



Morphometric and Morphotectonic Studies of Sindh Basin, Central India, Using Advance Techniques of Remote Sensing and GIS

S. C. Bhatt, Rubal Singh, Rahul Singh, V. K. Singh, and Adesh Patel

Abstract

In the present paper, morphometric and morphotectonic attributes of Sindh basin of Central India were attempted. The remotely sensed Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) data were used to extract drainage, density and contour maps. The drainage of Sindh and its subwatersheds exhibiting dendritic pattern show mean bifurcation ratio ranging from 3.85 to 5.66. It reveals that the drainage flowing in hilly and dissected area is geologically and structurally controlled. The low density (0.82) and frequency (0.4) implies that the basin is consisting of coarse permeable soil with dense vegetation. The values of elongation and form factor ratio infer that the basin is elongated and less prone to erosion. The ruggedness values infer that the Sindh basin is slightly rugged and less prone to erosion and sediment transport. The drainage orientations of Sindh River and its subwatersheds showing polymodal distribution are represented by highly conspicuous NNE-SSW and NNW-SSE trends. The four sets of major lineaments trending NE-SW, NW-SE, WNW-ESE and NNW-SSE are observed in the Sindh basin. The high density of lineaments represented by fractures, faults, foliations and bed rock structures are controlling the drainage of low order streams. The high order NE-SW trending streams show major tectonic control.

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1 Introduction

In present scenario, the natural resources are playing significant role in socioeconomic development of a country. The excessive depletion of these resources is affecting the ecosystem and is degrading the environment globally (Bhatt 2020). Land degradation has become one of the important factor to decline agricultural productivity and soil fertility. Bundelkhand craton located in central India is facing severe problem of soil erosion, land degradation and drought. Its 11,000 square kilometer area is occupied by waste land and maximum part is affected by gully erosion. The rocky degraded land affected by gullies and ravines is more dominant in catchment and lower basins of most of the Cratonic Rivers (Betwa, Ken, Sindh and Pahuj) of Bundelkhand. Despite having good network of rivers, ponds and wells this region is facing scarcity of water. Therefore, there is a need to conserve water, soil and other resources for development of society in such underprivileged area. The morphometric analysis is considered the best tool to understand the physical, hydrological and geological properties of a basin and for planning of water harvesting and soil protection schemes.

Morphometric analysis is a method that reveals the shape, size, hydrological, erosional and physical properties of landforms and soil of a basin (Horton 1932, 1945; Strahler 1956, 1964; Melton 1958; Miller 1953; Clark 1966; Pareta and Pareta 2012; Samal et al. 2015; Prakash et al. 2016, 2019; Bhatt et al. 2017, 2020; Smith 1950). It gives information about the characteristics of drainage system, topographic pattern, dimension of landforms, lithological and structural control on drainage pattern (Pati et al. 2006, 2008; Pareta and Pareta 2011; Prakash et al. 2016, 2017; Panda et al. 2019; Bhatt et al. 2017, 2020). The morphometric parameters also explore the status of erosion-prone areas, potential of surface and groundwater resources (Huang and Niemann 2006; Aparna et al. 2015). The geological and geomorphological studies based on remote sensing and GIS

are playing significant roles in understanding the landform processes and physical and erosional properties of soil (Horton 1945; Strahler 1952; 1964; Pareta and Pareta 2011; Prakash et al. 2016, 2019; Bhatt et al. 2017, 2020).

The morphometric analysis of Sindh basin and its sub-watersheds would be more significant in planning the strategies for conservation of soil and water resources. The lineament analysis would be significant in understanding the tectonic influence and structural control on drainage.

2 Study Area

Sindh a major tributary of Yamuna River originates from Malva plateau of Vidhisha district of Madhya Pradesh in India and is 470 km in length (Figs. 1 and 2a). Its total catchment area is spreading in 26699 square km. It covers 461 km in Madhya Pradesh and 9 kilometer in Uttar Pradesh. Geologically the study area consists of Bundelkhand granitoids, sedimentaries of Gwalior basin. The detailed geology of the region studied by several workers (Bhatt and Hussain 2008, 2012; Bhatt and Mahmood 2008, 2012; Bhatt and Gupta 2014; Bhatt et al. 2011; Bhatt 2014, 2020; Singh

and Slabunov 2015; Singh et al. 2021a, b). Sindh is flowing north-northeast through the districts of Guna, Ashoknagar, Shivpuri, Datia, Gwalior and Bhind in Madhya Pradesh to join the Yamuna River in Jalaun district, Uttar Pradesh, just after the confluence of the Chambal River with the Yamuna River. It is lying between 21°17' N to 26°36' N latitude and 74°02' E to 82°26' E longitude (Fig. 1). Important tributaries (subwatersheds) of Sindh are Pahuj, Parbati, Mahuar, Kunwari and Vaishali. The basin receives maximum precipitation from June to September.

Pahuj another subwatershed of Sindh is flowing through granitic terrain of Jhansi district and meets to Sindh in Jalaun district. It is also known as Puspavati and is flowing in northeast direction. It lies between 25°18'30" and 25°31'27" North latitude and 78°17'33"–78°33'22" East longitude in Central India. It is 175 km in length and occupies 4258.40 sq km area. A small river having small course and dried during summer season is known as Mahuar. It is also known as Samoha river and is passing through Karera wildlife sanctuary. It is forming small subwatershed of Sindh. Kunwari, locally called Kwari a tributary of Sindh is flowing through Bhind and Morena districts of Madhya Pradesh. Kailaras, Sheopur, Morena and Bijeypur are its small tributaries.

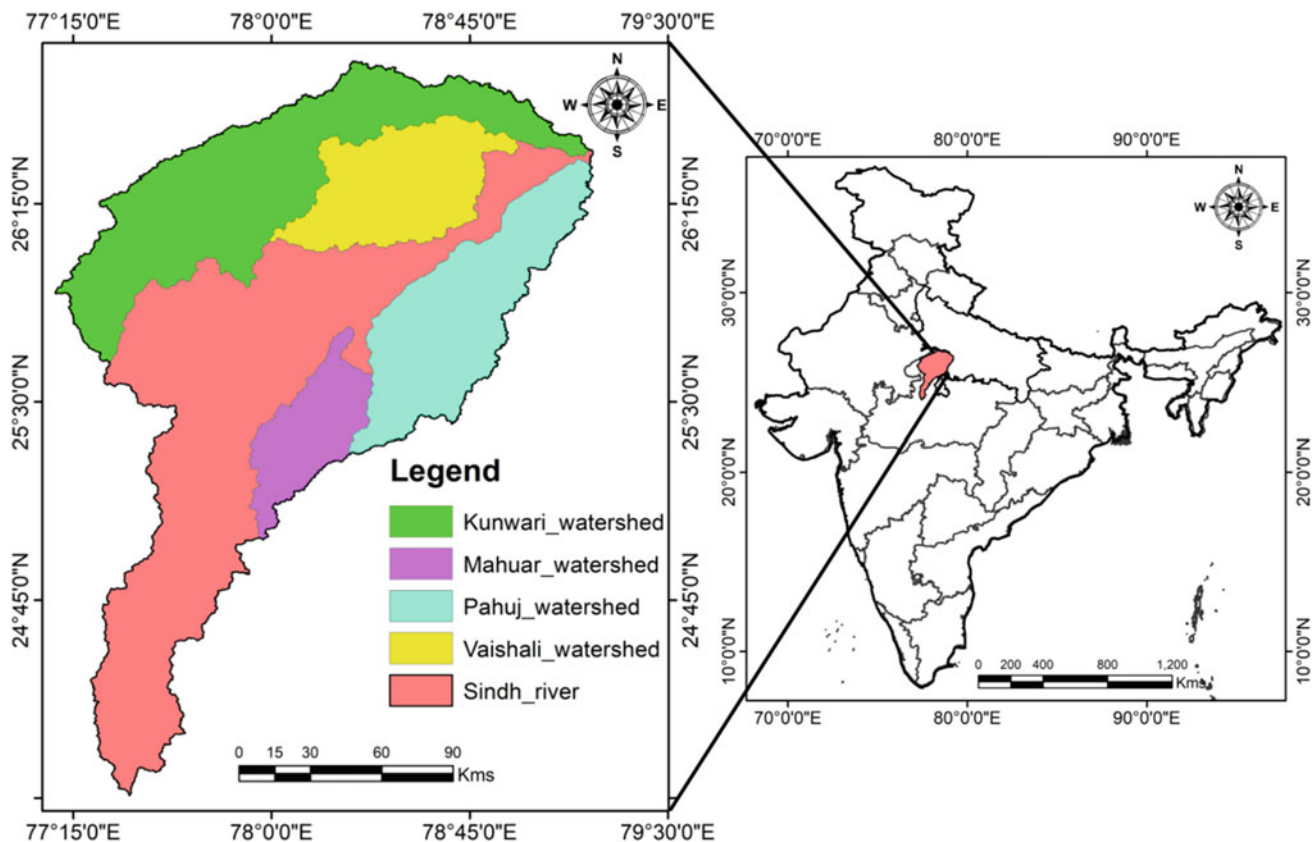


Fig. 1 Location map of Sindh and its subwatersheds

3 Methodology

In the present work, the remotely sensed SRTM and DEM data with capture resolution of 3 arc second and pixel resolution of 30 m were used to extract the drainage, density, contour, aspect and other maps (Figs. 2, 3, 4, 5 and 6). The DEM data were mosaic to subset the study region and the drainage map was extracted from the DEM data. The map was projected into proper coordinate system and WGS 1984 UTM Zone 44 N was used as appropriate tools in Arc Toolbox. The ArcGIS software was used to determine the length, area of the subwatershed and main watershed and stream order has been found out using the system, and the Arc Hydro tool in ArcGIS-10 software.

