A GIS-based Approach for Morphometric Analysis of Jamini Basin and Its Subwatersheds: Implication for Conservation of Soil and Water Resources

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Abstract

Jamini a tributary of Betwa River has Jamrar, Onri, Sajnam, Shanzad and Baragl five subwatersheds. The quantitative morphometric analysis of its subwatersheds was carried out by using advanced techniques of remote sensing and GIS. The linear, areal and relief parameters along with hypsometric values were generated for each subwatershed of Jamini basin. The remotely sensed Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) data with a capture resolution of 3.0 arc second and pixel resolution of 30 m were used to extract the drainage map, density, contour, aspect and other maps. The mean bifurcation ratio (3.79 to 5.04) of Jamini and its all subwatersheds indicate that the drainage is structurally controlled. The Rho coefficient values reveal that the higher hydrologic storage during the flood and a decrease in the erosion during elevated discharge are observed in the basin. The drainage density (1.0 to 1.04) indicates that the basin is impermeable and shows low groundwater storage capacity in hard rock granitic terrain. The form factor (0.18 to 0.49), elongation and circulatory ratios indicate that the Jamini basin and subwatersheds are significantly elongated and show low peak flow of longer duration. The values of Ruggedness and Melton ruggedness number infer that the basin is slightly rugged and less prone to erosion and sediment transport. The S-shaped hypsometric curves show that the basin is susceptible to moderate erosion and the hypsometric index values (0.49 to 0.50) imply that the basin has mature geomorphic terrain with moderately eroded landscapes.

1 Introduction

Morphometric parameters reveal the quantitative evaluation of shape and size of landforms and characteristics of the basin (Horton 1945; Melton 1958; Strahler 1964; Miller 1953; Pareta and Pareta, 2011; Prakash et al. 2016, 2019; Bhatt et al. 2017, 2020; Bhatt 2020). It can be defined as an indicator of landform structure and hydrologic processes, erosional and physical properties of soil (Horton 1932; 1945; Strahler 1964; Smith 1950). Morphometric parameters determine the lithological and structural control on drainage and characteristics of fluvial landscapes (Pati et al. 2006; 2008; Prakash et al. 2016; 2017; Pareta and Pareta 2011; Bhatt et al. 2017, 2020). The findings of morphometric analysis give information about hydrogeologic and erosion-prone area and characters of surface and groundwater potentials of a watershed (Aparna et al. 2015).

The morphotectonic and morphometric studies of tributaries of the Ganga river have been done by several researchers (Tangri 1992; Shukla et al. 2012). Contrary to this the morphometric and morphotectonic parameters of most of the tributaries of Yamuna particularly coming from Bundelkhand craton have not been studied in detail except by few workers (Prakash et al. 2016; 2017; Pareta and Pareta 2011; 2012; Bhatt et al. 2017, 2020; Bhatt, 2020; Panda et al. 2019). Therefore, in present work, the morphometric and hypsometric analysis has been carried out to explore the

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status of water and soil resources in the subwatersheds of Jamini basin.

The natural resources are playing a significant role in the economic and social development of all countries and their overexploitation is causing a threat to the economic development of all developing countries and are unbalancing the ecosystems (Bhatt 2020). The productivity of agricultural cropland is depending on the presence of soil water and resources. Despite rich in natural resources and having good river network Bundelkhand is facing severe problems with water and land resources. Due to a small cropped area (35 to 40%) and low rainfall, it belongs to a hot spot of dry land (Bhatt 2020). Due to drought and low agricultural productivity, it falls under privilege region and people are facing starvation and famine. Therefore, there is a need to protect these resources and the implications of GIS and ASTER/SRTM-based studies are used to monitor soil erosion. The morphometric and hypsometric data of subwatersheds of Jamini River would be useful input to plan the conservation of soil and water resources.

2 Study Area

Jamini a tributary of Betwa River occupies 4584.42 sq km area and is 201 km in length. It is originating from Vindhyan mountain in Sagar district of Madhya Pradesh, India and is flowing SW to NE direction. It joins Betwa near Orcha, Tikamgarh district of Madhya Pradesh. It has five subwatersheds viz. Shahjad, Sajnam, Baragl, Onri and Jamrar and covers 4584.42 sq km area. Its basin lies between 24°4′36" N to 25°13′4" N latitude and 78°17′49" E to 78°56′23" E longitude (Fig. 1). Jamini basin is a rugged granitic terrain showing undulating topography with average elevation. The semiarid climatic conditions and erratic rainfall are very common in this study area.

