



Extraction of lineaments from different azimuth angles using geospatial techniques: a case study of Pravara basin, Maharashtra, India

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Abstract

Lineaments are the linear or curvilinear geological surface features which reflect the tectonic history, groundwater potential, oil, and mineral resource availability of a given area. In view of the importance of lineaments, the present study is carried out to understand the spatial distribution, orientation, density, and the influence of lineaments on drainage network. The study focuses on the extraction of lineaments in Pravara basin, Maharashtra, by using Cartosat Digital Elevation Model (CartoDEM). The lineaments are extracted and analyzed in ArcGIS and Rockworks software, respectively. Comparative analysis is performed on eight different lineament outputs which are extracted from various azimuth angles to prepare one final lineament map of the study area. Total number of lineaments found in the study area is 709 with the length of 1194.77 km. The western part of the Pravara basin shows higher lineament density as compared to the central and eastern part. Therefore, these areas might be affected by higher structural deformation. Also, this area might have higher groundwater infiltration potential due to the higher density of lineaments as they work as the structural weaknesses and influence the water to infiltrate in sub-surface region. The study has shown that the predominant orientation of lineaments trending to NNW-SSE. About 10% of the total stream length is found to have the influence of lineaments on the drainage network. More control of lineaments is observed in the source region of the drainage, where mostly first-order streams are found. Apart from the significant findings, this study has been generated a detailed structural information over the study area and the output could be applied for future planning and management of the water resources, tectonic evolution, and in other fields of geosciences.

Keywords Lineaments · Western Ghat · Cartosat DEM · GIS · Maharashtra · Pravara basin

Introduction

Lineaments are the linear or curvilinear geological features on the earth's surface, which can be identified and mapped through satellite images (Das and Pardeshi 2018). Hobbs (1903, 1912) introduced the concept of lineaments and their importance. Since then, numerous studies have been performed and many definitions are given by the researcher based on their perspective of lineament studies (O'Leary et al. 1976; Wheeler 1983; Spencer 1988; Sabins 1996). The study of lineament can directly be

applied to the understanding of tectonic deformation, water resource exploration and abstraction, hydrogeomorphology, ore and mineral exploration, hazard assessment, geological mapping for several purposes, etc. (e.g., Lattman and Parizek 1964; Wallace 1975; CFCFF 1996; Henderson et al. 1996; Karnieli et al. 1996; Mostafa and Zakir 1996; Arlegui and Soriano 1998; Suzen and Toprak 1998; Magowe and Carr 1999; Zakir et al. 1999; Griffiths and Stokes 2008; Teixeira et al. 2013; Chaminé et al. 2013, 2015; Chaminé 2015; Das et al. 2017; Das and Pardeshi 2018).

Earlier, aerial photographs have been used to extract geological lineaments to understand the structural deformation (Lattman 1958). The advancement of technology and introduction of remote sensing have made geological mapping easier than ever before (Farina et al. 2005). Therefore, it is observed that remote sensing data and GIS software are extensively used to extract lineaments (Qari 1991; Qari and Şen 1994; Chang et al. 1998; Suzen and Toprak 1998; Arlegui and Soriano 1998; Leech et al. 2003; Nama 2004; Chandrasekhar

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et al. 2011; Teixeira et al. 2013; Das and Pardeshi 2018). Automatic extraction techniques are developed in late twentieth century; since then, several works have been carried out by different authors (Zlatopolsky 1992, 1997; Majumdar and Bhattacharya 1998; Costa and Starkey 2001; Mostafa and Bishta 2005); however, many researchers also focused on extraction of lineaments manually from Digital Terrain Model (DTM) or high-resolution satellite images (Henderson et al. 1996; Chaabouni et al. 2012; Raj et al. 2017). Manual extraction of lineament is more common when the objective is limited to trace only geological features (Das and Pardeshi 2018). Automatic extraction combines the information of both the geological as well as surface features present on the earth's surface.

Review of earlier literature reveals that only a few researchers have made effort to extract lineaments and interpreted the structural features of the Pravara basin (Bondre et al. 2006). However, these studies are highly regional and describe a very general picture of geological lineaments and their orientation. Compared to the previous studies, this paper delivers the most comprehensive information of geological lineaments in the study area.

The aim of the present study is to extract geological lineaments of the Pravara basin by using remotely sensed data and GIS technology. Also, the objective is extended to understand the spatial concentration of lineaments in the study area, orientation, and the influence of lineaments on the drainage network.