4 Results and Discussion

4.1 Morphometric Analysis

4.1.1 Linear Aspects

Linear parameters are one-directional character revealing the stream order, stream number, stream length, stream number ratio and collection of segments (Horton 1945; Strahler 1957). Based on Strahler's method the stream order was classified. Each rill or gully generated first is designated as first order stream. When two first order streams meet then the second order stream is developed. Similarly, when two similar order streams confluence then the higher order streams are formed. Eighth orders of streams were identified in the Sindh basin (Fig. 2a) and seventh in Kunwari (Fig. 3a), fifth in Mahuar (Fig. 4a), sixth in Vaisali subwatershed (Fig. 5a) and sixth order of streams in Pahuj subwatersheds were validated (Fig. 6a). The drainage, density, contour, aspect and slope maps were extracted from the DEM (Figs. 2b–d, 3b–d, 4b–d, 5b–d and 6b–d). The total number of streams are found 11,003. Out of which 8493 belong to first order, 1955 to second order, 428 to third order, 93 to fourth order, 20 to fifth order, 11 to sixth order, 2 to seventh order and one to eighth order. The smaller streams are more prominent in steeper slope while the longer streams are represented by gentle and flat terrains. The number of streams decreases as the order increases and the stream length is inversely proportional to the number of stream (Horton 1945). The maximum number of streams (8493) were recorded in low order of streams of Sindh and its subwatersheds. The basin and its subwatersheds are showing dendritic to subdendritic stream patterns and were evolved in a massive hard rock terrain with numerous stream flows. The mean stream length ratio computed for Sindh and its subwatershed varies from 1.90 to 2.74 (Table 1). The bifurcation ratio is defined as the ratio of number of streams of a given order (N_u) to the number of streams to next higher

order (Strahler 1964). The values of bifurcation ratio computed for Sindh basin and its subwatershed are given in Table 1. Its value varies minimum of 2 for flat or rolling drainage basins and 3–4 in mountainous or highly dissected drainage basins (Horton 1945). The bifurcation ratio computed for Sindh is ranging from 1.81 to 5.50 and for its subwatersheds varies from 2.00 to 9.00 (Table 1). Mean bifurcation ratio varies from 3.85 to 5.66 (Table 1). This infers that the basin was evolved in homogenous geological terrain and is influenced by geological structures.

4.1.2 Areal Parameters

The two-dimensional properties of a basin are discussed under areal parameters. The total basin area is spreading in 27,820 square kilometer and the perimeter of a basin is 1394.22 km. Horton (1945) and Strahler (1964) explained drainage density as the sum of stream lengths per unit area or it is an expression of closeness or spacing of channels. The density can be classified into five types (Smith 1950); extremely low (0–1), low (1–2), moderate (2–4), moderately high (4–6) and high (>6) density. The high density is related to fine texture with impermeable soil, sparse vegetation and high relief showing high run off and high potential of erosion (Horton 1945; Strahler 1964). Contrary to this the low density representing coarse texture is indicating occurrence of permeable soil with thick vegetation cover and low relief (less prone to erosion activity) in the basin. The value of density calculated for Sindh and its subwatersheds is ranging from 0.76 to 1.10 (Table 1; Figs. 2c, 3c, 4c, 5c and 6c). It infers that the basin is consisting of coarse permeable soil with, thick vegetation and is showing gentle slope less susceptible to erosion. Horton (1945) defined stream frequency as the number of streams per unit area in a basin or it is a ratio of total number of streams (N_u) in a basin. It can be classified as low (0–5 km⁻²), moderate (5–10 km⁻²), moderately high (10–15 km⁻²), high (15–20 km⁻²) and very high (20–25 km⁻²) by Horton (1945). The stream frequency (F_s) calculated for Sindh and its subwatersheds varies from 0.39 to 1.39. It is indicative of occurrence of permeable soil and dense vegetation cover in the basin.

The elongation ratio is defined as the ratio of diameter of a circle having the same area as of the basin and maximum basin length (Schumm 1956). Four categories of elongation ratio are found: elongated (0–0.7), less elongated (0.7–0.8), oval (0.8–0.9) and circular (>0.9). The value of elongation ratio for Sindh and its subwatersheds ranges from 0.45 to 0.62 (Table 1). It implies that the Sindh basin and its subwatersheds are elongated with moderate relief and are showing low vulnerability to erosion. The circulatory ratio refers to the ratio of watershed area (A) to the area of a circle having the same circumference as the perimeter of the watershed. Its value ranges from 0 to 1 it is influenced by geological structures, stream frequency, stream length,

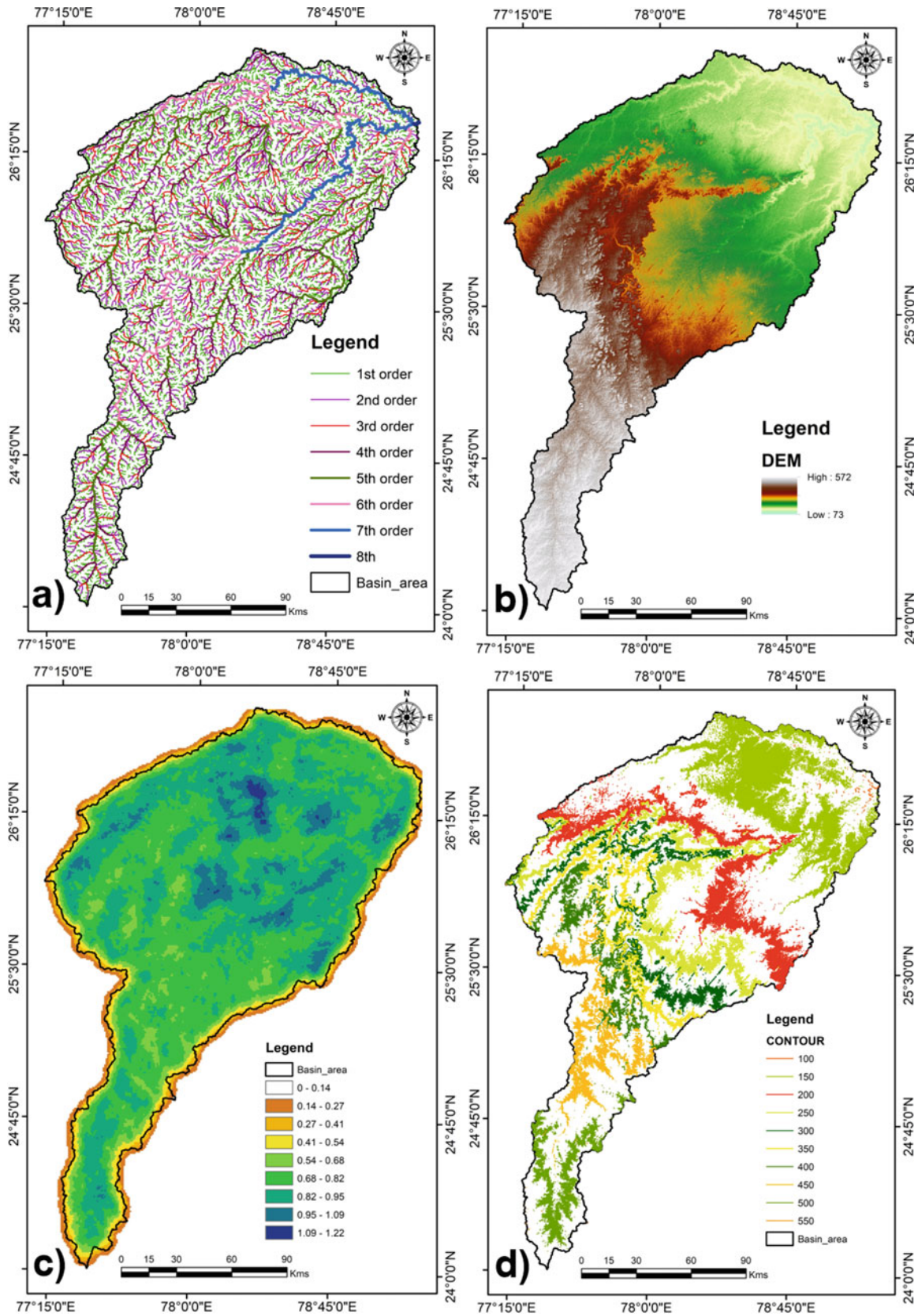


Fig. 2 a Drainage map, b DEM map, c Density map and d Contour maps of Sindh basin