Its subwatershed Shahjad emerges from Dushai village and meets Jamni near Hazaria village of Lalitpur district (Fig. 1). The watershed covers 1111.49 sq km area and lies between 24°25′41``N to 25°2′14'N latitude and 78°17′49``E to 78°38′40'E longitude. Sajnam another subwatershed occupying 988.72 sq km area originates in SW of Lalitpur and meets Jamni at Chandawali (Lalitpur, U.P.). Baragl covering 320.80 sq km area is meeting to Jamini near Didora of Tikamgarh district. It lies between 24°55′15``N to 25°9′21'N latitude and 78°38′37``E to 78°53′21'E longitude. Onri emerges in the northeast of Madhya Pradesh and has confluence with Jamni near Tikamgarh. It is occupying 320.80 sq km area and is lying between 24°55′15``N to 25°9′21'N latitude and 78°38′37``E to 78°53′21'E longitude. Jamrar a subwatershed of Jamini originating in the southern part of Lalitpur is meeting to Jamini near a junction located between Sujanpura and Minora villages of Tikamgarh district, M.P. (Fig. 1).
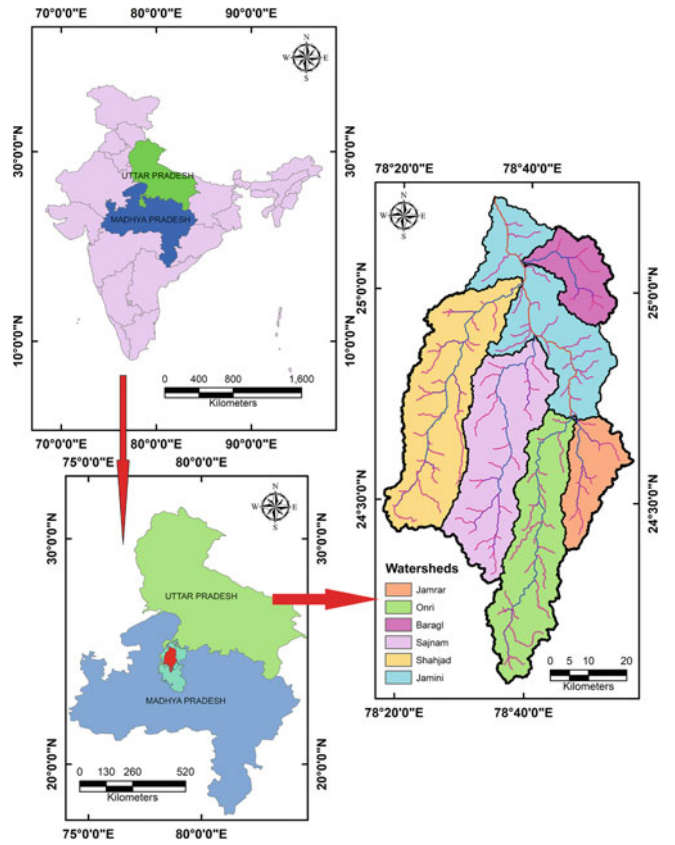
3 Geology of the Study Area

The Jamini basin mainly consists of Bundelkhand granites, Vindhyan Supergroup, Bijawar and Deccan Traps. The larger part of the basin is covered by Bundelkhand granites in the north. The southeastern borders of the basin area are surrounded by Bijawar Group of rocks. The Vinhyans are exposed in the southeastern and southwestern margins whereas the southern boundaries of the basin are occupied by Deccan Traps (Fig. 2).

Bundelkhand craton comprises three major groups of rocks. The oldest Bundelkhand Gneissic Complex consists of Tonalite Trondhjemite granodiorite (TTG) gneisses and mafic gneisses (3.5–3.2 Ga). The Banded Iron Formation, Quartzites and metavolcanics are important rock unites of Bundelkhand Greenstone Complex. The various types of granitoids, quartz reefs and doleritic dykes belong to Bundelkhand Granitic Complex (2.6–2.0 Ga; Bhatt and Mahmood 2008, 2012; Bhatt et al. 2011, 2017; Bhatt and Gupta 2014; Bhatt 2014; Bhatt and Hussain 2008, 2012; Singh and Slabunov 2015; Singh et al. 2021). The coarse-grained porphyritic and medium-grained pink granite at places showing gneissic foliation belong to Bundelkhand Granitic Complex (Basu 1986; Bhatt and Mahmood 2012; Bhatt 2014; Pati et al. 1997, 2007).

Rewa Group belonging to upper Vindhyan Supergroup consists of Panna shale, Lower Rewa sandstone, Jhiri shale and Upper Rewa sandstone (Govindgarh and Dramnandganj sandstone). This group varying in thickness from 100 to 300 m is showing diamond-bearing conglomerate in its upper and lower boundaries. It consists of a series of shale and sandstone Formations and is containing Kimberlite-derived diamondiferous conglomerate. The medium to fine-grained iron pigmented arenaceous sandstone belonging to Upper Rewa sandstone Formation is characterized by planar, trough and herringbone cross stratification. The laminated shale, sandstone, flagstone, porcellanites and limestone overlying the Semri Group are important units of Kaimur Group of Upper Vindhyan (Fig. 2). A basal conglomerate containing pebbles of jasper is observed an important unit of Kaimur Group in Bundelkhand.

The Bijawar Group belonging to Middle Proterozoic Formations were deposited over the Bundelkhand craton along its southeastern (Hirapur and Sonarai Basins) and northwestern (Gwalior Basin) margins. The Bijawar Group consists of a succession of a basal conglomerate and quartzite overlain by hornstone breccia, limestone, phyllitic shales, red jaspers, and dioritic traps. Quartzites and sandstones, sometimes conglomeratic form the basal beds resting on gneisses and a siliceous limestone is found with the quartzites. These rocks are again well exposed along the