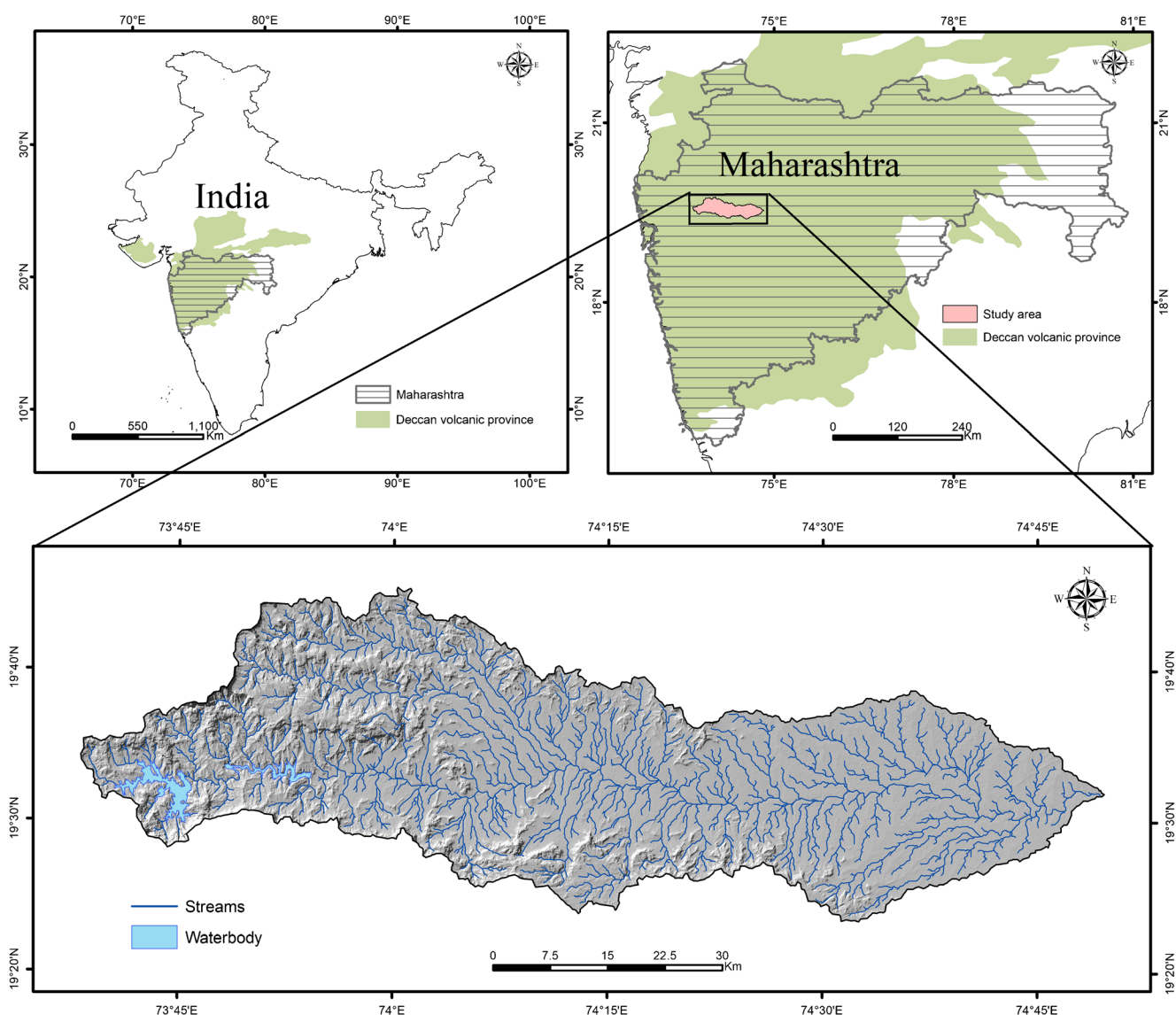


Fig. 1 Location map of the study area with respect to Maharashtra and India. Deccan Volcanic Province (DVP) is a major geological formation in India, characterized by Deccan Flood Basalt of the Cretaceous-Tertiary

period (DVP layer is generalized from geological map of India, published by GSI). All the streams shown in the figure are flowing towards east direction

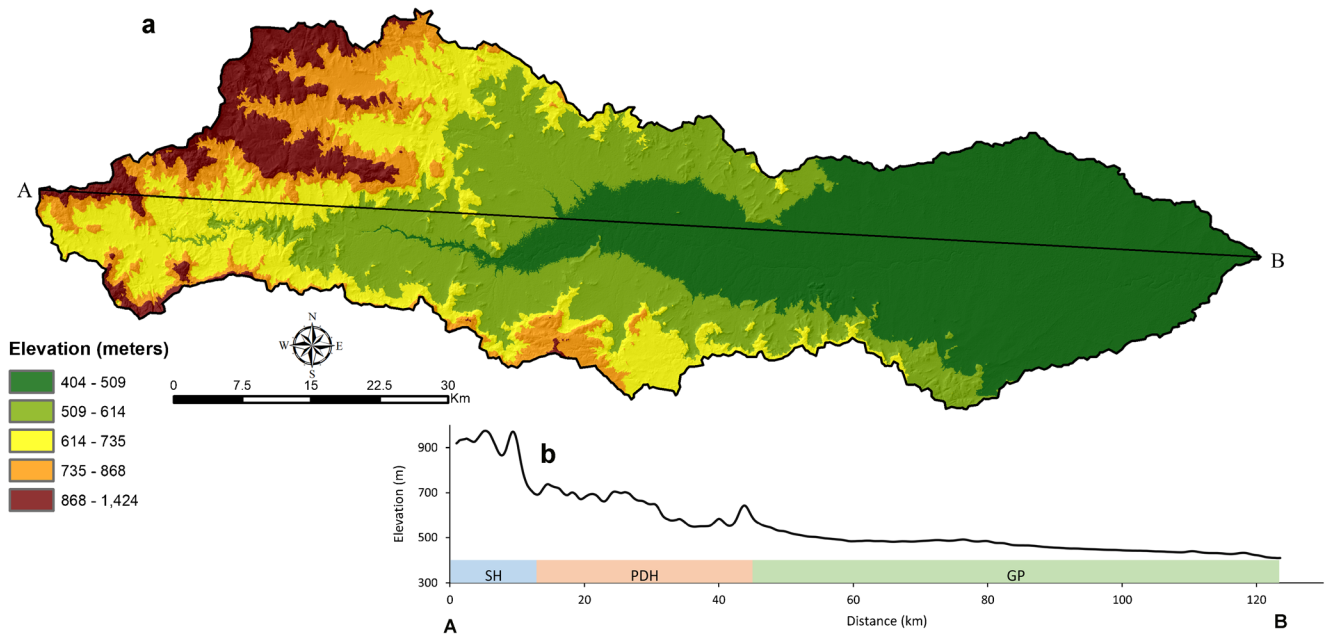


Fig. 2 a DEM represents the altitudinal variation of the study area. b The swath profile is presenting broad physiographic divisions of the Pravara basin (SH structural hills, PDH undulating pediment with dissected hills, GP gentle plateau)