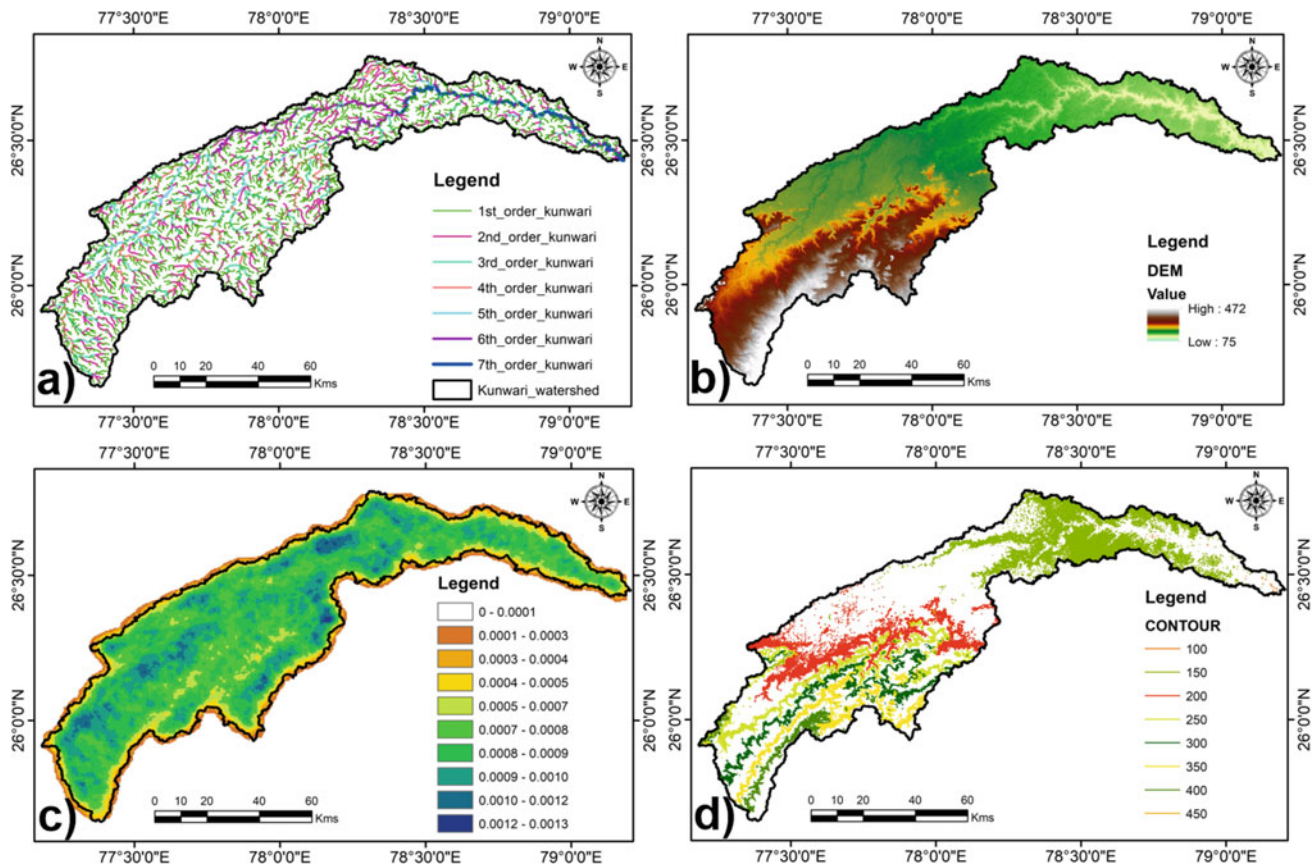


Fig. 3 a Drainage map, b DEM map, c Density map and d Contour map of Kunwari subwatershed

climate land cover, relief and slope of a watershed (Miller 1953; Strahler 1964). It also indicates the young, mature and old maturity level of the geomorphic cycle (Magesh et al. 2011). The circulatory ratio of Sindh watershed is computed 0.18. It is indicative of youth to mature stage of watershed development.

The shape of the watershed is represented by form factor (Horton 1945). It is a ratio of watershed area and square of total watershed length (Horton 1945). The high values of form factor (>0.78) would always have circular basin with high peak flows for shorter duration whereas the low values (<0.45) form factor would have elongated basin with low peak flows for longer duration. The value of form factor for Sindh and its subwatersheds varying from 0.16 to 0.30 (Table 1) indicates that the basins are elongated and show low peak flow of longer duration.

4.1.3 Relief Parameters

The relief parameters are three-dimensional characters of a basin and can be expressed in terms of area, volume and altitude of a watershed (Sahu et al. 2016). Basin relief is the difference in height between the highest and lowest points of the watershed (Hadley and Schumm 1961). It is a parameter that determines the stream gradient and influences flood

pattern and volume of sediments that can be transported (Hadley and Schumm 1961). The minimum elevation in Sindh basin is 73 m and the maximum height is 572 m above sea level. The relief ratio has direct relation with erosion potential of a basin. The value of relief ratio computed for Sindh basin and its subwatersheds (Table 1) implies that the low erosion risk is in the gentle slopes of granitic and Vindhyan hills.

Ruggedness (R_s) is defined as the product of basin relief and drainage density (Strahler 1958). It has direct relationship with structural complications and erosion potential of a basin since it joins the gradient and its length (Pareta and Pareta 2011; Bhatt et al. 2020). The ruggedness value is ranging from zero to one. The relatively more rugged terrain shows one ruggedness value. Whereas the smoother terrain shows less than one or zero ruggedness value. If the value of drainage density and relief are high then the value of ruggedness becomes higher. It indicates that the slope is not only steeper, but it is long also (Strahler 1958). Farhan et al. (2015) has given the four categories of ruggedness value: subdued morphology (<0.1), slight morphology (0.1–0.4), moderate morphology (0.4–0.7) and sharp morphology (0.7–1.0) and high morphology (>1.0) refers to high erosion-prone area. The ruggedness value of Sindh basin and

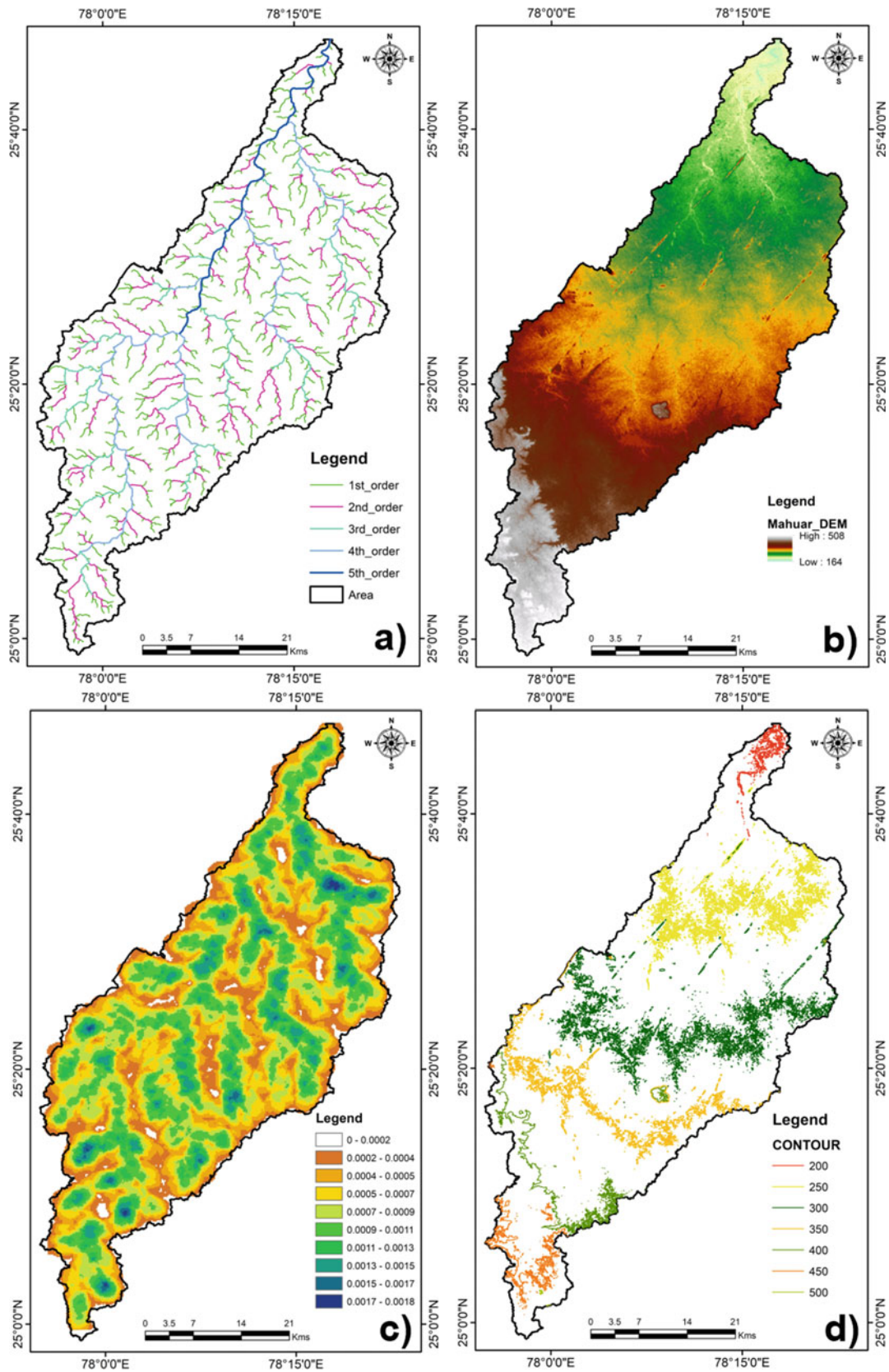


Fig. 4 a Drainage map, b DEM map, c Density map and d Contour map of Mahuar subwatershed