Fig.1 Location map of the study area

Fig. 2 Geological map of the study area
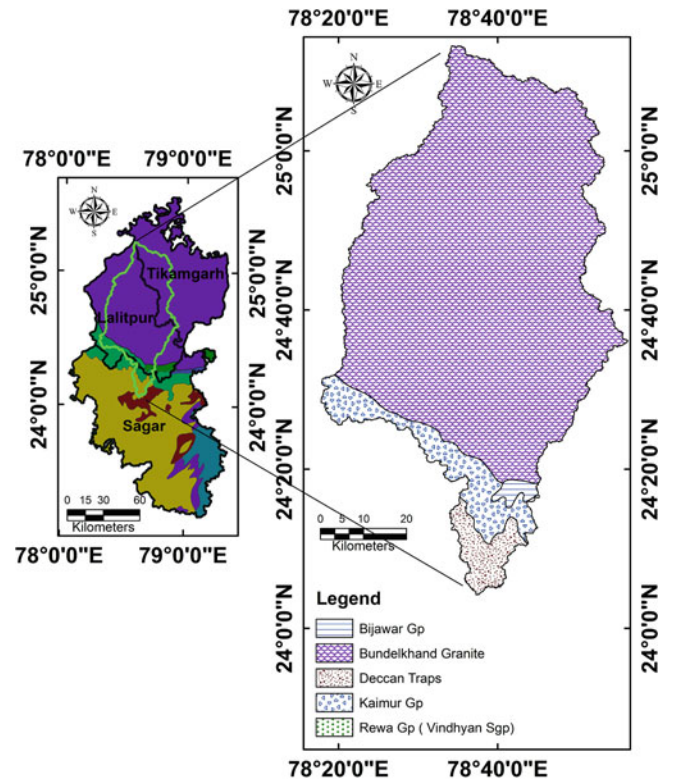
southeastern edges of the Vindhyan Syncline where they dip under the Semri Group under the Vindhyan Supergroup. The geological maps of Jamni basin show that the Deccan traps are dominant in the southern part of the basin, and it has a very irregular boundary with the underlying Vindhyan Formation (Fig. 2). The Deccan Traps exposed in peninsular India between 69°–79°E longitudes and 16°–22°N latitude comprises of one of the biggest volcanic provinces on the earth (Mahoney et al. 2002; Courtillot et al. 1988; Bose 1995; Ghosh et al. 2006).

4 Methodology

The morphometric analysis of the Jamni watershed was carried by using the remotely sensed Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model data with a capture resolution of 3.0 arc second and pixel resolution of 30 m. The SRTM Digital Elevation Model (DEM) was downloaded from USGS (United State Geological Survey) website. The base map was prepared to extract the drainage, density, contour, aspect and other maps.

Watershed and drainage network was analyzed using Horton's (1945) scheme while in-stream ordering Strahler (1964) methods were adopted. The basic parameters like length of the individual stream, basin area, and perimeter of the basin were extracted from the ArcGIS-10.3 geodatabase and further used for calculating morphometric parameters such as linear, areal, relief and tectonic aspects using various equations.

5 Results and Discussion

The mathematical evaluation of the area, altitude, volume, and slope, profiles of the land and basin characteristics are determined under morphometric analysis (Clark 1966). The various parameters of linear, areal and relief aspects were computed and the thematic maps of each watershed were prepared (Table 1 and Figs. 3, 4, 5, 4, 7, 8 and 9). The Jamini watershed is characterized by dendritic to sub dendritic drainage and is flowing from different elevation to different directions (Fig. 3a). The polymodal distribution is noticed in the orientation of drainage of Jamini basin. The NNW-SSE orientation is highly conspicuous (Fig. 4). The first, second and third lower-order streams are trending in NW-SE, E-W and NNW-SSE directions respectively (Fig. 4a, b and c). The NNW-SSE, NNE-SSW and NW-SE trends are shown by fourth, fifth and sixth order of streams respectively (Fig. 4 d, e and f). The fifth to sixth order of streams in Jamini watershed and its subwatersheds (Jamrar, Shahzad, Sajnam, Onri and Buragi) were validated in the study area (Figs. 3a, 5a, 6a, 7a, 8a and 9a).

5.1 Linear Parameters

All linear, areal and relief parameters of Jamini watershed and its subwatersheds were analyzed and are shown in Table 1. The nature of surface runoff can be expressed by stream length. The streams having smaller length are characterized by steeper slope while the streams of longer length are indicative of gentle slope and flat topography. According to Horton's law (1945), the total length of the stream segment is observed maximum in the first order and it decreases as the stream order increases. The relationship between watershed area and stream length is characterized by the predominance of headward erosion for the drainage network development and expansion (Hack 1957). The maximum stream length (2339.5 km) is computed for first order and minimum (77.21 km) for sixth-order streams of Jamini watershed (Table 1). Similarly, the maximum length for the first order and minimum length for the highest order of each subwatershed (Sajnam, Shajad and Onri subwatersheds) was calculated (Table 1). The presence of a large number of smaller stream lengths in Jamini watershed and its subwatersheds implies that the terrain is consisting of impermeable rock formations.

The maximum stream length ratio observed in Onari (4.34) and Shahjad (3.51) subwatershed of Jamini basin and minimum in Baragl (2.87) and Jamrar (2.06) subwatershed. It infers that the evolution of all streams of Jamini basin is controlled by lithology and geological structures. The ratio of a number of streams of a given order (Nu) to the number of streams to the next higher order is defined as the bifurcation ratio (Strahler 1964). It varies from 2.0 in flat or rolling drainage basins to 4.0 in mountainous or highly dissected drainage basins (Horton 1945). The bifurcation ratio ranging from 2.67 (Baragl) to 8.00 (Onri) and the mean bifurcation ratio varies from 3.79 to 5.04 in subwatersheds of Jamini basin (Table 1). It was observed that the bifurcation ratio and mean bifurcation ratio is more than 3 (Table 1). It reveals that the Jamini basin and its subwatersheds were developed in a lithologically and structurally controlled terrain. The Rho coefficient (ρ) values are ranging from 0.53 (Jamrar) to 0.69 (Shahjad) in subwatersheds of Jamini basin (Table 1) and it is computed 0.59 for Jamini basin. These values are indicating that the high drainage density is intended to increase higher hydrologic storage during the flood.