Study area

Pravara basin is located in the eastern part of the Western Ghat, upland Maharashtra. Latitudinal and longitudinal extension of the study area is roughly 19° 25' N - 19° 45' N and 73° 35' E - 74° 50' E, lying in Maharashtra State, India (Fig. 1). The total area of Pravara basin is about 2600 km². All the major streams in Pravara basin are originating from Western Ghat and flowing towards east. The main river draining within the study area is Pravara, which is a major tributary of Godavari river. Altitudinal variation of the study area is 404 to 1424 m above sea level, which represents moderate relief over the study area (Fig. 2). Mainly three types of broad physiographic divisions can be seen in the study area; the Western

Ghats and its offshoot ranges with high elevation and steep slope in the western part, undulating pediment in the central part, and almost flat plateau with a gentle slope on the east of the Pravara basin. Almost the entire study area is covered by Deccan basalt of the Cretaceous-Eocene age (Fig. 3). The flat-lying basalt is (south facing regional dip of 0.5° to 1°) Thakurvadi formation of Kalsubai sub-group (Khadri et al. 1988; Subbarao and Hooper 1988). Few high peaks in the western part of Pravara basin are characterized by basalt lava of the Bhimashankar formation (Bondre et al. 2006). Extensive alluvium deposition (about 30 m thick in few regions) of the Quaternary period, overlies the basalt along the Pravara main river and few of its tributaries (Bondre et al. 2006; Das 2017). Mainly compound Pahoehoe basalt flows

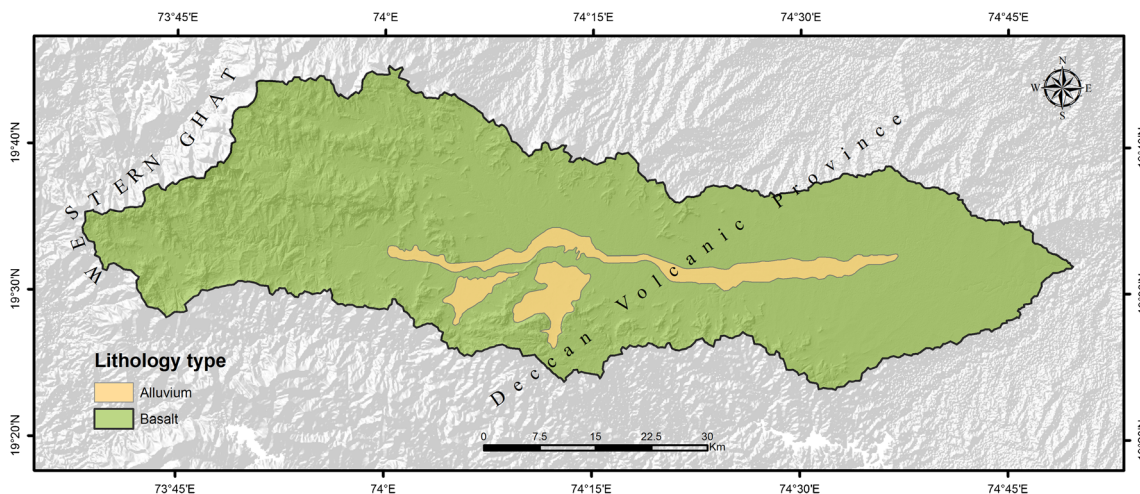


Fig. 3 Geological map of the study area. The entire study area is a part of the Deccan Volcanic Province

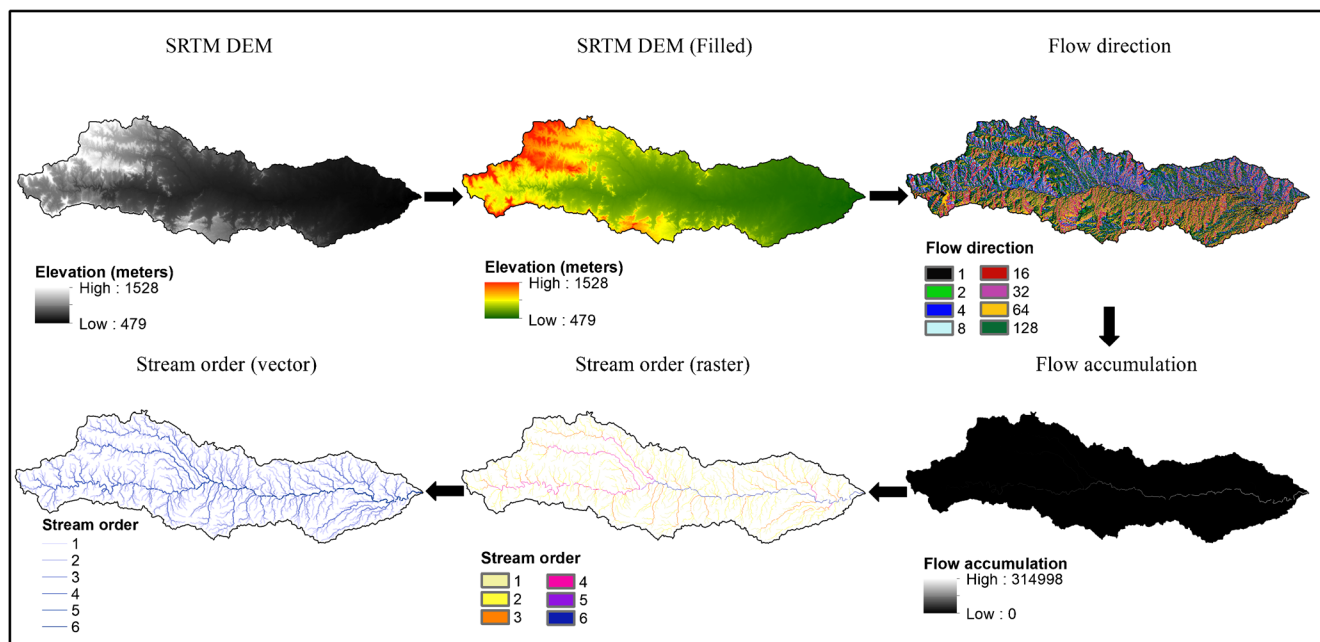


Fig. 4 Methodology carried out to generate stream network within the study area

are found in this region having a thickness of 10 to 50 m (Bondre et al. 2000, 2004). The study area is characterized by numerous fractures, joints, and dikes. In the western part of the basin, these linear geological features can be identified clearly through the satellite images or aerial photographs due to the rugged terrain, lack of vegetation cover. Consequently, in the eastern part of Pravara basin, these features are hard to see in aerial photographs or satellite images because of the relatively flat topography and deep alluvium deposition, dense vegetation, and agricultural land. Most of the lineaments in this area can easily be followed by several kilometers. Numerous dikes of Plagioclase, Olivine, Clinopyroxene, and Aluminum-Oxide are found with N-S, NNW-SSE, and NNE-SSW direction within the study area (Bondre et al. 2006).

