CHAPTER - 2

GEOLOGY AND LINEAMENTS OF THE KHAPRI WATERSHED

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The occurrence, distribution and chemistry of groundwater in any region is highly influenced by the geology. The groundwater is held up in the void spaces (pores) present in the rocks. These pore spaces either form at the time of formation of the rock, imparting primary porosity and permeability (sedimentary rocks) or after the formation of the rocks on account of geological discontinuities giving rise to secondary porosity and permeability (igneous and metamorphic rocks) (Todd, 2004). The nature of porosity and permeability influence the hydraulic characteristics of the rock and thereby the groundwater potential (Gonzalez, 2021). Also, the mineralogical composition of rocks influence the groundwater chemistry. Therefore, it is necessary to understand the geological set-up and lineament framework of the region to assess the groundwater regime with respect to quantity as well as quality.

2.1 Regional geology

The general geology of Gujarat state comprises hard rocks of Precambrian metamorphics, related intrusive, sedimentary successions of Jurassic, Cretaceous and Tertiary Periods and Trappean flows of Deccan volcanics belonging to Cretaceous-Eocene periods (Merh, 1995). The geological map of Gujarat and stratigraphy is presented in figure 2.1 and table 2.1 respectively. The Precambrian metamorphites (Aravalli and Delhi Supergroups) are dispensed in the NE part of Gujarat adjacent to Madhya Pradesh and Rajasthan and are characterized by meta-sedimentaries and extensive magmatism. The rocks of Delhi Supergroup rest unconformably over the Aravalli Supergroup; separated on the basis of unconformable character, structural discordance and magmatic episodes such as Sendra-Ambaji granite and gneiss, Godhra granite and gneiss, Erinpura granite and gneiss and Idar granite (Prakash et al., 2012). At the end of the Proterozoic era, from Cambrian to Triassic periods, a hiatus is witnessed in the geological records of Gujarat (Prakash et al., 2012). The Mesozoic sequences stretching from middle Jurassic to Lower Cretaceous are dispensed in parts of Kutch, Sabarkantha, Surendranagar, Panchmahal, Kheda, Vadodara and Rajkot districts. These sequences are extensively characterized by fossiliferous sedimentary rocks (Prakash et al., 2012). The closure of Mesozoic era witnessed extensive outpouring of lava (Deccan trap volcanic activity) in several parts of southern Gujarat, eastern Panchmahals and

Vadodara districts, Saurashtra and Kutch. The Deccan Traps occupy around 61,000 km^2 area in Gujarat, which is almost 31 % area of the state (Prakash et al., 2012).

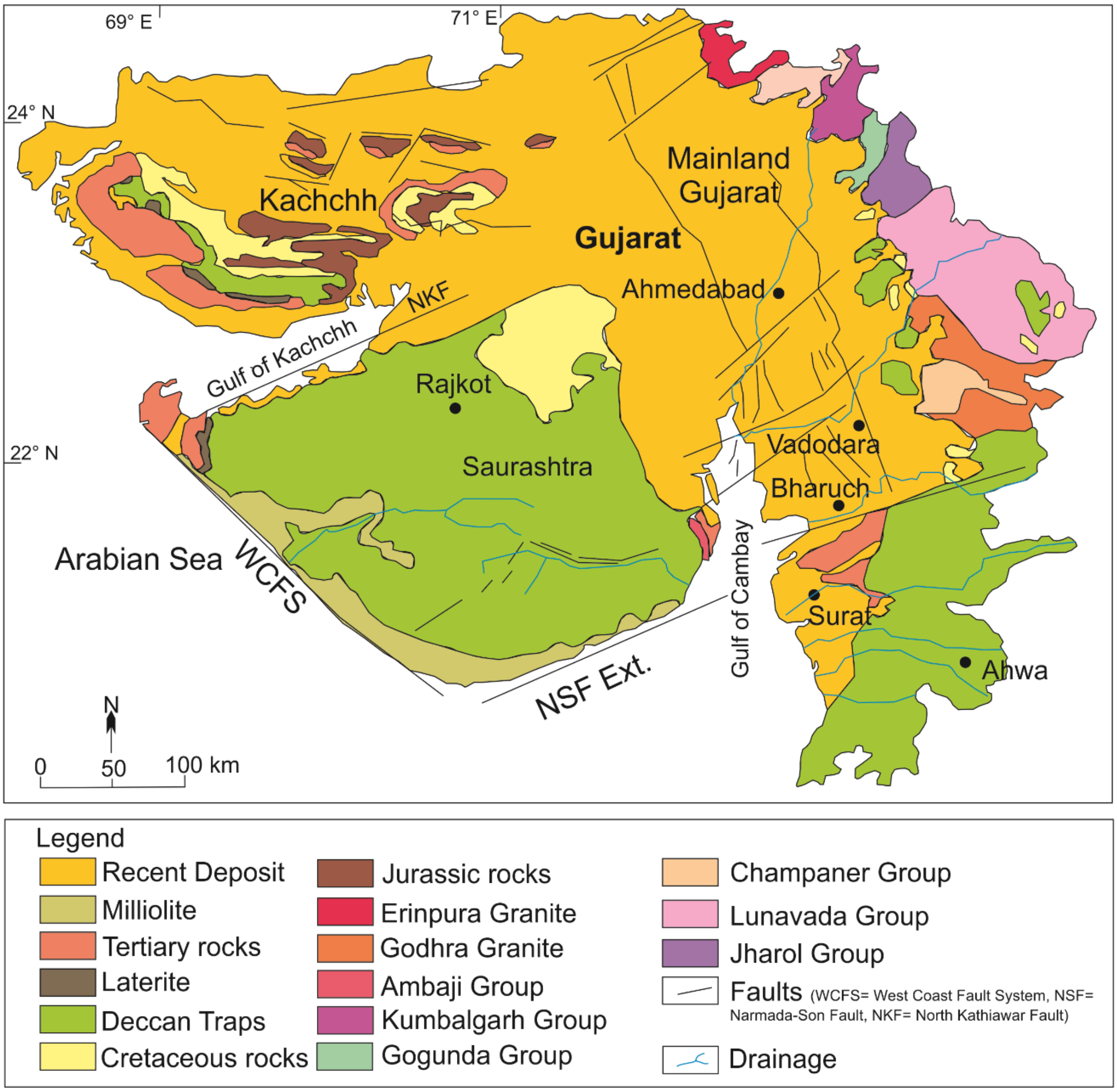

Figure 2.1 Geological Map of Gujarat (After Merh, 1995).

The Deccan Trap volcanic activity initiated in the late cretaceous and continued until the early Eocene with atleast four different phases of eruption (Rao, 1936). Deccan Volcanic Province (DVP) is regarded as the second most widespread geological formation in Peninsular India after – igneous and metamorphic complex of Archean eon (Krishnan, 1982). Sykes (1833), initially coined the term Deccan traps for the southern country due to its appearance of step like terraces. The Deccan traps expanses over 500,000 km^2 in the states of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh and Maharashtra (Krishnan, 1982 and Powar, 1981). Borehole records off the west coast of India in Arabian Sea also showed presence of basalts below tertiary sediments, suggesting 1.5 million km^2 expanse of DVP during Upper Cretaceous-Palaeocene period (Vaidyanadhan and Ramakrishnan, 2010). Older volcanics falling in alkali basalt field of Total Alkali Silica (TAS) diagram and older traps (Kaila et al., 1981) have been reported at the base of Dhrangadhra Sandstones at Lodhika and at Dhanduka, 150 km NE of Lodhika respectively. The Deccan Traps are overlain by the tertiary rock sequences, occurring all along the coastal tracts of Saurashtra in Cambay basin and in parts of Kutch (Biswas, 1971). The Eocene and Oligocene sediments of Cambay basin possess oil and gas producing horizons (Raju, 1968). The Quaternary sediments dispensed in the state are characterized by recent alluvium, miliolites, coral reefs (Merh, 1995 and Chamyal et al., 2003).