5.2 Areal Parameters

The drainage density, frequency, drainage texture, form factors, circulatory ratio and other parameters were discussed under this subheading. Drainage density is defined as the sum of stream lengths per unit area and is an expression of closeness or spacing of channels (Horton 1945 and Strahler 1964). The total area of Jamini basin is 4584.42 sq

Table 1 showing Linear, areal and relief parameters of Jamini and its subwatersheds (JW-Jamni watershed; SW1-Shahjad subwatershed; SW2-Sajnam subwatershed; SW3-Baragl subwatershed; SW4-Onri subwatershed; SW5-Jamrar subwatershed)

S.No	Parameters	JW	SW1	SW2	SW3	SW4	SW5
Linear Parameters							
(1)	Stream Order (Su)	1 to 6	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5
(2)	Stream Length (Lu), km	4586.41	1142.97	1006.51	327.40	913.75	358.52
(3)	Mean Stream Length Ratio (Lurm)	2.85	3.51	2.93	2.87	4.34	2.06
(4)	Weighted Mean Stream Length Ratio (Luwm)	2.45	2.61	2.49	2.33	2.89	2.16
(5)	Mean basin Width (Wb), km	53.61	15.52	15.77	12.59	12.48	10.34
(6)	Main Channel Length (Cl), km	169.69	99.16	85.24	39.16	92.51	43.93
(7)	Fitness ratio (Rf)	0.35	0.40	0.39	0.33	0.41	0.36
(8)	Wandering ratio (Rw)	1.98	1.38	1.36	1.54	1.32	1.29
(9)	Maximum Basin Length (Lb), km	85.52	71.60	62.71	25.47	70.09	33.97
(10)	Basin Perimeter (P), km	484.99	246.42	220.55	116.98	227.17	122.84
(11)	Bifurcation Ratio (Rb)	4.4–5.36	4.26–6.0	4.0–6.25	2.67–4.88	3.0–8.0	3.0–5.0
(12)	Mean Bifurcation Ratio (Rbm)	4.81	5.04	4.90	3.79	5.03	3.91
(13)	Weighted mean bifurcation ratio (Rbwm)	4.54	4.39	4.49	4.58	4.67	4.62
(14)	Rho coefficient (ρ)	0.59	0.69	0.59	0.76	0.86	0.53
(15)	Length area relation (Lar)	220.24	94.12	87.73	44.65	81.52	47.14
(16)	Lemniscate's (k)	1.59	4.61	3.98	2.02	5.62	3.29
(17)	Shape factor (Sf)	1.59	4.61	3.98	2.02	5.62	3.29
(18)	Texture ratio (Rt)	5.22	2.52	2.46	1.55	2.20	1.70
19)	Sinuosity, S (Higher Order)	1.27	1.26	1.33	1.51	1.32	1.24
Areal Parameters							
(1)	Basin Area (A), sq km	4584.42	1111.49	988.72	320.80	874.82	351.14
(2)	Relative Perimeter (P_r), km	9.45	4.51	4.48	2.74	3.85	2.86
(3)	Stream Frequency (Fs), km^{-2}	0.71	0.72	0.71	0.72	0.73	0.76
(4)	Drainage Density (Dd), km^{-1}	1.00	1.03	1.02	1.02	1.04	1.02
(5)	Drainage Intensity (Di), km^{-1}	0.71	0.69	0.69	0.71	0.70	0.74
(6)	Infiltration Number (If), km^{-3}	0.71	0.74	0.72	0.73	0.76	0.78
(7)	Elongation Ratio (Re)	0.89	0.52	0.56	0.79	0.48	0.62
(8)	Circularity Ratio (Rc)	0.24	0.23	0.26	0.29	0.21	0.29
(9)	Circularity Ration (Rcn), km	9.45	4.51	4.48	2.74	3.85	2.86
(10)	Compactness Ratio (Cc)	2.02	2.08	1.98	1.84	2.17	1.85
(11)	Form Factor (Ff)	0.63	0.22	0.25	0.49	0.18	0.30
(12)	Length of Overland Flow (Lg), km	0.5	0.48	0.49	0.49	0.48	0.49
(13)	Constant of Channel Maintenance (C), km	1.00	0.97	0.98	0.98	0.96	0.98
(14)	Drainage Texture (Rt), km^{-1}	6.69	3.27	3.17	1.98	2.81	2.17
Relief Parameters							
(1)	Minimum Height of Basin (z), m	241	278	294	274	330	333
(2)	Maximum Height of Basin (Z), m	580	495	559	396	580	421
(3)	Total Basin Relief (H), m	339	217	265	122	250	88
(4)	Slope Analysis	1.16–42.4	1.18–33.4	1.17–37.3	1.07–24.8	1.33–42.4	0.98–17.9
(5)	Contour Interval (Cin), m	30	30	30	20	30	20
(6)	Relief Ratio (Rh)	3.96	3.03	4.22	4.79	3.57	2.59

(continued)

Table 1 (continued)