Climatically, western part of Pravara basin shows hot and humid conditions, whereas the eastern part is characterized by semi-arid conditions (Doke et al. 2018). Humid conditions in the hilly region trigger frequent slope failures and various mass movement processes over the western section of Pravara basin.

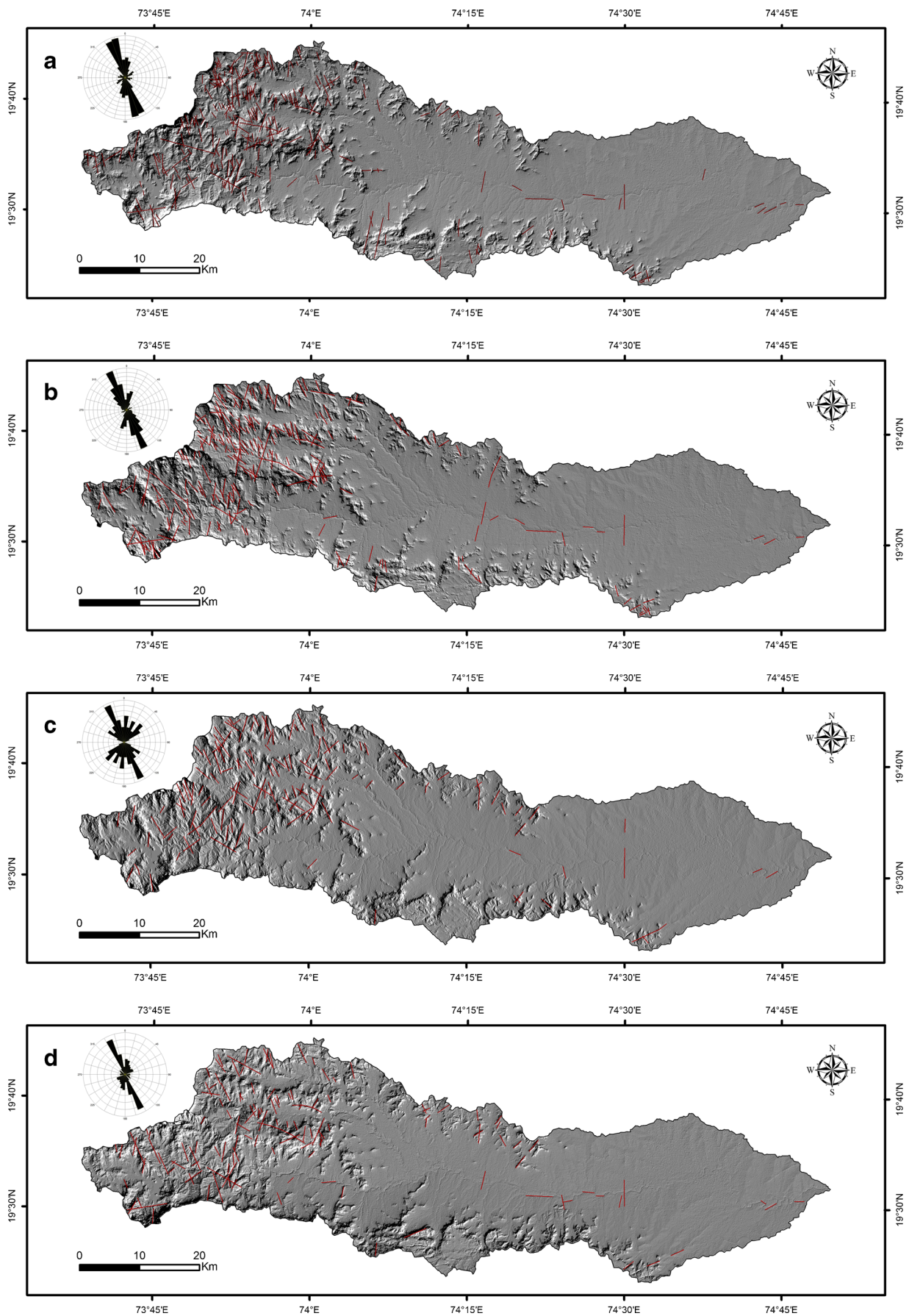
Data and methodology

Extraction of lineaments

A recent study of Das and Pardeshi (2018) has shown that Cartosat Digital Elevation Model (CartoDEM) is one of the most suitable datasets to extract geological surface features such as lineament. Hence, to perform this study, CartoDEM has been selected and acquired for the entire study area from

Bhuvan portal (<http://bhuvan.nrsc.gov.in>). CartoDEM is having a spatial resolution of 30 m, and it is freely available only for Indian sub-continent. In recent times, extraction of lineaments from different azimuth angles has been carried out by many researchers to ensure mapping of all the lineaments available within the study area (Abdullah et al. 2010; Masoud and Koike 2011, 2017; Hubbard et al. 2012; Muhammad and Awdal 2012; Tahir et al. 2015; Raj et al. 2017). At first, DEMs are filled in ArcGIS using “Fill” command. After that, in order to accurate identification of lineaments, eight shaded relief maps of 45° intervals of light illumination angle are generated in ArcGIS environment using “Hillshade” tool. Light illumination azimuth angles of the shaded relief maps are 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°, respectively. After generation of shaded relief maps, all the geological linear ground features such as a cliff, straight valleys, dikes, and straight stream segments are digitized manually in 1:100,000 scale. To ensure all the digitized lineaments are geological feature, the extracted lineaments of all eight azimuth angles are compared with Landsat 8 images of 30 m resolution. Landsat 8 imageries are freely downloaded from <https://earthexplorer.usgs.gov> website. After comparing all the extracted lineaments, cultural or man-made linear features such as roads, rail lines, and canals are eliminated from the lineament outputs. Final lineament map for the study is