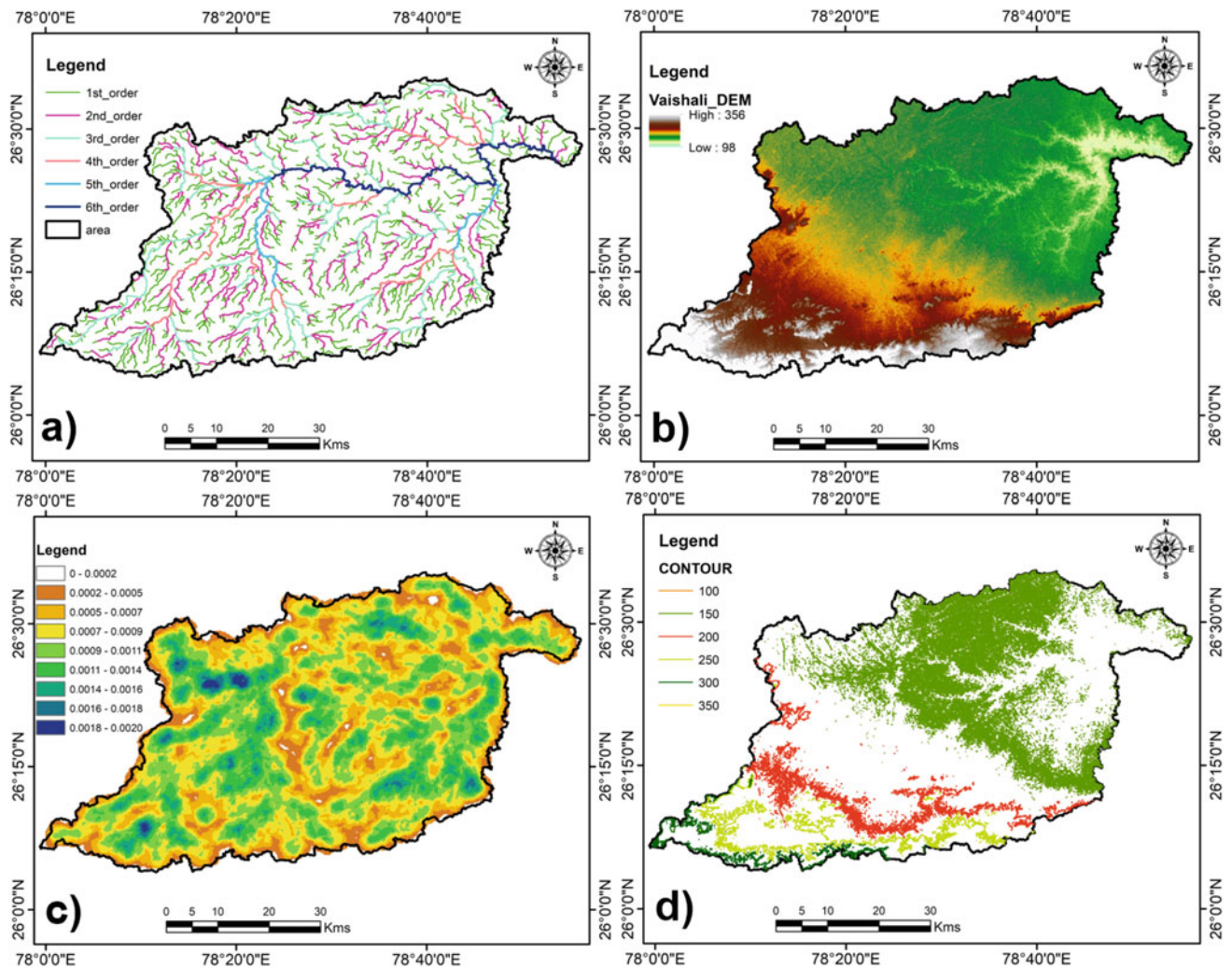


Fig. 5 a Drainage map, b DEM map, c Density map and d Contour map of Vaisali subwatershed

its subwatershed varies from 0.26 to 0.41 (Table 1). It indicates that Sindh watershed has smoother terrain and has low potential of erosion. It infers that the Sindh is slightly rugged and less prone to erosion and sediment transport.

4.2 Morphotectonic Parameters

4.2.1 Drainage Pattern

The characteristic of streams can be used as indicators of underlying geological structures. Stream incisions, diversions and drainage network give strong evidence to understand geological and structural history of the area and the properties of streams are very important for the study landform processes (Strahler 2002). The dendritic to subdendritic drainage pattern is shown by the Sindh watershed and its all subwatersheds (Figs. 2a, 3a, 4a, 5a and 6a). The drainage orientations of Sindh River and its subwatersheds are shown

by polymodal distribution Figs 7, 8, 9, 10 and 11. The NNE-SSW (Figs. 7b, e, 8a, d, e, 9d, e, 10c-f and 11b, c, e) and NNW-SSE trends (Figs. 7c, d, 8c, d, 9a, c, d, e, g and 11d) of streams are highly conspicuous.

The first and second order streams marked by rills and gullies are showing variable trends. The dominant WNW-ESE (Figs. 7a, 8a, g, h, 9d, 10a, g and 11a, g, i) and NW-SE (Figs. 7a, f, 8h, 9d, 10a, g, and 11a, i) trends were noticed in first order streams of Mahuar, Kunwari, Vaishali and Pahuj subwatersheds of the Sindh watershed. The maximum of rose diagrams of third and fourth order streams of all subwatersheds trends in NNW-SSE (Figs. 7c, d, 8c, d, 9a, c, d, e, g and 11d) and WNW-ESE directions (Figs. 7a, 8a, g, h, 9d, 10a, g, 11a, g, i). The azimuthal trend of higher order streams (V and VI order) showing straight and curved courses are trending in NE-SW (Figs. 7f, 9b, 10e, g and 11e), ENE-WSW (Fig. 9d) and NNE-SSW (Figs. 7b, e, 8a, d, e, 9d, e, 10c-f and 11b, c, e) directions.