S.No	Parameters	JW	SW1	SW2	SW3	SW4	SW5
(7)	Absolute Relief (Ra), m	580	495	559	396	580	421
(8)	Relative Relief Ratio (Rhp)	0.07	0.09	0.12	0.10	0.11	0.07
(9)	Dissection Ratio (Dis)	0.58	0.44	0.47	0.31	0.43	0.21
(10)	Gradient Ratio (Rg)	3.96	3.03	4.22	4.79	3.57	2.59
(11)	Watershed slope (Sw)	3.96	3.03	4.22	4.79	3.57	2.59
(12)	Ruggedness Number (Rn)	0.34	0.22	0.27	0.12	0.26	0.89
(13)	Melton's Ruggedness Number (MRn)	5.01	6.51	8.43	6.81	8.45	4.69
(14)	Hypsometric Integral (HI)	0.498	0.497	0.498	0.492	0.500	0.500
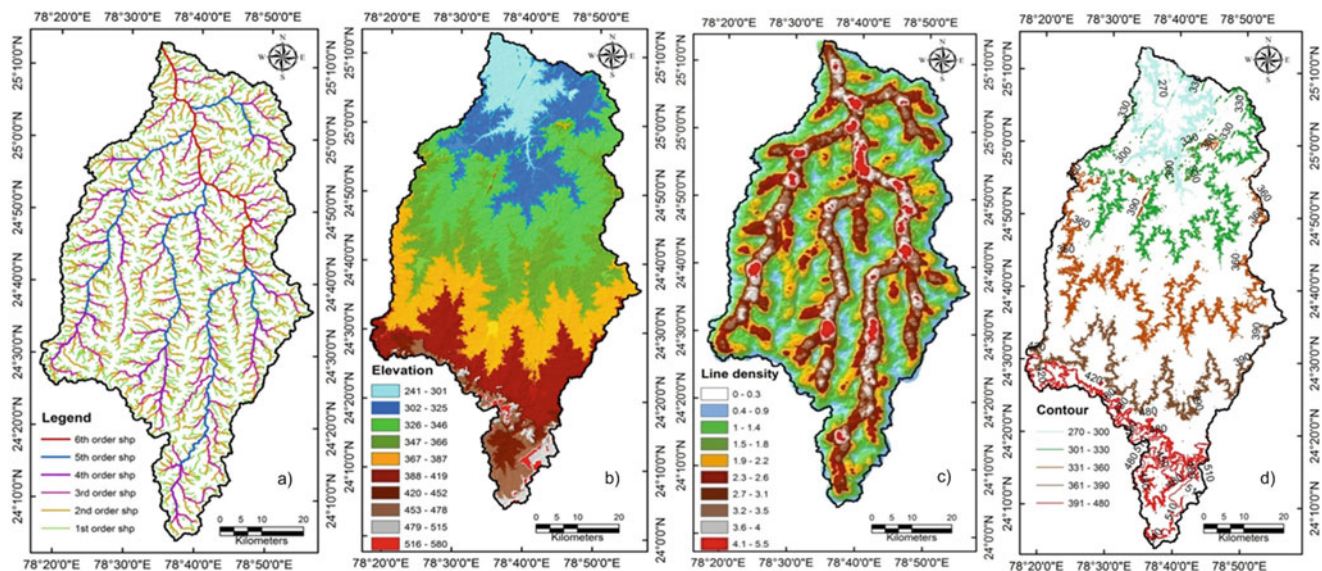
Fig. 3 **a** Drainage map; **b** Digital Elevation model (DEM); **c** Drainage density map and **d** Contour map of Jamini basin

km. The basin length is 85.52 km and the basin perimeter is 484.99 km. Among the five subwatersheds, Shahjad subwatershed has the largest perimeter (246.42 km). It is a factor determining the time travel by water (Schum 1956). Smith (1950) classified five types of density; extremely low (0 to 1), low (1 to 2), moderate (2 to 4), moderately high (4 to 6) and high (>6) density. The low density was observed in all subwatersheds of Jamini basin (Table 1; Figs. 3c, 5c, 6c, 7c, 8c and 9c). It reveals that the basin has dominantly consisted of permeable soil in a larger area with low erosion exposure. Stream frequency is expressed as the number of streams per unit area in a basin or it is a ratio of the total number of streams (Nu) in a basin (Horton 1945). The stream frequency (in km-2) is also classified as low (0 to 5), moderate (5 to 10), moderately high (10 to 15), high (15 to 20) and very high (20 to 25) by Horton (1945). The stream frequency (Fs) estimated for sub-watersheds and Jamini

basin is listed in Table 1. It ranges from 0.71 to 0.76 (Table 1). The low value of frequency shown by each watershed is suggestive of occurrence of permeable soil and dense vegetation cover in the basin.