Fig. 5 Lineaments traced from the shaded relief map of different azimuth angle. Inset rosette diagram is presenting the overall directions of lineament. 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** 135° azimuth angle. **e** 180° azimuth angle. **f** 225° azimuth angle. **g** 270° azimuth angle. **h** 315° azimuth angle



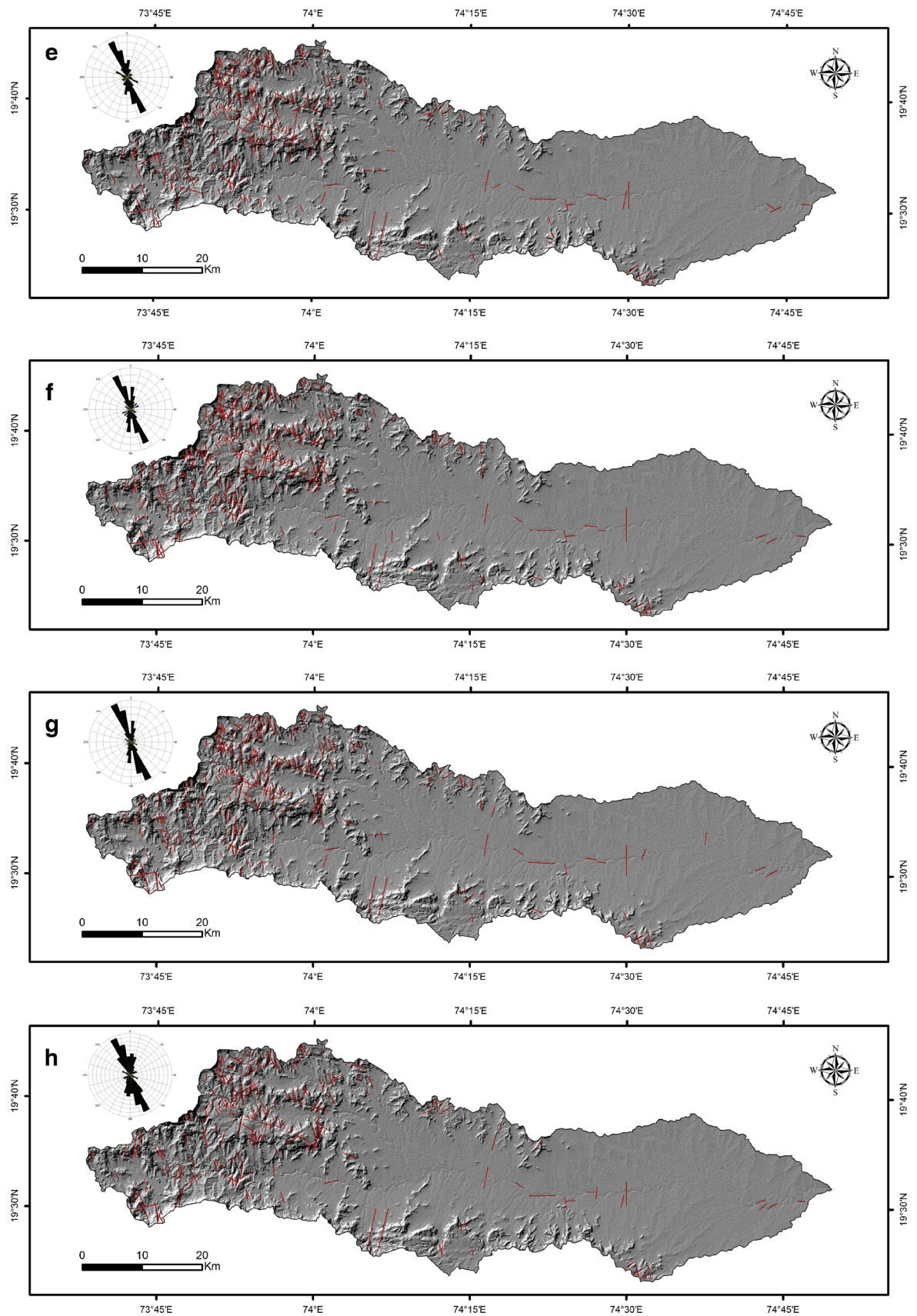


Fig. 5 (continued)

Table 1 Number and length of the lineament extracted from different azimuth angles

Lineament direction	Number (<i>n</i>)	Max length (km)	Min length (km)	Total length (km)
0°	293	9.42	0.02	525.77
45°	263	6.57	0.22	501.88
90°	140	6.19	0.73	345.78
135°	136	6.72	0.72	303.19
180°	274	8.58	0.35	429.34
225°	354	5.79	0.33	505.75
270°	265	7.05	0.42	434.53
315°	224	7.4	0.03	394.95
Final lineament	709	9.42	0.02	1194.77

prepared by combining all the eight different azimuth angle lineament outputs into a single shapefile, where all the duplicate lineaments are eliminated. Before performing the statistical analysis and construction of rose diagrams, a very extensive field verification has been carried out to validate the results. Lineament density map of the study area is computed in ArcGIS software by using the final lineament output. Rockworks software has been employed to prepare the rosette diagrams to understand the orientation of lineaments.

Generation of streams

Water has a tendency to flow through the cracks or fractures on the surface. These cracks or fractures force water to flow straight. Lineaments play same role where under the influence of lineaments, all the streams tend to flow straight through the lineament fractures. Understanding of the influence of lineaments on drainage network is only possible by generating a drainage network for the study area. To fulfill this aim, the following methods have been followed.