Table 2.1 Generalized stratigraphy of Gujarat (After Merh, 1995 and GSI, 2012).

<table>
<tr><th>Era</th><th>Period</th><th>Epoch</th><th>Supergroup</th><th colspan="2">Group/Formation</th><th>Intrusive/Extrusive</th></tr>
<tr><td rowspan="13">CENOZOIC</td><td rowspan="2">Quaternary</td><td>Holocene</td><td></td><td colspan="2">Undifferentiated alluvial & fluvial sediments/Rann deposits</td><td></td></tr>
<tr><td>Pleistocene</td><td></td><td>Porbander group</td><td>Chhaya Formation/ Miliolite Formation</td><td></td></tr>
<tr><td rowspan="11">Tertiary</td><td>Pliocene</td><td></td><td colspan="2">Sandhan Formation</td><td></td></tr>
<tr><td>Mio-pilocene</td><td></td><td colspan="2">Dwarka Formation/ Jhagadia Formation</td><td></td></tr>
<tr><td>Miocene</td><td></td><td colspan="2">Gaj Formation
Kand Formation
Babaguru Formation</td><td></td></tr>
<tr><td>Oligocene-Miocene</td><td></td><td colspan="2">Kharinadi Formation</td><td></td></tr>
<tr><td>Oligocene</td><td></td><td colspan="2">Maniyara Formation</td><td></td></tr>
<tr><td>Eocene-Oligocene</td><td></td><td colspan="2">Tarkeshwar Formation</td><td></td></tr>
<tr><td>Eocene</td><td></td><td colspan="2">Fulra Formation
Kakdi Nadi Formation
Nummulutic Formation
Vagadkhol Formation</td><td></td></tr>
<tr><td>Paleocene-Eocene</td><td></td><td colspan="2">Bhatia Formation
Salod Formation</td><td></td></tr>
<tr><td>Paleocene</td><td></td><td colspan="2">Matanomadh Formation</td><td></td></tr>
</table>

CENOZOIC-MESOZOIC		Cretaceous – Eocene			Deccan Traps, associated volcanics – Amba Dungar Carbonatite, Gabbro, Rhyolite/felsite/granophyre Basic dykes/sills/sheet: dolerite/diorite-monazite and Inter-trappeans
MESOZOIC		Cretaceous		Lameta Formation/ Bagh Formation Bhuj Formation/Wadhwan Formation Dhrangadhra Group/ Himmatnagar Formation	
		Jurrasic - Cretaceous		Katrol (Jhuran) Formation	
		Jurassic		Chari (Jumara) Formation Pachchham (Jhurio) Formation	
PROTEROZOIC		Neo-proterozoic		Syn- to post- Delhi intrusive	Idar (=Malani), Granite, Erinpura Granite and Gneiss, Godhra Granite and Gneiss
		Paleo-proterozoic – Meso-proterozoic	Delhi Supergroup	Sirohi Group Kumbhalgarh Group Gogunda Group	Sendra Ambaji Granite and Gneisses Phulad Ophiolite Suite
		Paleo-proterozoic	Aravalli Supergroup	Champaner Group Lunavada Group Jharol Group	Rakhabdev Ultramafic Suite
ARCHEAN				Pre-Champaner / Pre-Lunavada Gneissic Complex	

2.2 Geological setup of the Dangs district

The district Dangs located in the south-eastern part of Gujarat state shows extensive occurrence of Deccan Traps. It occupies an area of about 1700 km^2 and is characterized by bedded lava comprising thick pile of near-horizontal flows with exposed thickness of around 700 m (Merh, 1995). The topography of the district is highly rugged. The southern part of the district shows dominance of E-W trending flat topped ridges. In south-eastern direction (near Saputara hill station) sudden rise of 400 to 500 m in elevation, raises the altitude of ridges to more than 1000 m. These high ridges form steep escarpments and marks the northern most end of Great west coast escarpment. The overall step-like topography with disposed flat topped ridges and horsts and grabens have resulted due to combined effect of differential erosion, scarp retreat and unequal uplifts and subsidence parallel to significant fault trends respectively (Merh, 1995). The entire district is dissected by numerous valleys with diverse shape, sizes and trends having strong structural controls (Merh, 1995). The structural depressions are occupied by E-W trending broad flat bottom valleys, whereas the smaller V-shaped valleys with steep slopes and E-W as well as N-S trends suggests the erosion along slopes of joint planes. According to GSI 2005, the trap in the district is described as a mass of repetitive flows of (i) massive compact fine-grained basalt and Mega phenocryst basalt (ii) Amygdoloidal basalt and (iii) Porphyritic basalt. GSI has identified in total 11 flows in the district and established a lava stratigraphy (table 2.2).

The flows in the district are mainly of Pahoehoe type. The lava stratigraphy in the district has been established by considering porphyritic basalt as a marker horizon due to absence of the red-bole and intertrappeans. All the flows are intruded by numerous conspicuous dykes of doleritic and basaltic composition giving criss-crossed appearance of the district on the satellite imageries. These dykes are emplaced along the major fracture trends viz. ENE-WSW, E-W, ESE-WNW and NNW-SSE, N-S, NNE-SSW (GSI, 2005). Towards Maharashtra in southern and eastern directions the basalts of Dangs are tentatively correlated with the Jawahar and Igatpuri formations of the lower parts of Kalsubai sub-group of Deccan Volcanic Province (Merh, 1995).

Table 2.2 Lithostratigraphy of the Dangs district (After GSI, 2005).

Flow	**Description**	**Elevation (m amsl)**	**Age**
	Alluvium and soil	--	Holocene to Recent
Intrusive	Dolerite and Basaltic dykes	--	Cretaceous to Eocene
Flow XI	Amygdular basalt in association with fine grained basalt	880-1340	
Flow X	Mega phenocrysts basalt	860-1036	
Flow IX	Massive fine-grained basalt and amygdular basalt		
Flow VIII	Porphyritic basalt	630-730	
Flow VII	Honey yellow coloured basalt, fine grained basalt with rib and furrow structure, vesicular basalt with blebs of green glass	530-710	
Flow VI	Mega phenocryst basalt	480-610	
Flow V	Honey yellow coloured basalt and fine-grained basalt with spotted appearance	360-530	
Flow IV	Glomeroporphyritic basalt	340-510	
Flow III	Massive fine-grained basalt and amygdular basalt	140-455	
Flow II	Porphyritic basalt	120-140	
Flow I	Amygdular basalt and Massive fine-grained basalt	100-120	

2.3 Geological setup of the Khapri watershed

Geologically the Khapri watershed is completely underlined by Deccan basalts. The Deccan basalts are overlain by recent alluvium and alluvio-colluvial sediments of Quaternary age. The recent deposits consisting of gravels, sand, silt and clay sized particles are thin and are present in irregular patches along the river and at the confluence of river Khapri with Ambica. Amongst the eleven flows identified in the district, the Khapri watershed is underlined by nine basaltic flows (GSI, 2005) (figure 2.2). These flows are confined between elevations 120 m above mean sea level (amsl) to 1036 m amsl in the watershed. The flows are intruded by ENE-WSW, WNW-ESE, NW-SE and NE-SW trending dykes and are transacted by numerous regional joints trending NNE-SSW as well as fractures. Megascopically, the flows in Khapri watershed are light to dark grey, fine to coarse grained, non-porphyritic to porphyritic (figure 2.3 a-f). The porphyritic ones are mostly plagioclase phyric, with small to giant size phenocrysts (2 to 3.5 cm) showing sparsely to moderately porphyritic nature (figure 2.3 a-f). Vesicles, pentagonal joints, intrusives, agglutinated surfaces, warping and spheroidal weathering (figure 2.4 a-f) is very commonly observed in the flows throughout the watershed. The flows are mainly characterized as Pahoehoe type flows. The geological succession of the Khapri watershed is given in the table 2.3.