The low density shown by all subwatersheds of Jamini basin reveals that the coarse basin texture is predominant with permeable soil and thick vegetal cover. The elongation ratio is defined as the ratio of the diameter of a circle having the same area as the basin and maximum basin length (Schum 1956). The value of the elongation ratio generally varies from 0.6 to 10 over a large variety of climatic condition and geologic structures (Strahler 1964). The elongation value can be classified into three categories; elongated (0 to 0.7), oval (0.8 to 0.9) and circular (>0.9). The values of elongation ratio calculated for each subwatershed of Jamini basin ranges from 0.48 to 0.79 (Table 1). These values indicate that the all subwatersheds of Jamini basin are
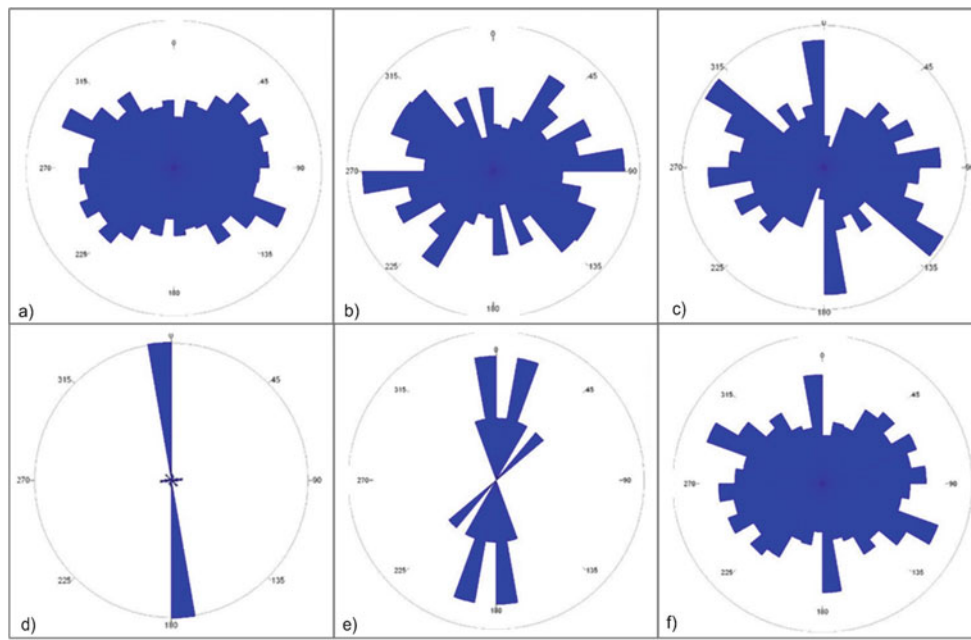
Fig. 4 **a–f** Rose diagrams showing Orientation of I, II, III, IV and V order of streams and mean orientation of all streams
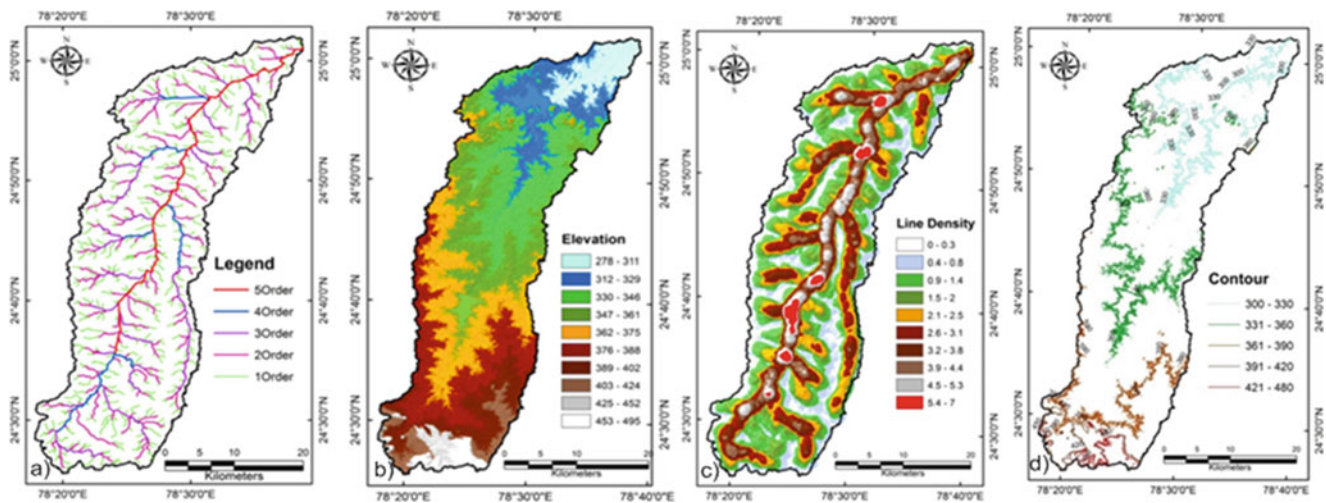
Fig. 5 **a** Drainage map; **b** Digital Elevation model (DEM map); **c** Drainage density map and **d** Contour map of Shahjad watershed

elongated (Figs. 3, 5, 6 7, and 9) except Baragl. Baragl is slightly oval (Fig. 8). Overall the Jamini basin is elongated in shape and is associated with low relief (Table to 1). The circulatory ratio is expressed as the ratio of basin area to the area of the circle (Miller, 1953; Strahler, 1964). The circulatory ratio is influenced by the length and frequency of streams, geological structure, land use land cover, climate, relief and slope of the basin (Miller, 1953). All subwatersheds of Jamini watershed are showing low values of circulatory ratio (Table 1). It implies that the Jamini basin is elongated and consists of permeable and homogenous geological terrain. All subwatersheds of Jamini basin are showing circulatory ratio (Rc) less than 0.4. It is indicative of a mature stage of watershed development.