To generate a stream network in the Pravara basin, SRTM DEM has been selected. The spatial resolution of SRTM DEM is 90 m, freely available at www.cgiar-csi.org. The main reason to select SRTM data to generate streams is smaller data size and capability of faster processing. ArcGIS software used to fill data gaps of SRTM DEM. It had been followed by flow direction, flow accumulation raster calculation (Fig. 4). Stream order raster is generated according to the Strahler’s (1952) method of stream ordering. Stream order raster is converted into stream order vector for the calculation of linear morphometric parameters.

Calculation of streams under the influence of lineaments

To find out the length of streams under the influence of lineaments, “buffer tools” have been used where all the lineaments were buffered by using 100 m threshold. All the streams, within the buffer zone, are extracted, and the length was calculated as per the stream order.

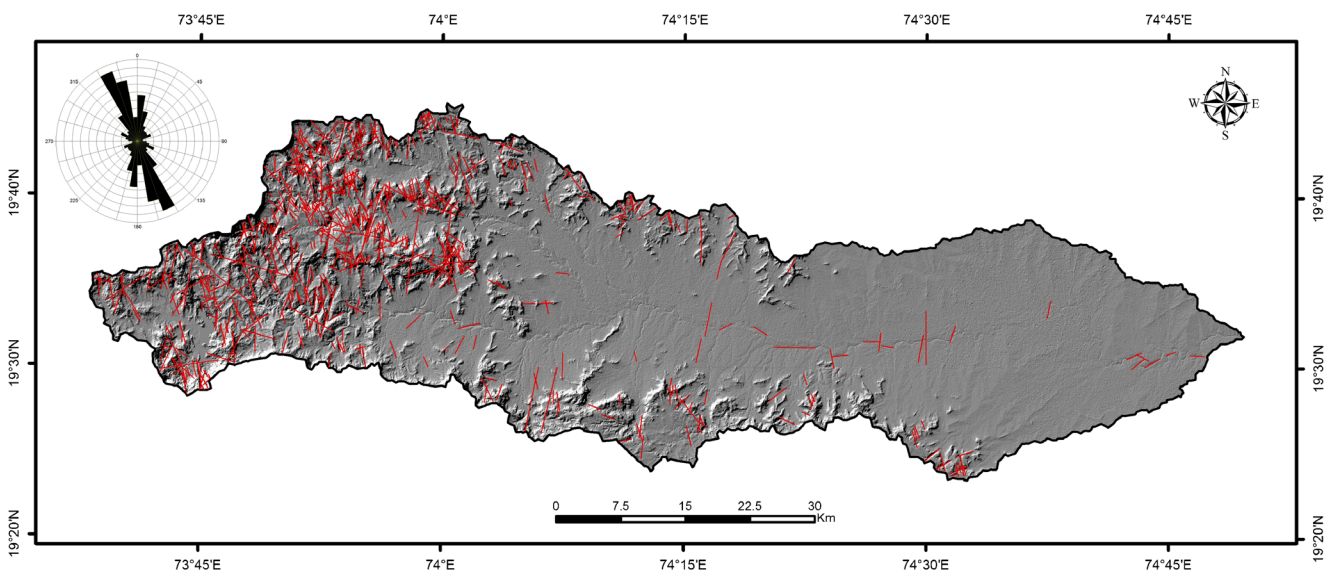


Fig. 6 Lineament map of the Pravara basin. Inset rosette diagram is illustrating the overall directions of all lineaments



Fig. 7 Photographs are representing field validation of lineaments in Pravara basin. **a, b** Dikes in between structural hills. **c** Large cracks in the hills. **d** Fractures on the basaltic lithology (near Randha waterfall). Notice the red circle where a camera is being placed for scale. **e** A segment of stream controlled by lineament, located near Randha fall, Pravara main river

Results and discussion

Number and length of lineaments within Pravara basin are traced from shaded relief maps of different azimuth angles (Fig. 5a–h). Observation reveals that maximum number of lineaments can be derived from 0° (293 lineaments) to 225° (354 lineaments) azimuth angle, whereas 90° (140 lineaments) and 135° (136 lineaments) azimuth angle provide the least number of lineaments (Table 1). In the final lineament output, a total number of lineament is 709, but when it comes to different azimuth angles, none of these eight directions is closed to this number (Fig. 6). A maximum number of lineaments are possible to extract from 225° azimuth angle, but still, the number is about one half of the final output.

Light plays a crucial role in observing an object properly and illumination of light from few angles cause False Topographic Perception Phenomena (FTPP), first time demonstrated by Saraf et al. (1996). The perception of valleys as ridges and vice versa is the result of FTTP have a strong influence on the identification of lineaments from different azimuth angles. Some azimuth angles are very good to provide a higher number of lineaments with a great accuracy where FTTP is not found or corrected. By contrast, images affected by FTTP show an inverse picture of the rugged terrain which makes difficult to identify such linear features (Saraf et al. 1996, 2011). The data show that lineaments extracted from 90° to 135° azimuth angles are having less number of lineaments. It is noteworthy to mention, these are the two images which are strongly affected by FTTP; a careful

Table 2 Morphometric drainage network characteristics of Pravara basin

Stream order	Stream length (km)
1	1079.27
2	598.75
3	260.29
4	146.32
5	7.45
6	82.87

observation can clearly identify the false perception of the terrain. Earlier, an attempt has been made by Oguchi et al. (2003) to identify faults using shaded relief maps in Japanese Alps; however, they have made similar observations where they found certain illumination angle is easier to identify the fault while some other angle failed to reveal the fault.