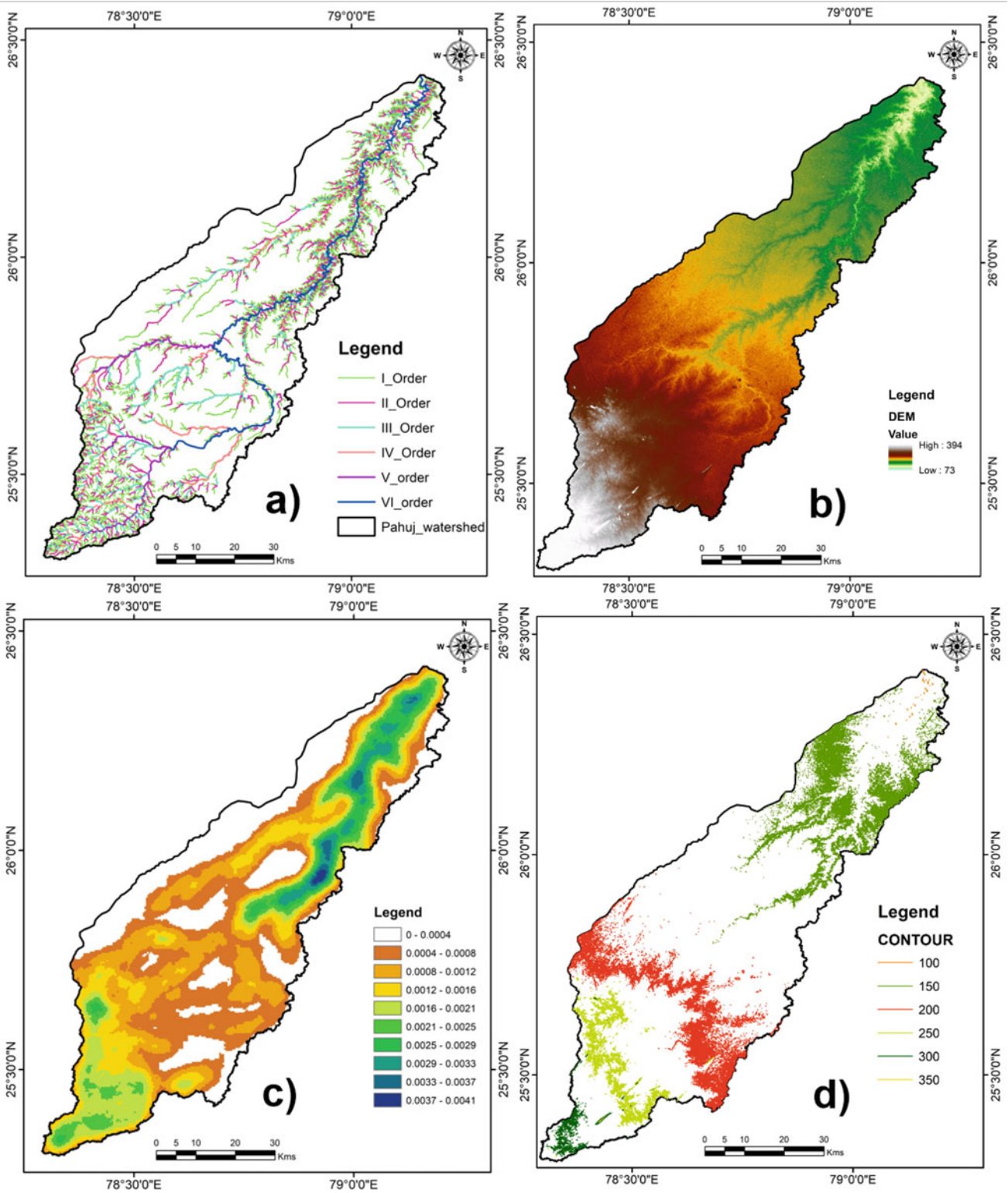


Fig. 6 a Drainage map, b DEM map, c Density map and d Contour map of Pahuj subwatershed

Table 1 Linear, areal and relief parameters of Sindh basin and its subwatersheds

S. no	Parameters	Sindh river	Mahuar river	Kunwari river	Vaisali river	Pahuj river
<i>Linear parameters</i>						
(1)	Stream order (S_u)	1–8	1–5	1–7	1–6	1–6
(2)	Stream length (L_u) (Km)	22,754.9	1374.91	5614.09	2754.11	4700.78
(3)	Total number first order streams (N_1)	8586	567	2043	923	4555
(4)	Total number of streams (N_u)	11,091	735	2629	1203	5939
(5)	Mean stream length ratio (L_{urm})	1.996	2.74	2.21	2.55	1.90
(6)	Weighted mean stream length ratio (L_{uwm})	2.20	2.52	2.19	2.25	2.18
(7)	Fitness ratio (Rf)	0.28	0.20	0.16	0.3	0.37
(8)	Maximum basin length (Lb) (Km)	314.46	95.00	208.36	102.32	150.49
(9)	Basin perimeter (P) (Km)	1394.22	328.70	908.46	421.74	482.40
(10)	Bifurcation ratio (R_b)	1.81–5.5	4.12–5.44	2.0–4.49	3.00–4.98	4.00–9.00
(11)	Mean bifurcation ratio (R_{bm})	3.92	4.89	3.85	3.98	5.66
(12)	Weighted mean bifurcation ratio (R_{bwm})	4.39	4.39	4.51	4.31	4.34
(13)	Texture ratio (R_t)	6.16	1.72	2.25	2.19	9.44
<i>Areal parameters</i>						
(14)	Basin area (A)	27,819.99	1816.41	6775.75	3123.61	4258.40
(15)	Relative perimeter (P_r)	19.95	5.53	7.46	7.41	8.83
(16)	Stream frequency (F_s)	0.40	0.40	0.39	0.39	1.39
(17)	Drainage density (D_d)	0.82	0.76	0.83	0.88	1.10
(18)	Drainage intensity (D_i)	0.49	0.53	0.47	0.44	1.26
(19)	Infiltration number (If)	0.33	0.31	0.32	0.34	1.54
(20)	Elongation ratio (R_e)	0.60	0.51	0.45	0.62	0.49
(21)	Circularity ratio (R_c)	0.18	0.21	0.10	0.22	0.23
(22)	Form factor (F_f)	0.28	0.20	0.16	0.30	0.19
(23)	Length of overland flow (L_g)	0.61	0.66	0.60	0.57	0.45
(24)	Constant of channel maintenance (C)	1.22	1.32	1.21	1.13	0.91
(25)	Drainage texture (D_t)	7.95	2.24	2.89	2.85	12.31
<i>Relief parameters</i>						
(26)	Minimum height of basin (z) (m)	73	164	75	98	73
(27)	Maximum height of basin (Z) (m)	572	508	472	356	394
(28)	Total basin relief (H) (m)	499	344	397	258	321
(29)	Contour interval (C_{in}) (m)	50	50	50	50	50
(30)	Relief ratio (R_n)	1.59	3.62	1.91	2.52	2.13
(31)	Ruggedness number (R_n)	0.41	0.26	0.33	0.23	0.35

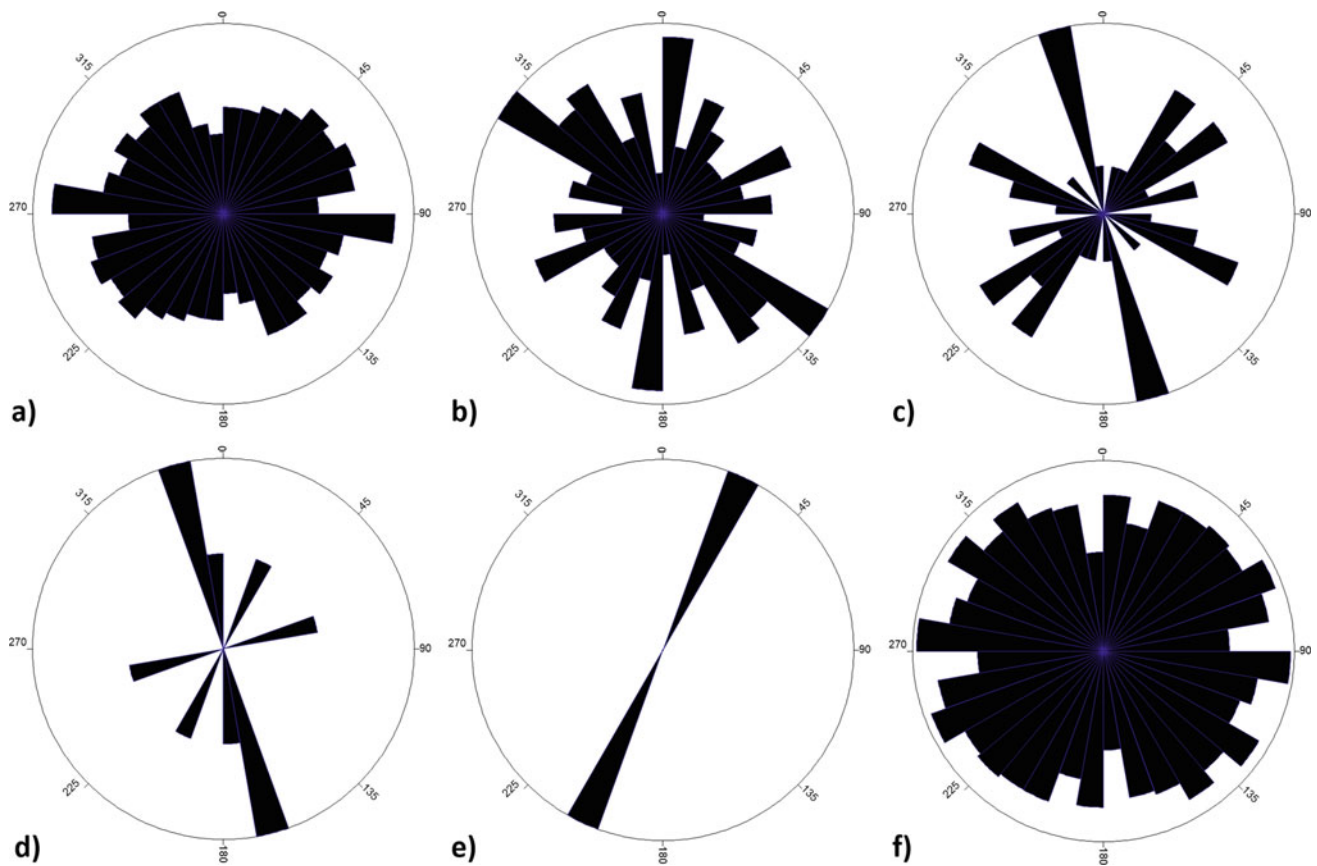


Fig. 7 Rose diagrams showing orientation of first (a), second (b) third (c), fourth (d), fifth stream order (e) and mean of stream orders (f) in Mahuar subwatershed

4.2.2 Orientation of Lineaments

The structural and morphological features and intensity of deformation on earth's surface are represented by important lineaments (Nur 1982). The lineament map of the Sindh basin and its subwatersheds was prepared by using SRTM and DEM Geomatica software (Fig. 12). The lineaments were classified based on orientations of structural and morphological features, drainage pattern, textural contrast and tonal differences. The four sets of major lineaments showing NE-SW, NW-SE, WNW-ESE and NNW-SSE were commonly observed in this study (Figs. 12 and 13). The orientations of lineaments extracted for each subwatershed of Sindh basin are represented by rose diagrams (Fig. 13). The NE-SW trending major lineaments following the trend of major tectonic unit in the study area are dominant in all subwatersheds of the basin (Fig. 13a, b, d, e). The NW-SE lineaments (other major linear features) were also observed in the basin (Fig. 13c).