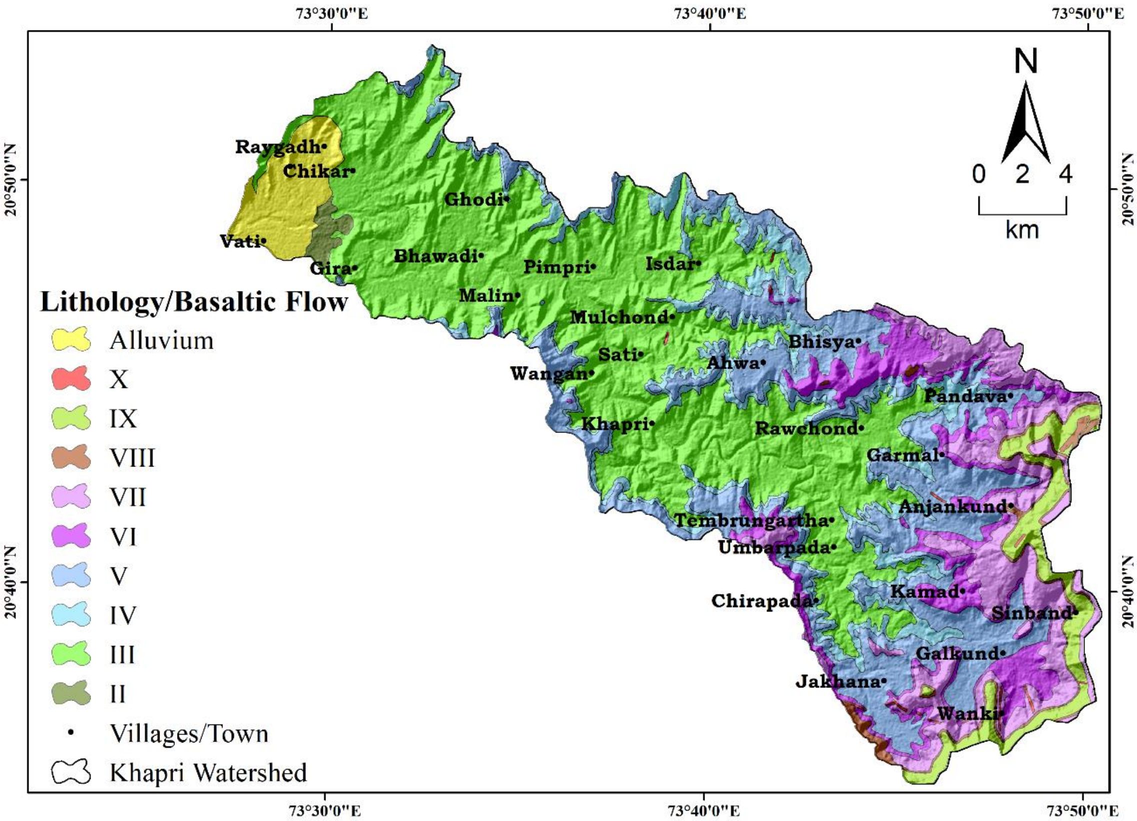

Figure 2.2 Geological map representing nine flows (II to X) in the Khapri watershed (After GSI, 2005).

Table 2.3 Geological succession of the Khapri watershed (After GSI, 2005).

Flow	**Description**	**Elevation (m amsl)**	**Age**
	Alluvium and soil	--	Holocene to Recent
Intrusive	Dolerite and Basaltic dykes	--	Cretaceous to Eocene
Flow X	Mega phenocrysts basalt	860-1036	
Flow IX	Massive fine-grained basalt and amygdular basalt		
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Flow VII	Honey yellow coloured basalt, fine grained basalt with rib and furrow structure, vesicular basalt with blebs of green glass	530-710	
Flow VI	Mega phenocryst basalt	480-610	
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Flow III	Massive fine-grained basalt and amygdular basalt	140-455	
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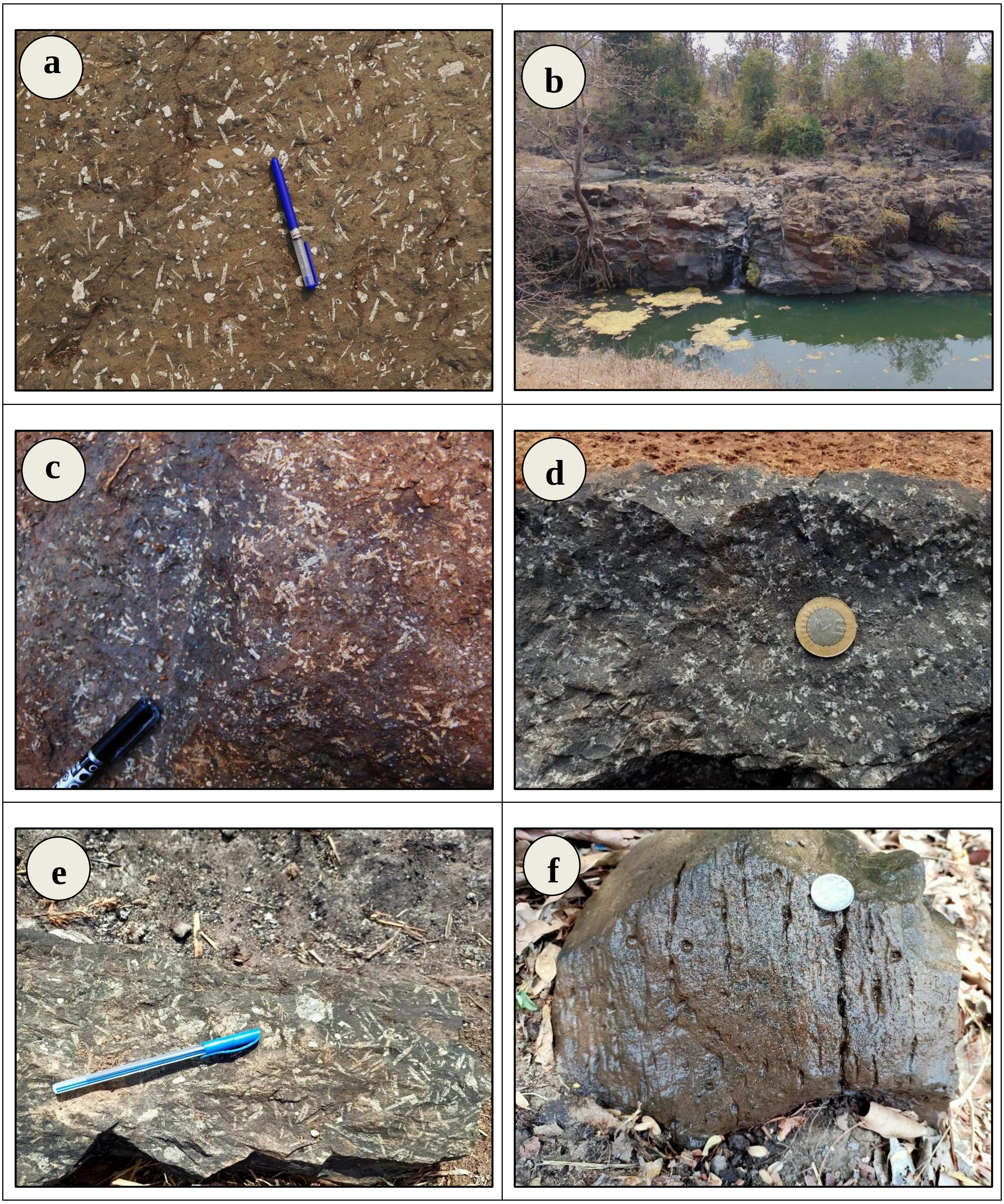