The total length of lineaments is very high in case of 0° (525.77 km), 45° (501.88 km), and 225° (505.75 km) azimuth angles. Among all the shaded relief maps of different directions, maximum (9.42 km) and minimum (0.02 km) length of a single lineament segment are possible to extract from 0° azimuth angle. The total length of lineaments in the final output is 1194.77 km. Length of the lineaments derived from various directions is very less compared to the final output. Therefore, it can be clearly understood that the most common method to extract lineament from a single azimuth angle cannot provide detailed information of available lineaments of an area. However, more accurate information can be extracted by tracing the lineaments from different azimuth angles, and a similar observation is recorded by Raj et al. (2017). An extensive field verification has been carried out in order to validate the results before performing the statistical analysis. In Pravara upstream where bare rocks are found is characterized by profuse intrusion of lineaments (Fig. 7). In many regions,

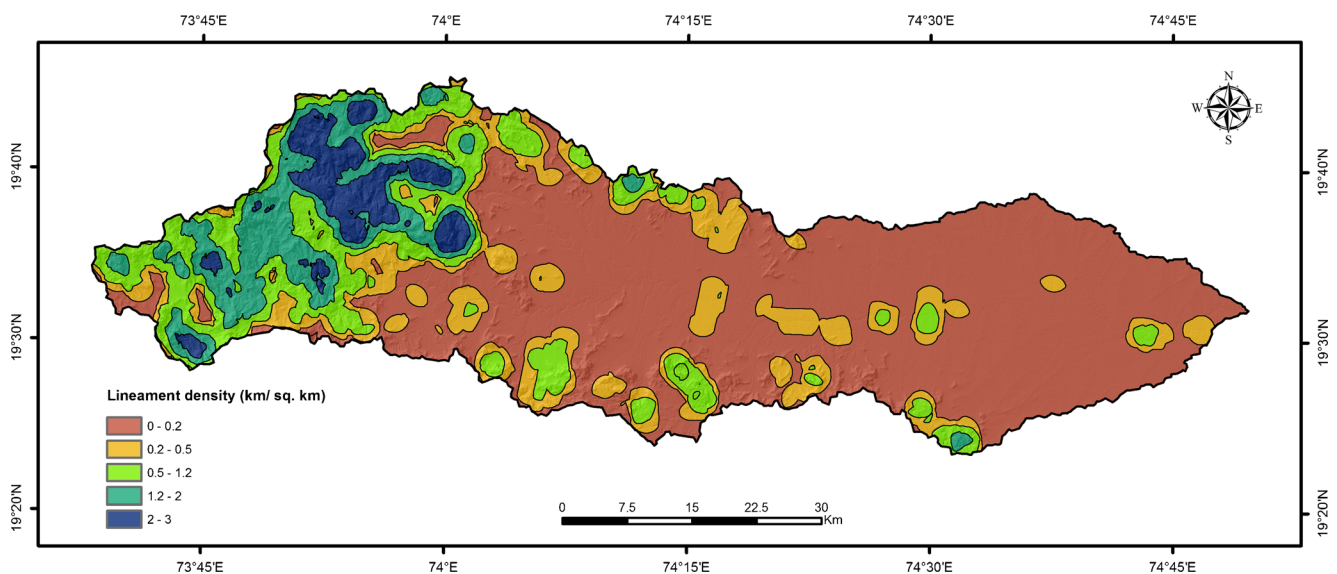


Fig. 8 Lineament density map of the Pravara basin

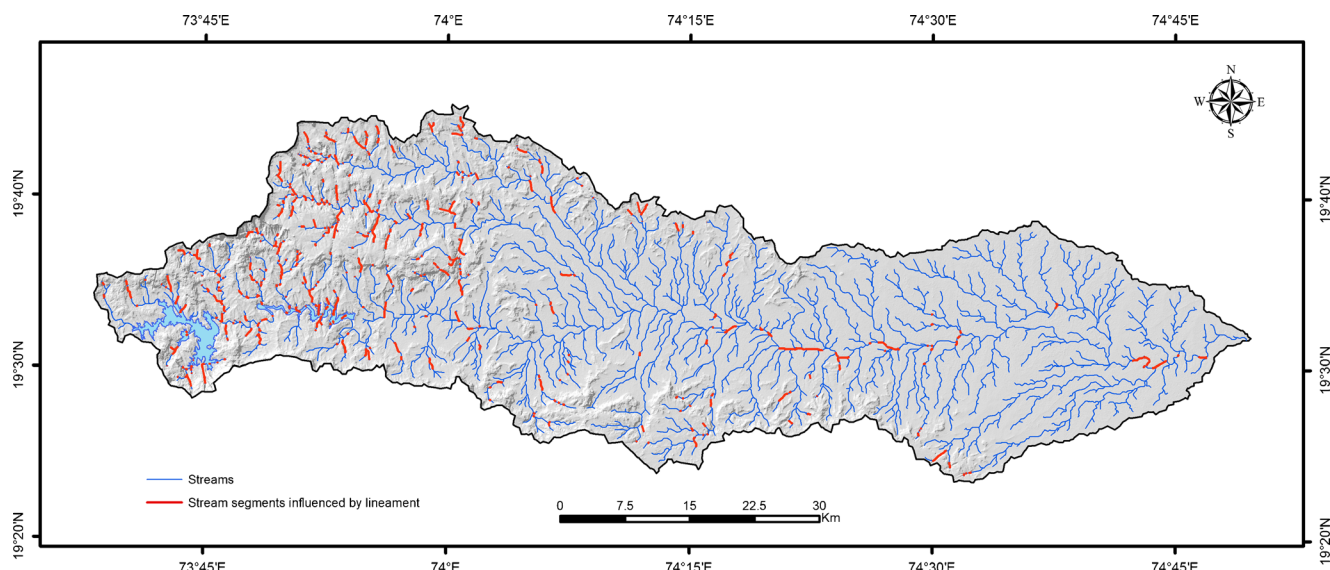


Fig. 9 Streams influenced by lineaments in Pravara basin. Streams are flowing towards east. Red segments of streams are controlled by available lineaments in the study area

these intrusions play a key role to control the drainage network, which is also identified during field visits.