4.2.3 Relationship Between Orientations of Lineaments and Drainage Pattern

The tectonic processes, climatic perturbations and their interactions at long time scales exert primary controls on the trajectory of landscape evolution, which defines the physical appearance of landscape (Bishop 2007). Each river basin in India evolved in different geological and tectonic history and developed in millions of years of time scale (Tangri 1992). The north flowing cratonic rivers are tectonically inactive and are represented by low relief granitic hills and reefs (Shukla et al. 2012; Jain et al. 2020). The Archean to Palaeoproterozoic gneissic and granitic terrain of Bundelkhand craton delineated by E-W and NE-SW shear zones are inherently controlled the drainage of these cratonic rivers (Bhatt et al. 2017, 2020; Bhatt 2020).

The NE-SW lineaments showing low frequency resemble the NE-SW trends of high order streams of subwatersheds of Sindh basin. The high frequency lineaments trending in WNW-ESE, NW-SE and NNW-ESE are following the

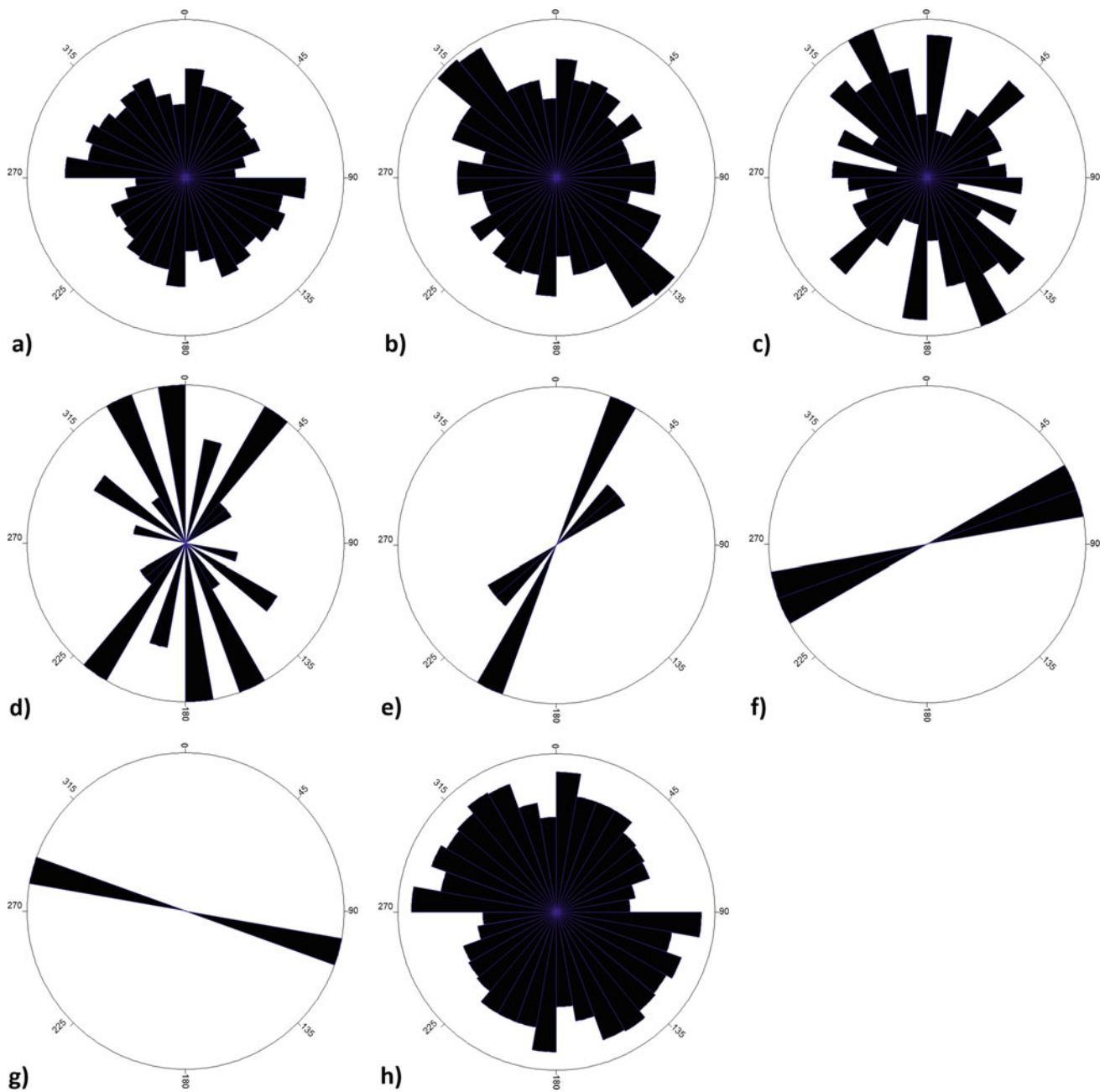


Fig. 8 Rose diagrams showing orientation of first (a), second (b) third (c), fourth (d), fifth (e), sixth (f), seventh stream order (g) and mean of stream orders (h) in Kunwari subwatershed

trends of low order streams (I, II and III order) of subwatersheds of the basin. The E-W trending lineaments are representing E-W crustal shear zones and the NE-SW and NW-SE lineaments are following the trends of quartz reefs and dykes respectively. The high density of lineaments represented by fractures, faults, foliations and bedrock structures are controlling the drainage and forming the passages to low order streams.

5 Conclusions

The morphometric analysis envisages that the elongated Sindh basin and its subwatersheds are showing impermeable to semi-permeable hard rock terrain in high elevated area and permeable soil in low lying area. The Sindh basin and its subwatersheds are significantly elongated and are more