Figure 2.3 Various types of basalts observed during ground truth verification a) Porphyritic basalt (flow-II), b) Massive fine grained basalt (flow-III), c) Glomeroporphyritic basalt (flow-IV), d) Honey yellow colored basalt and fine grained basalt with spotted appearance (flow-V), e) Mega phenocrysts basalt (flow-VI), f) Fine grained basalt with ribs and furrows structure and vesicles (flow-VII).

Figure 2.4 a) Vesicular basalt (flow-VII), b) Amygdaloidal basalt (flow-IX), c) Intrusive, d) Agglutinated surface of lava channel, e) Warping in basaltic flow, f) Spheroidal weathering in basalt.

2.4 Lineaments

Lineament is defined as any linear or curvilinear mappable feature of the earth's surface with distinct patterns (O'Leary et al., 1976, Ahmadi and Pekkan, 2021). It signifies the sub-surface continuation of faults, fractures, joints, dykes, bedding planes, foliation, streams, boundaries of litho-contacts between stratigraphic formations and volcanic flows. The lineaments have attracted geologists since the inception of use of aerial photographs and satellite imageries in geological studies. Geologist such as Hobbs (1904, 1912) and O'Leary et al. (1976), were first to place on record the existence and importance of linear geomorphic features which were the expressions of zones of weakness or structural offsets on the earth's surface. Lineaments have shown a close association with occurrences of economic minerals, petroleum deposits and groundwater flow as well as yield and thus are proved to be significant tool in their investigations. The lineaments are generally underlain by zones of localized weathering and indicates the regions of structural weakness. Specifically, in hard rock terrains, the lineaments induce the secondary porosity and permeability and facilitate infiltration of surface runoff as well as the movement and storage of groundwater. Wherever, these lineaments show consistency and regional continuity they give rise to a good groundwater source of appreciable size. Numerous workers have observed close association between the lineament and groundwater potential and have opined that the presence of lineaments significantly affect the groundwater potential (Ahmed et al., 2019, Akinluyi et al., 2018, Burning et al., 2011, Chandra et al., 2006, Henriksen and Braathen, 2006, Kim et al., 2004, Nag, 2005, Mahmood, 1996, Mogaji et al., 2011, Sander, 2007, Glesson and Novakowski, 2009, Varade et al., 2018). Thus, the identification and mapping of lineaments plays a decisive role in determination of groundwater occurrences, specifically in hard rock terrains. The identification and mapping of lineaments in the Khapri watershed is discussed in the section to follow.

2.5 Lineament framework of the Khapri watershed

The lineaments of the Khapri watershed, are extracted with the help of IRS LISS-III (24 m) satellite data of May 2019 and Carto-DEM. To extract the lineaments from IRS LISS-III satellite data the False Colour Composite (FCC) is prepared by combining Bands 4, 3, 2 i.e., SWIR, NIR and Red respectively. On the other hand, to extract lineaments from Carto-DEM, shaded relief maps with light illumination angle set at 45°

intervals (45°, 90°, 135°, 180°, 225°, 270°, 315°, 360°) are generated in GIS environment by applying “Hill-shade” tool. Upon generation of the FCC and shaded-relief maps, the apparent geological lineaments were digitized using line tool in Arc GIS 10.4 (figure 2.6– 2.10). To ascertain the mapped lineaments are geological features, these are validated through google earth and ground-truth verification at selected locations (figure 2.5). The lineaments relating to public utilities such as roads, bridges, powerlines etc. were discarded. The comprehensive lineament map of the Khapri watershed is prepared by combining all the lineaments mapped from FCC and eight shaded-relief maps, where all the duplicate lineaments are discarded (figure 2.11). Later, these lineaments were characterized into two categories viz. (i) Positive lineaments and (ii) Negative lineaments (figure 2.12). The ridges, plateaus and dykes on the satellite data are categorized as positive lineaments (Abdullah, 2010). While, offsets, regional and decipherable local joints, straight stream segments are categorized as negative lineaments. The primary reason of categorization of lineaments is to assign appropriate importance based on their water infiltration capacity. The positive lineaments dominantly trend in NE-SW, ENE-WSW, NNE-SSW and WNW-ESE (figure 2.12), while the negative lineaments dominantly show N-S, NNW-SSE, NNE-SSW, ENE-WSW and NE-SW trends (figure 2.12). In general, the positive lineaments due to their exposed bare rock and steeply sloping surfaces will constitute runoff and not contribute to groundwater as effectively as the negative lineaments (Javed and Wani, 2009). Moreover, prominent zones of localized weathering occur along the negative lineaments which give rise to secondary porosity and permeability resulting into good groundwater repository. The negative lineament density map used for weighted overlay analysis is represented in figure 2.13.

Figure 2.5 Ground truth verification and measuement of lineament trend.

