreters around the world are without doubt important in this process.

Author details

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