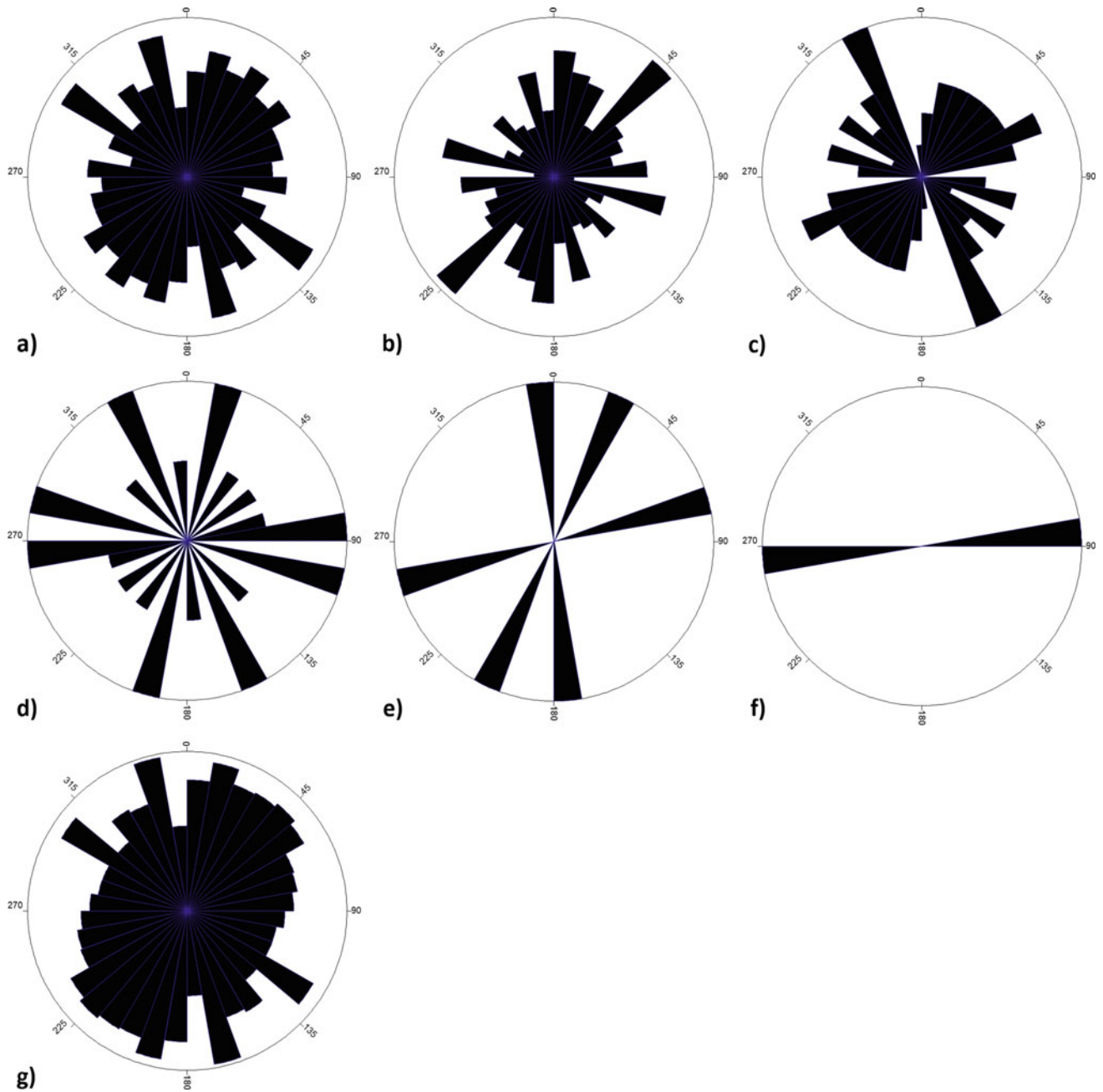


Fig. 9 Rose diagrams showing orientation of first (a), second (b) third (c), fourth (d), fifth (e), sixth (f), and mean of stream orders (g) in Vaishali subwatershed

susceptible to erosion and sediment transport in high elevated area. The low-density E-W, NE-SW and NW-SE lineaments are controlling the high order streams in the area.

The high density of lineaments represented by fractures, faults, foliations and bedrock structures are controlling the drainage of low order streams.

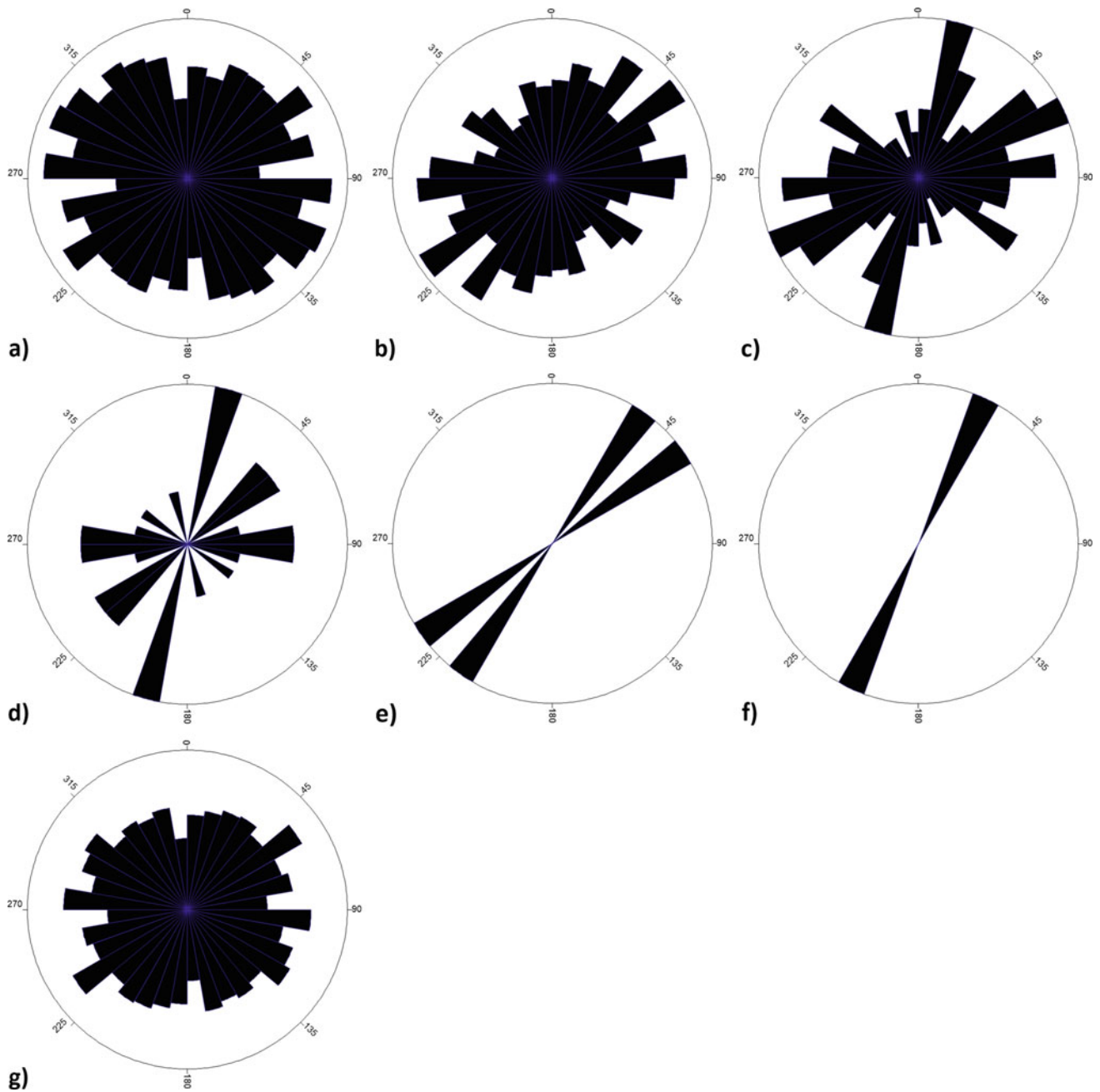


Fig. 10 Rose diagrams showing orientation of first (a), second (b) third (c), fourth (d), fifth (e), sixth (f) and mean of stream orders (g) in Pahuj subwatershed