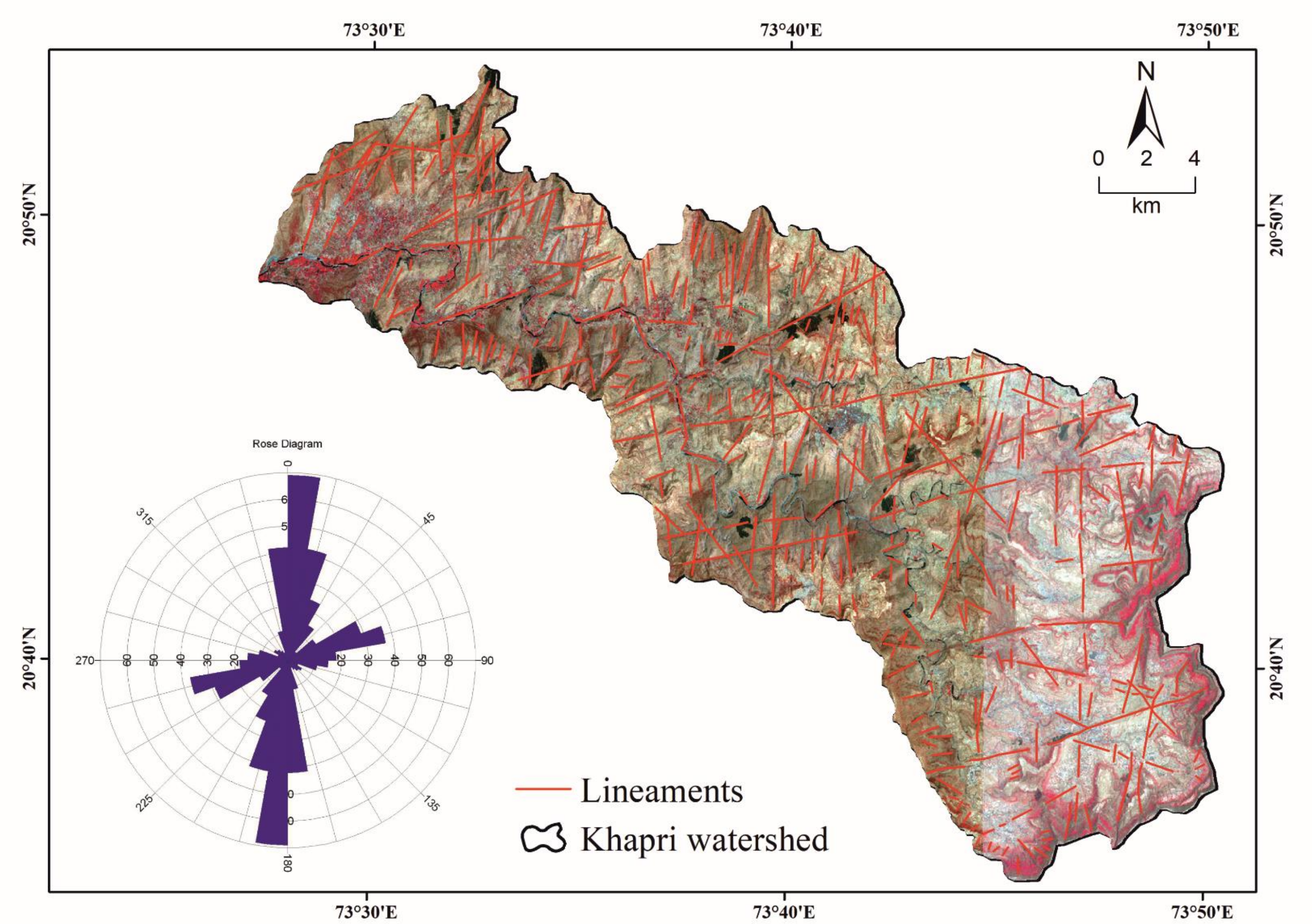

Figure 2.6 Extraction of geological lineaments from IRS LISS-III FCC satellite data. Inset rosette diagram represents the prominent trend of lineaments.

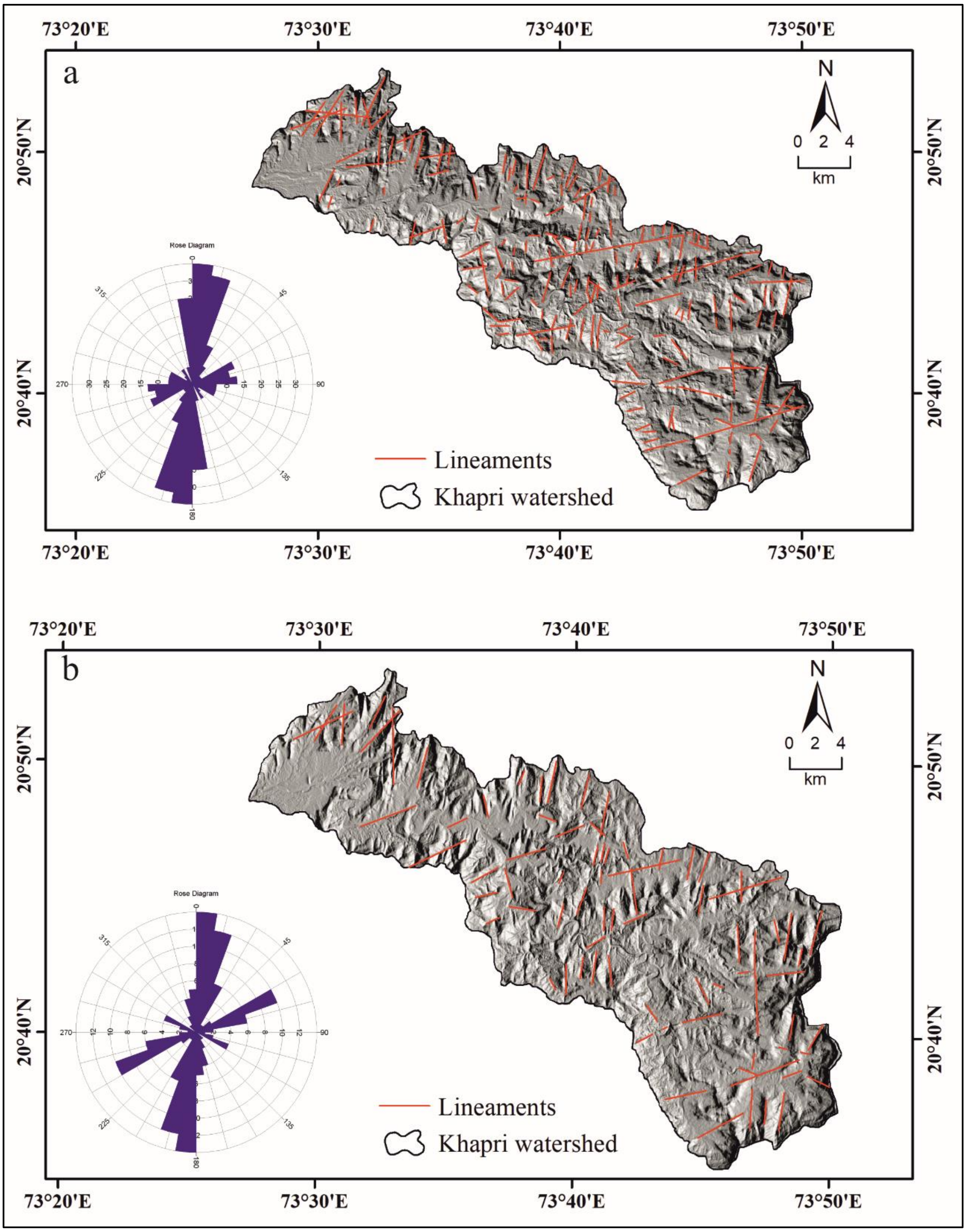

Figure 2.7 Extraction of lineaments from shaded relief map having (a) 45° azimuth angle (b) 90° azimuth angle. Inset rosette diagram represents the trend of lineaments.