Lineament density, also referred as “Lineament length density” (Greenbaum 1985), is defined as the total length of lineaments per unit area. Density of lineaments provides valuable information regarding the intensity of tectonic deformation (Hung et al. 2002; Das et al. 2003), rock fracturing and shearing (Edet et al. 1998; Kanungo et al. 1995; Chandrashekhar et al. 2011), permeability of rock (Masoud and Koike 2011) and groundwater potential (Nag 2005; Das et al. 2017). Figure 8 illustrates the lineament density where it can clearly be seen that the highest density of lineament is in the northwestern part where the terrain is very rugged and characterized by basaltic lithology. Lineament density is moderate in case of south-west part of the Pravara basin. Central and eastern part of the study area shows very low lineament concentration mainly due to the availability of deeply buried colluvio-alluvium deposition. The high density of lineaments is vulnerable to slope failure or landslide (Kiran Raj and Ahmed 2014; Raj et al. 2017). Therefore, areas under high-lineament density are not recommended to

construct dams and other engineering structures. However, areas with higher lineament density are characterized as high-permeability region due to high frequency of joint and cracks on the lithology.

To understand the orientation of lineaments, rosette diagrams are prepared in Rockworks software through statistical analysis of the extracted data for all azimuth angles. Inspection on rosette diagrams has shown that NNW-SSE, N-S, and NNE-SSW orientation predominates for all the eight lineament maps from different azimuth angle. However, at 90° azimuth angle, a major variation in the alignment is found. Various alignments of lineaments in different azimuth angle in Pravara basin may be occurred as the result of dissimilar structural deformation in the geological past.

The final lineament output shows lineament trend is mainly predominant in the NNW-SSE direction (Fig. 6). Many small and regional lineaments are found to have an orientation in N-S, NNE-SSW direction. Some major lineaments are found in the study area having an orientation in NE-SW and E-W directions which are also confirmed by Bondre et al. (2006).

Table 3 Drainage network affected by lineaments in Pravara basin

Stream order	Length influenced by lineaments (km)	% of total influenced length
1	121.23	52.57
2	56.04	24.30
3	20.92	9.07
4	13.55	5.87
5	0	0
6	18.84	8.17
–	∑ 230.58	∑ 100

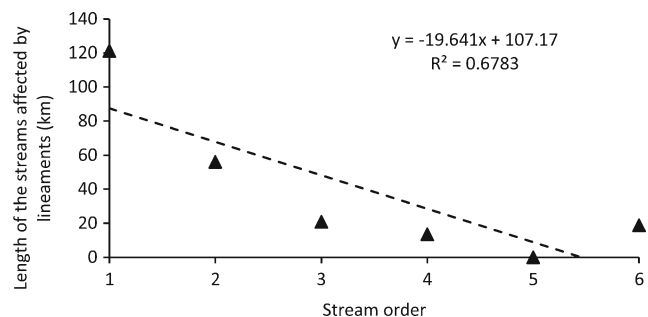


Fig. 10 Scatter plot of stream order and length of the streams affected by lineaments in Pravara basin. The plot shows that as the stream order increases in downstream, the control of lineament decreases

However, the study of Bondre et al. (2006) demonstrates Geochemical characteristics of the lineaments (restricted to the dike swarm of Sangamner region) where they found diverse variation in the chemical composition in different dikes. Their study also suggests that there could be a minor influence of the lava from different formations in this area which leads to different chemical characteristics. Additionally, abundant availability of dikes in this region is manifesting as a major vent system of Deccan volcanism in Cretaceous-Tertiary (K-T) period (Bondre et al. 2006; Chenet et al. 2009).

Table 2 shows the general linear morphometric characteristics of the Pravara basin. The study area is characterized as a sixth-order drainage basin. Maximum number of streams are observed in the first order. Total length of all the streams is 2175 km. Out of the total length, about 230.5 km streams are influenced by lineaments in the study area (Fig. 9). Among all the controlled stream's length, 53% control is found in the first order, about 24, 9, and 6% influence found in second, third, and fourth orders, respectively (Table 3). In the case of fifth-order streams, not a single segment was controlled by lineaments while about 8% length of the sixth-order streams has shown control of lineaments on the drainage network in downstream. The result indicates most of the influence occurred within first-order streams; it denotes that impact of lineament is very high in the source region of the streams in the area of steep slope and rugged terrain (Fig. 10). As the slope gradient decreases in the downstream, the dominance of lineament is diminished in the study area.

Conclusions

Extraction of lineaments using a shaded relief map is a highly valuable and well-known practice. In this study, an attempt has been made to extract lineaments of Pravara basin by using different azimuth angle method. The analysis of number and length of the extracted lineaments from eight different azimuth angles indicates that extraction of lineament is more accurate and comprehensive if different azimuth angle is considered instead of a particular azimuth angle. The present study reveals that western part of the Pravara basin is characterized by high-lineament density. Therefore, these areas might have greater groundwater infiltration potential, but should be avoided for engineering constructions due to high vulnerability of erosion and slope failure. The trend of the orientation of lineaments is predominant in NNW-SSE directions, and similar results are found in all azimuth angles; it indicates homogeneous structural deformation of the rocks through geological past. It also indicates that the stress developed and exerted on the rocks, mainly from one direction and may be continued. Higher influence of lineaments on drainage network is found on first-order streams while as stream order increases the dominance of lineaments decreases in the Pravara basin.

Lineaments along with other evidence can be used as indicators of the structural deformation of Deccan basalt formation in the study area. Apart from the significant findings, the present study provides valuable information about geological lineament structures over the study area which might be useful for future management and development. Also, this work provides the most detailed information of geological lineaments in the study area compared to the previous regional works. Hence, this work will contribute towards the fields of structural geology, tectonics, engineering geology, hydrogeology, and hydrological studies. Finally, the impressive quotation of Şengör (2014) states the essence of our work: "Properly made geologic maps are the most quantitative data in geoscience: while we may debate the nature of a contact, the contact and dip-strike measurements, if properly located, should be there 100–200 years hence and are therefore both quantitative and reproducible, something that cannot be said of experiments in some of the other sciences".

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