Form factor (Ff) is represented by the shape of the watershed. 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 a circular basin with high peak flows for shorter duration whereas the low values (<0.45). Form factor would have an elongated basin with low peak flows for a longer duration. The value of the form factor calculated for all subwatershed of Jamini basin ranges from 0.18 to 0.49 (Table 1). It indicates that all subwatersheds are elongated and exhibit low peak flow with longer duration.
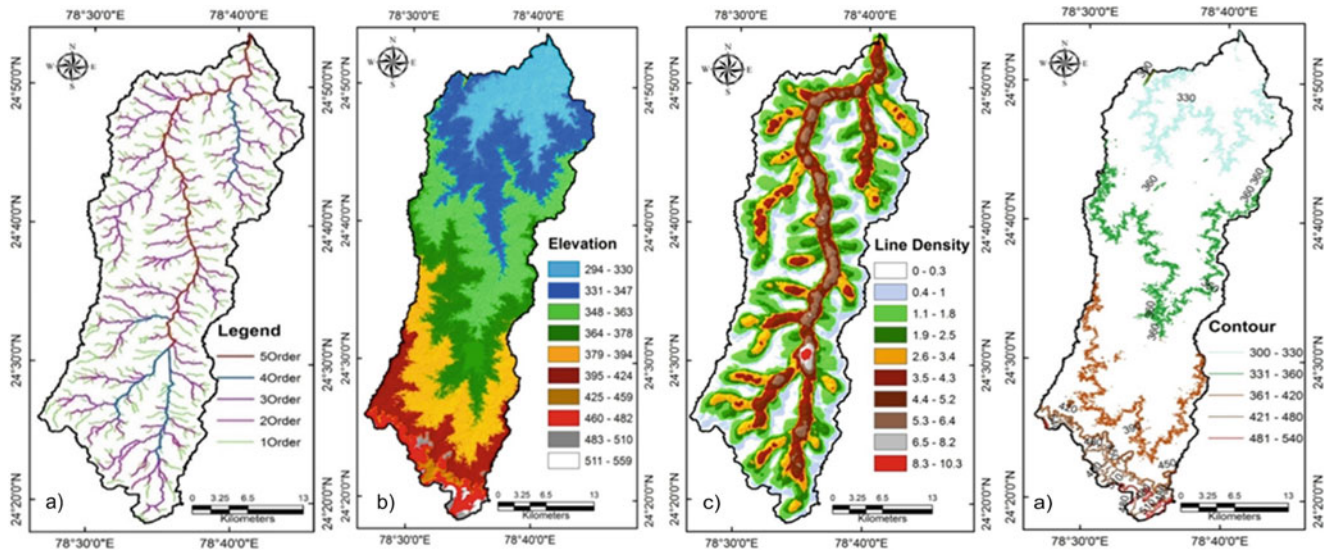
Fig. 6 **a** Drainage map; **b** Digital Elevation model (DEM); **c** Drainage density map and **d** Contour map of Sajnam watershed
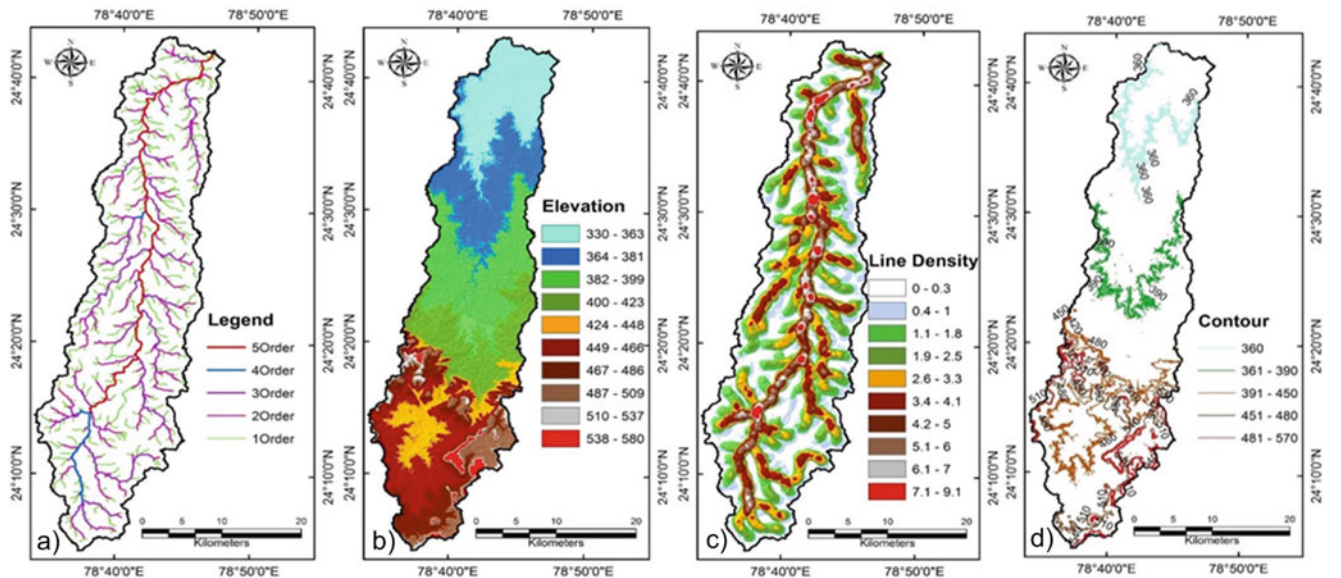