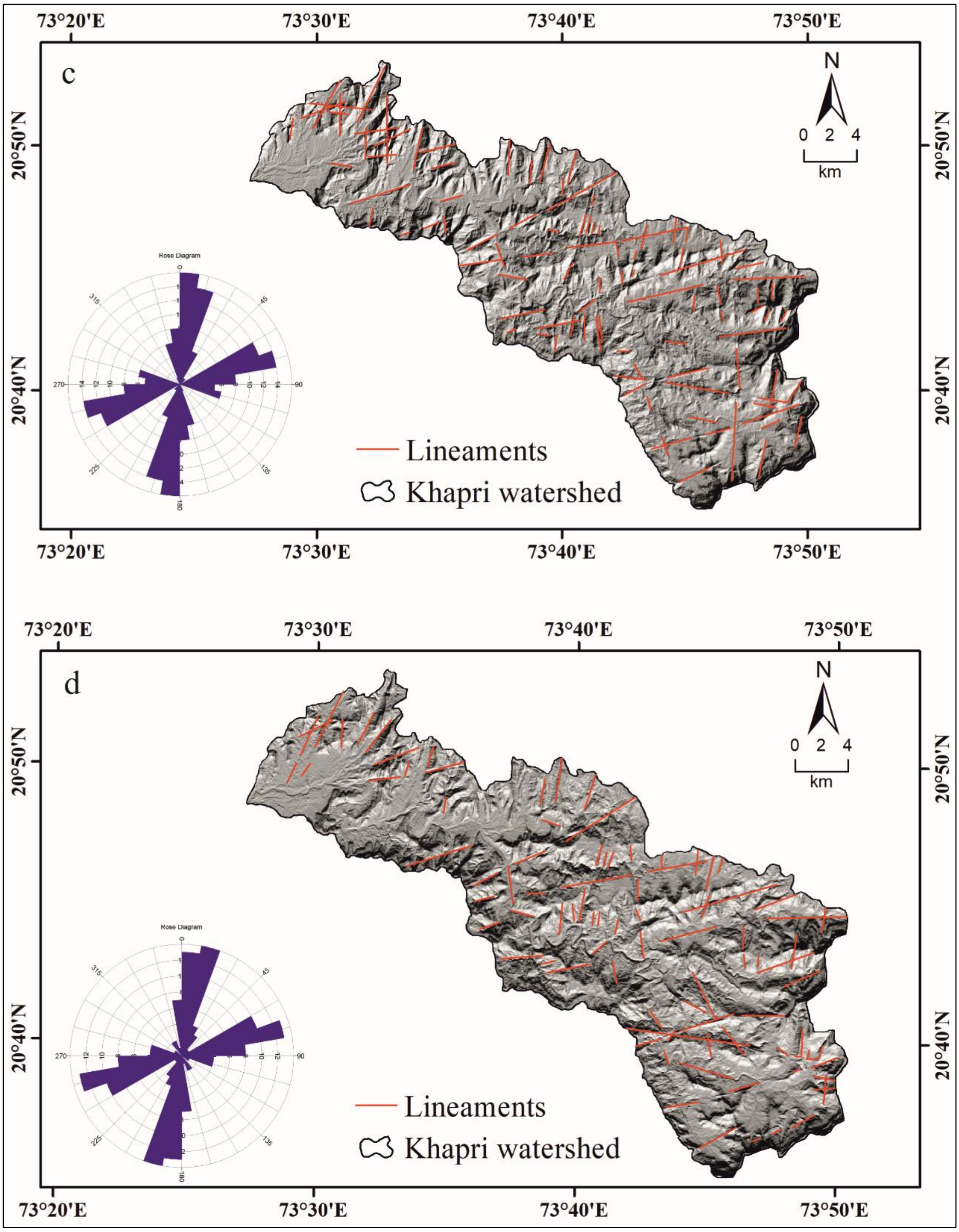

Figure 2.8 Extraction of lineaments from shaded relief map having (c) 135° azimuth angle (d) 180° azimuth angle. Inset rosette diagram represents the trend of lineaments.

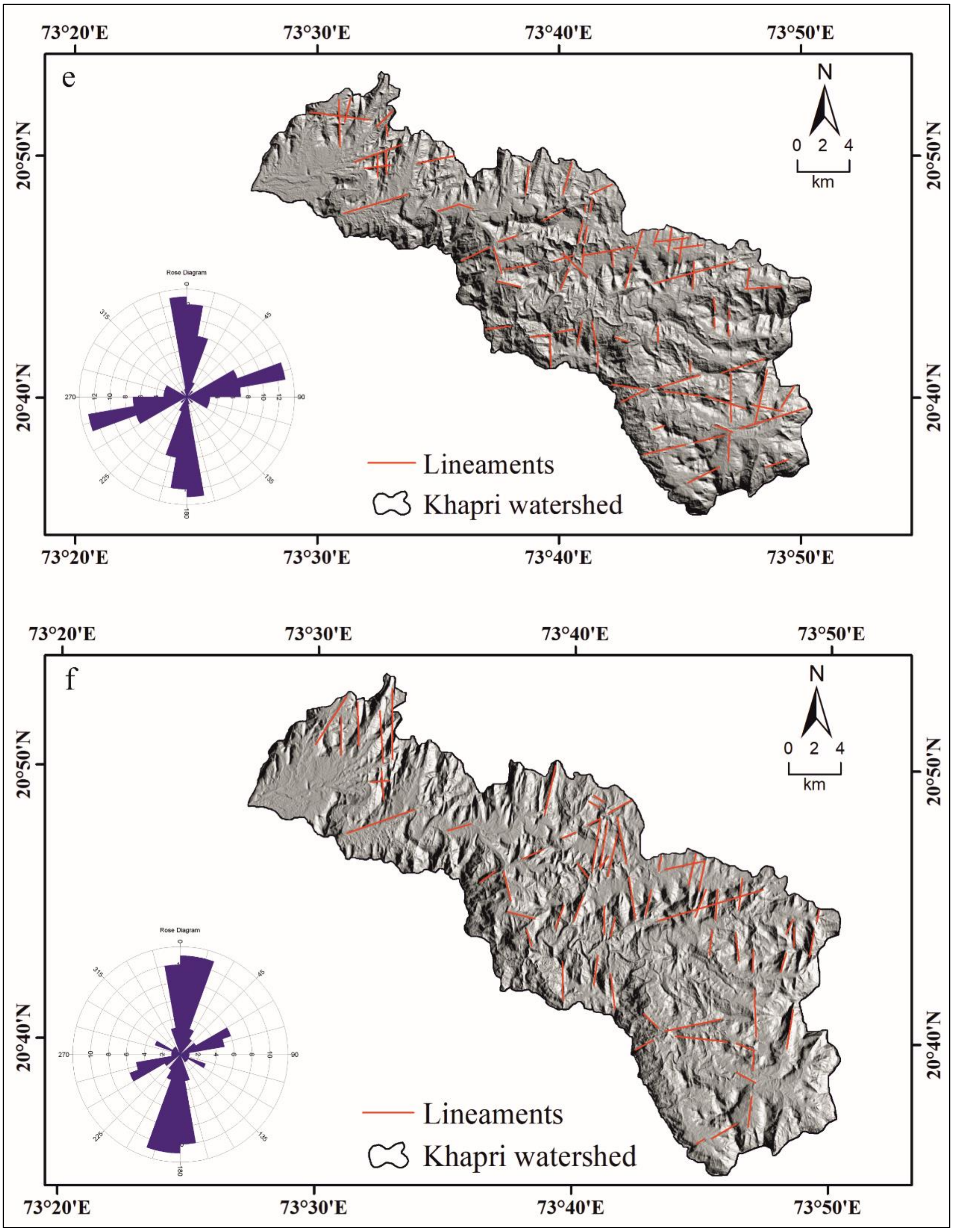

Figure 2.9 Extraction of lineaments from shaded relief map having (e) 225° azimuth angle (f) 270° azimuth angle. Inset rosette diagram represents the trend of lineaments.