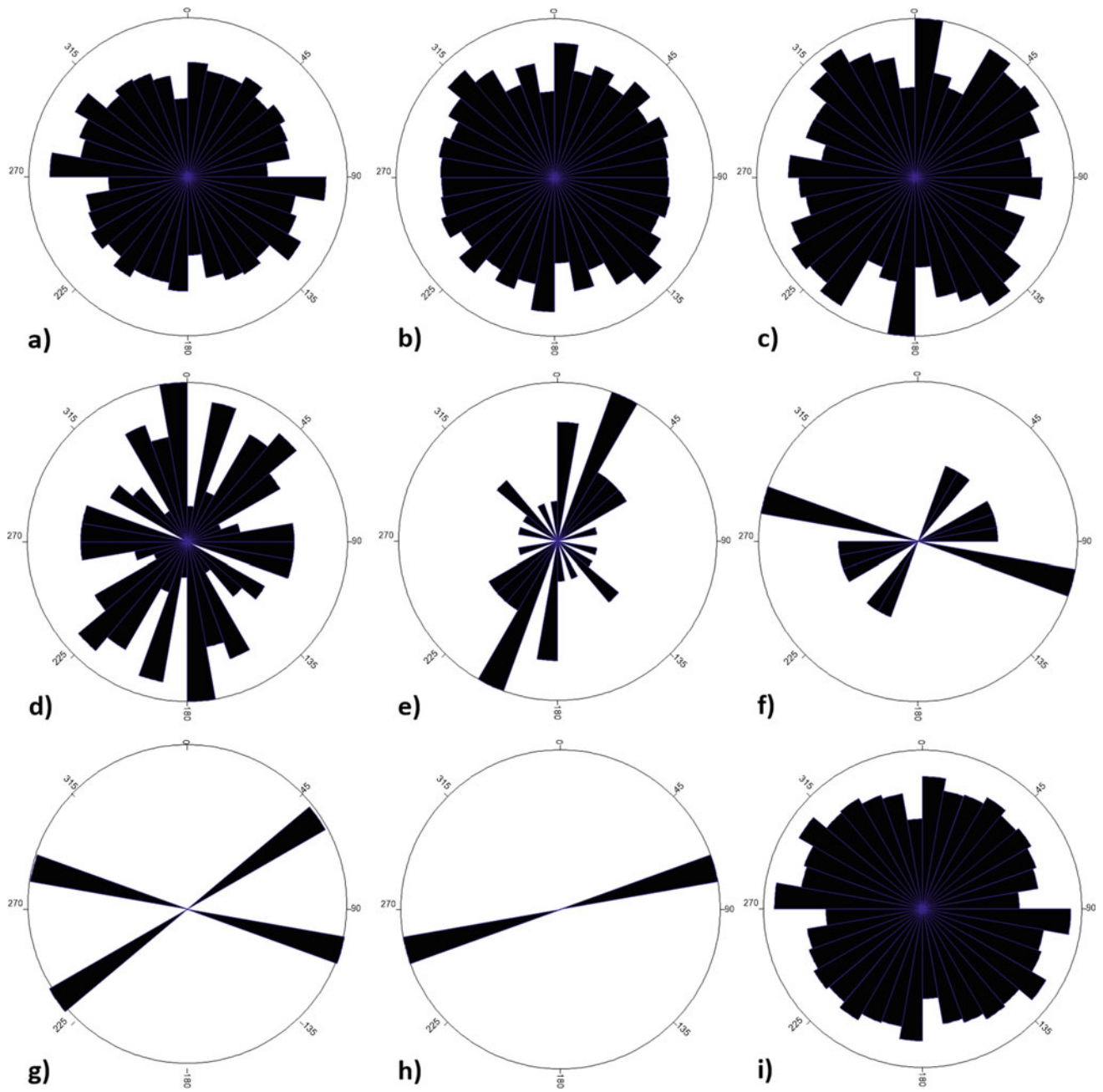
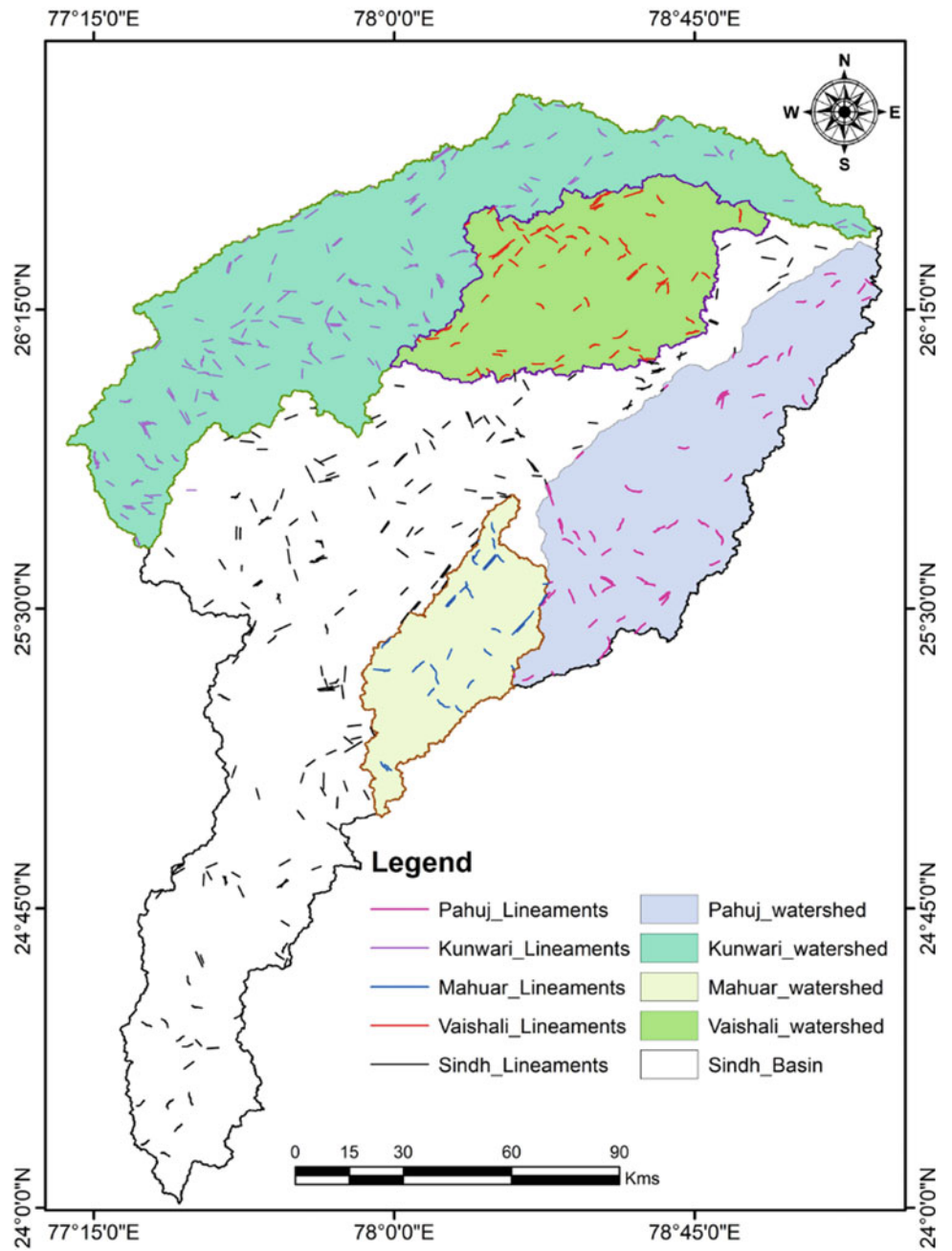


Fig. 11 Rose diagrams showing orientation of first (a), second (b) third (c), fourth (d), fifth (e), sixth (f), seventh (g), eighth stream order (h) and mean of stream orders (i) in Sindh basin

Fig. 12 Lineament map of Sindh basin and its subwatersheds



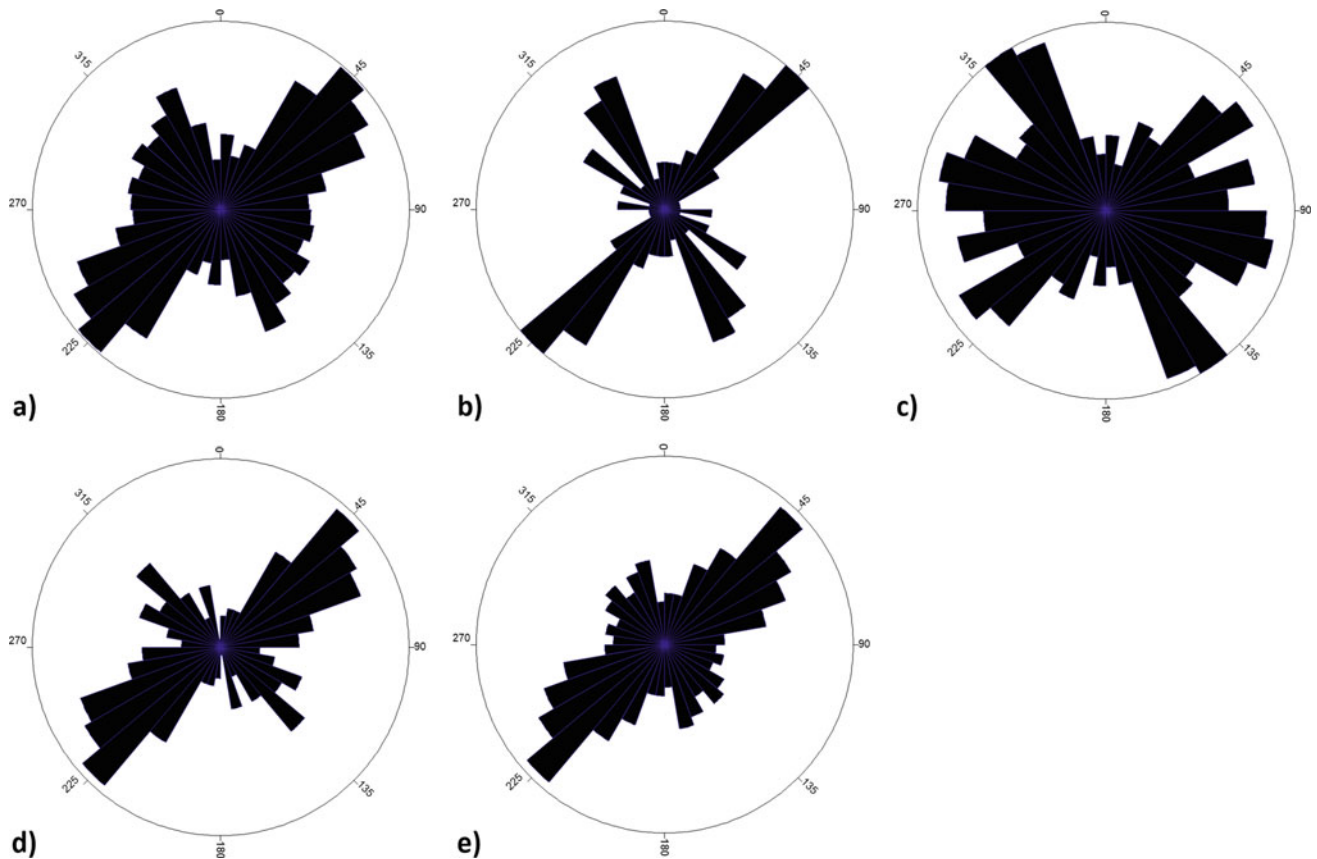


Fig. 13 Rose diagram showing orientation of lineaments; **a** Sindh basin, **b** Mahuar watershed, **c** Kunwari watershed, **d** Vaishali watershed and **e** Pahuj watershed

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