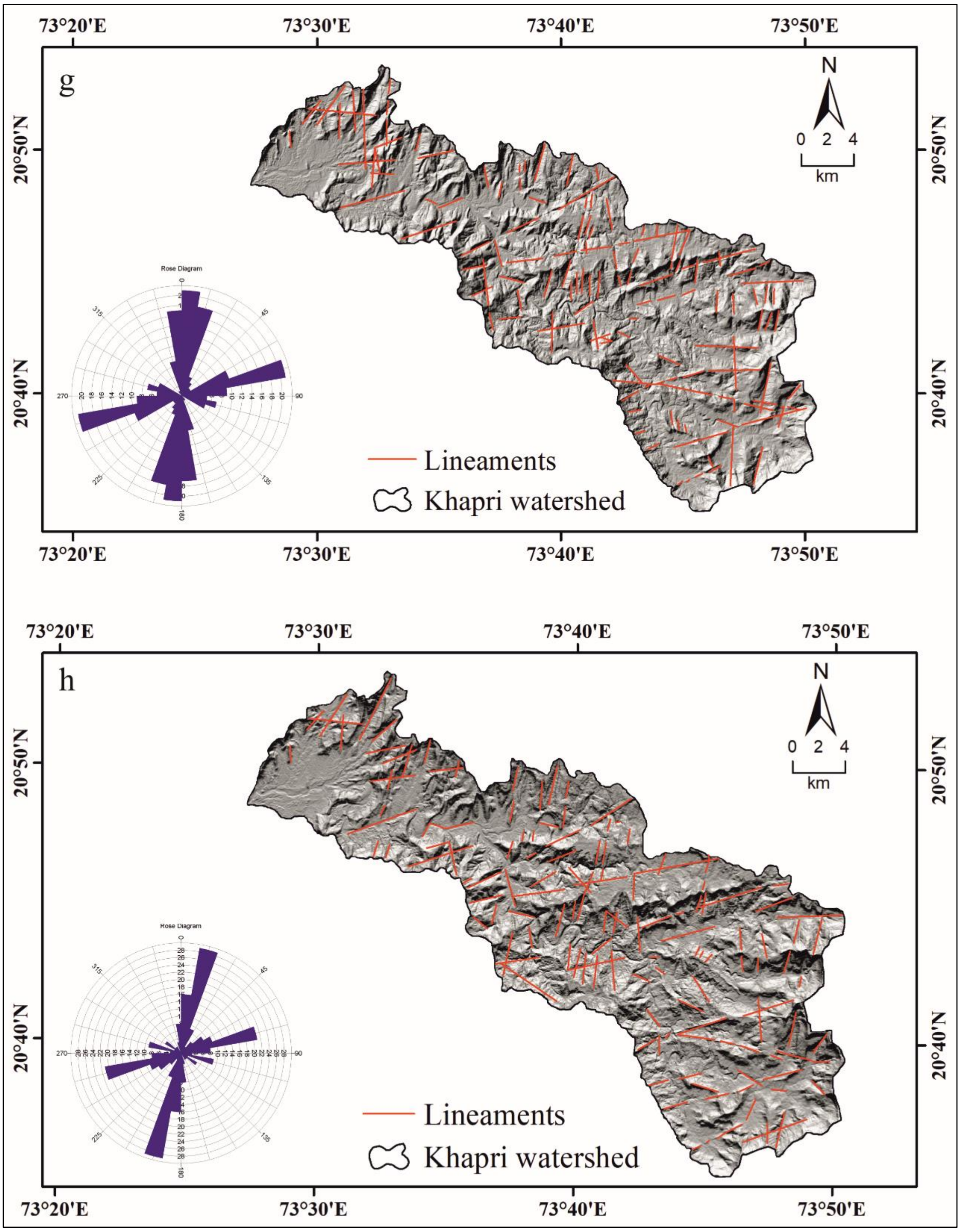

Figure 2.10 Extraction of lineaments from shaded relief map having (g) 315° azimuth angle (h) 360° azimuth angle. Inset rosette diagram represents the trend of lineaments.

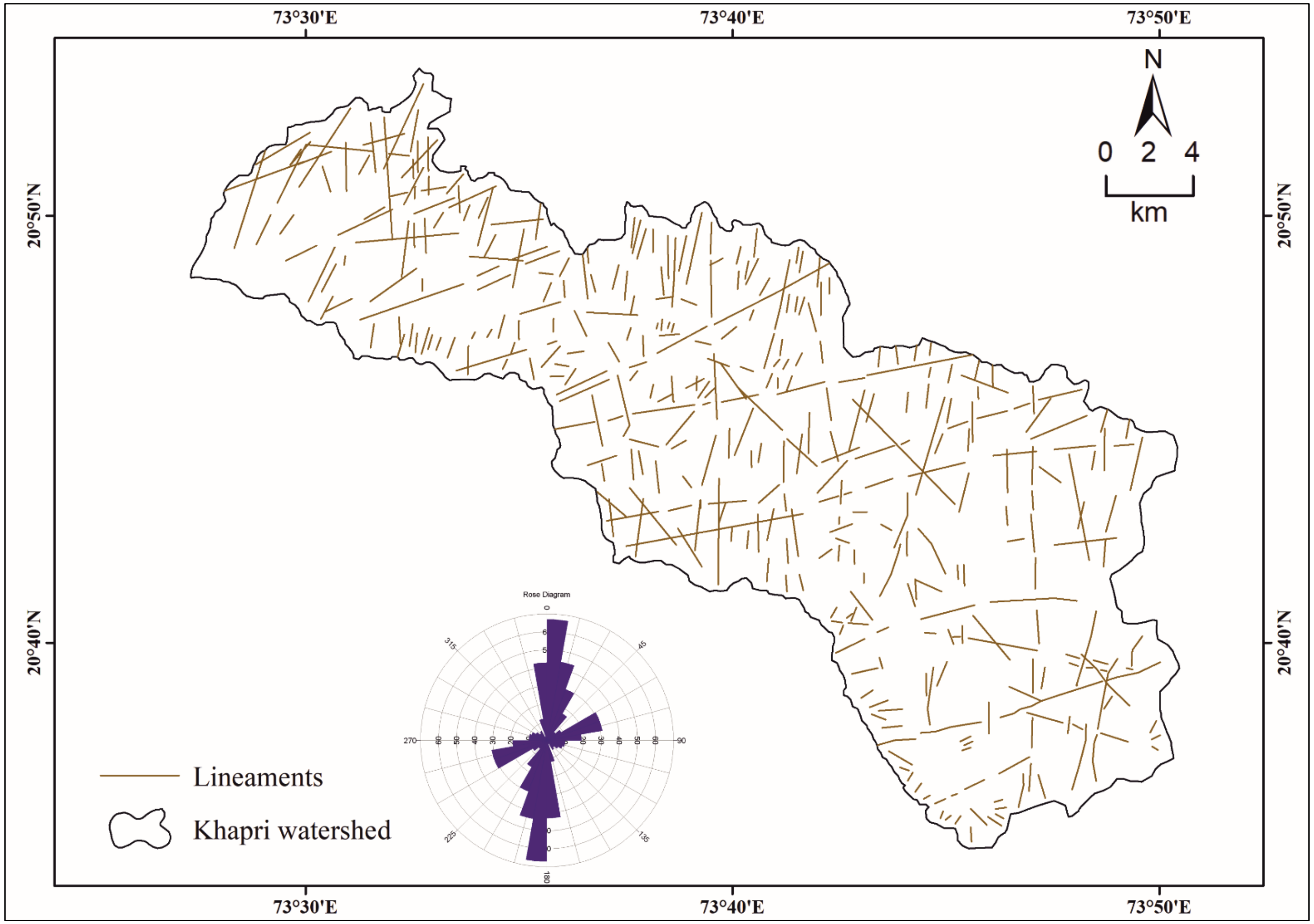

Figure 2.11 Comprehensive lineament map of the Khapri watershed, prepared by combining all the lineaments mapped on IRS LISS-III FCC satellite data and eight shaded-relief maps. Inset rosette diagram represents the prominent trend of lineaments.

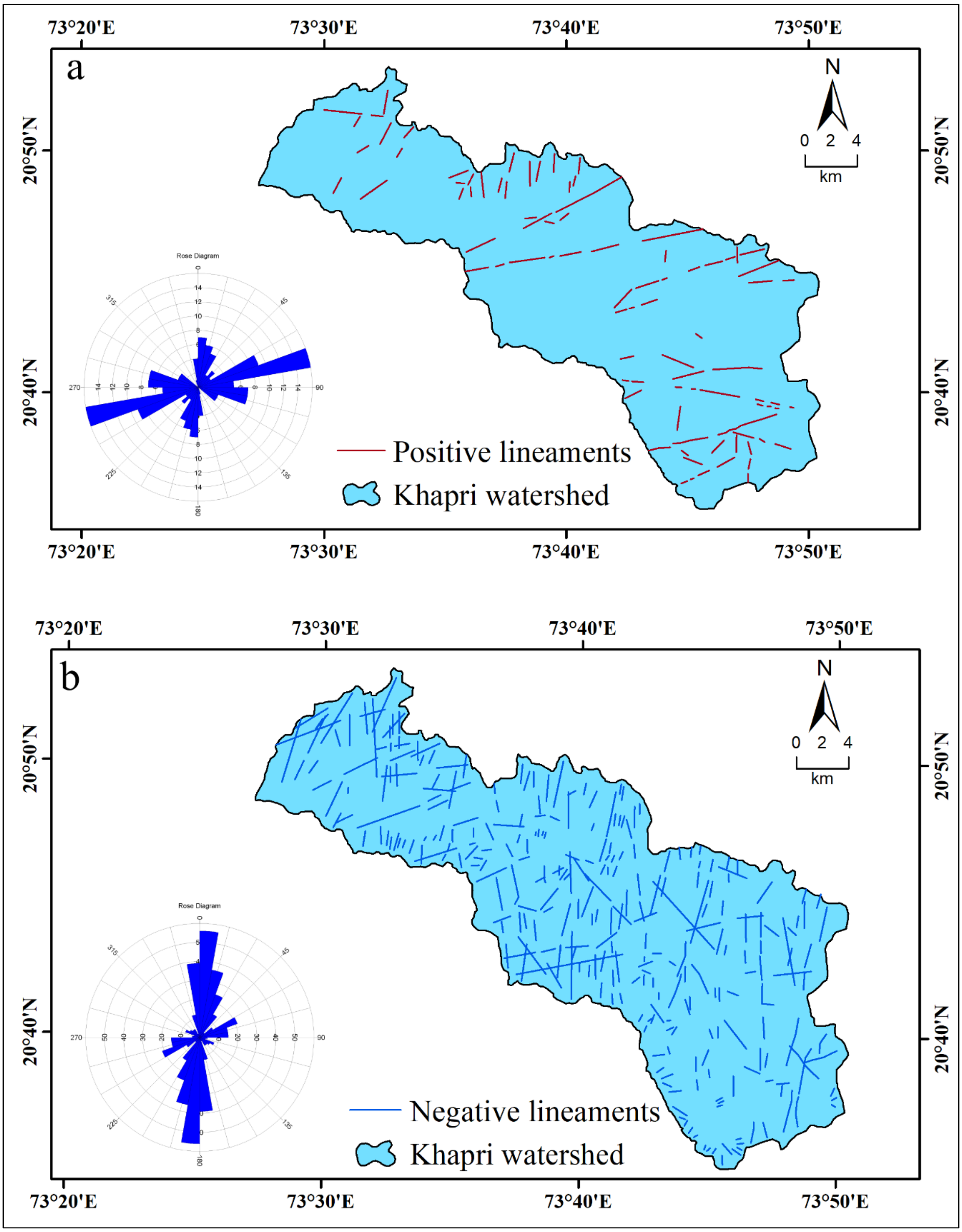

Figure 2.12 (a) Positive and (b) Negative lineamens of the Khpari watershed. Inset rosette diagram represents the prominent trend of lineaments.

2.6 Epilogue

The present chapter provides the details of the geological setup and lineament framework of the Khapri watershed. Geologically, the Khapri watershed is completely underlined by Deccan basalts which are unconformably overlain by recent alluvium and alluvio-colluvial sediments of Quaternary age. Amongst the eleven flows identified in the district Dangs, the watershed is underlined by nine basaltic flows of Pahoehoe type. These flows are intruded by ENE-WSW, WNW-ESE, NW-SE and NE-SW trending doleritic dykes and are transacted by numerous regional joints trending NNE-SSW as well as fractures. Joints and spheroidal weathering is very commonly observed in the flows throughout the watershed. The watershed is characterized by repetitive flows of (i) massive compact fine-grained basalt and mega phenocryst basalt (ii) amygdoloidal basalt and (iii) porphyritic basalt with flat-top ridges and structurally controlled valleys of diverse shape, sizes and trends. In Khapri watershed the lineaments are categorized into two viz. (i) Positive lineaments and (ii) Negative lineaments. The ridges, plateaus and dykes on the satellite data are categorized as positive lineaments. While, offsets, regional and decipherable local joints, straight stream segments are categorized as negative lineaments. The negative lineaments in the traps are underlain by zones of localized weathering, responsible for inducing the secondary porosity and permeability, allowing the infiltration as well as the storage of water in the sub-surface.

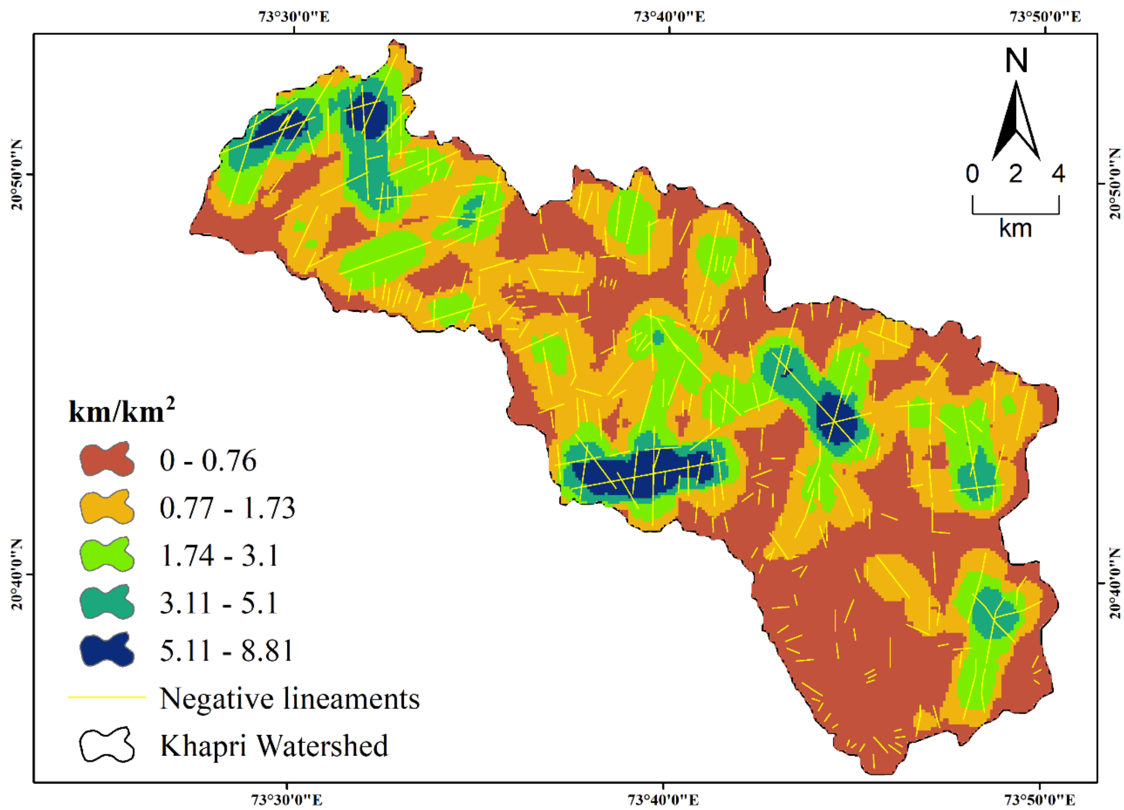

Figure 2.13 Negative lineament density map of the Khapri watershed.