Fig. 7 **a** Drainage map; **b** Digital Elevation model (DEM); **c** Drainage density map and **d** Contour map of Onri watershed
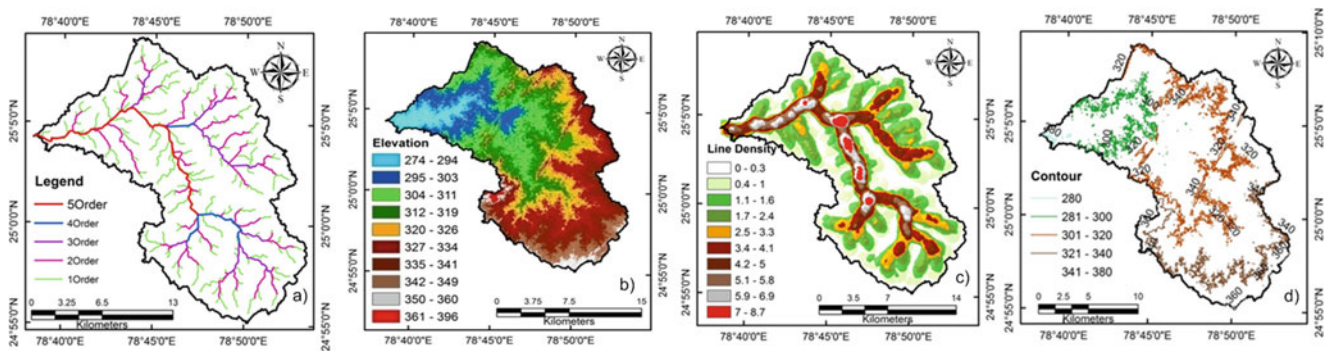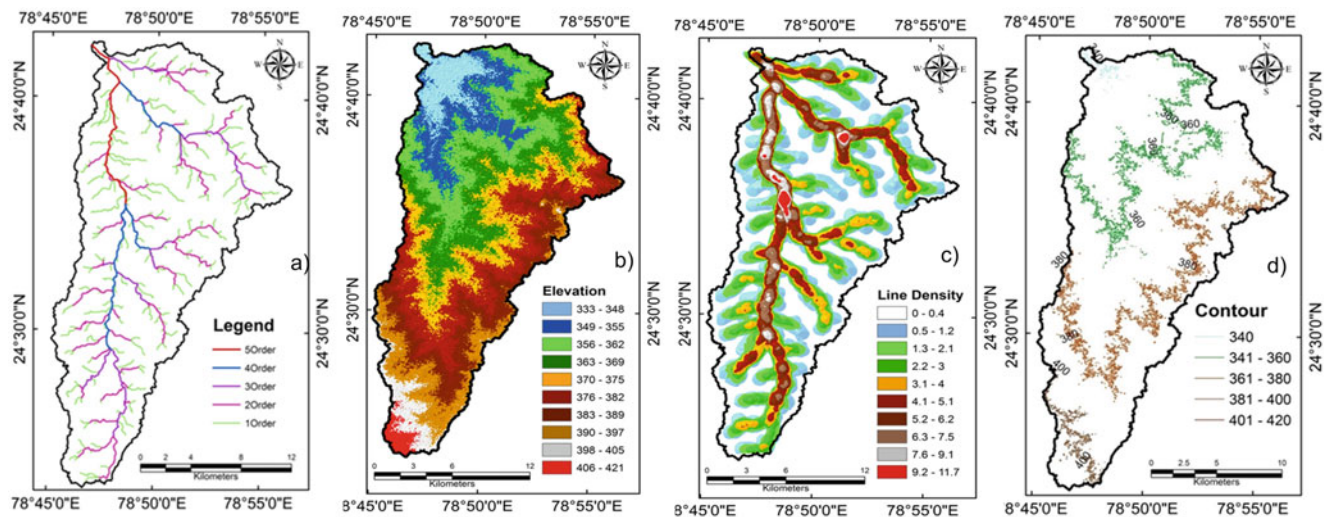

Fig. 8 **a** Drainage map; **b** Digital Elevation model (DEM); **c** Drainage density map and **d** Contour map of Bagal watershed

Fig. 9 **a** Drainage map; **b** Digital Elevation model (DEM); **c** Drainage density map and **d** Contour map of Jamrar watershed

5.3 Relief Parameters

The various relief parameters are given in Table 1. The highest and lowest points of a basin are referred to as the total relief of the basin. The stream gradient and influences of flood pattern and volume of sediments that transported are determined by basin relief (Hadley and Schumm 1961). The relief can be expressed as an area of a basin in three-dimensional view (Sahu et al. 2016). Basin relief measures the overall steepness of drainage and is an indicator of the intensity of erosion that occurred on the slope of a basin. The altitudinal differences in the Jamini basin (highest relief point 580 m and lowest point 241 m) and its subwatersheds from the sea level are listed in Table 1. The relief ratio is defined as the ratio of maximum basin relief to the longest horizontal distance of the basin measured parallel to the major stream (Samal et al. 2015). The relief ratio calculated for Jamini basin and its subwatersheds varies from 2.79 to 4.79. It indicates that the moderately steeper terrain is prone to erosion.

Ruggedness number (Rn) is expressed as the product of basin relief and drainage density (Strahlar, 1958; Vijith and Satheesh, 2006). It is related to the level of smoothness and roughness of the basin terrain or surface unevenness (Selvan et al. 2011). The ruggedness value is ranging from zero to one. The relatively more rugged terrain shows one ruggedness value. Contrary to this the smother terrain has ruggedness value less than one or zero. If the value of drainage density and relief is high then the value of ruggedness becomes higher. It indicates that the slope is not only steeper but is also long (Strahler1958). According to (Farhan et al. 2015), the ruggedness can be classified into four categories: subdued morphology (<0.1), slight morphology (0.1 to 0.4), moderate morphology (0.4 to 0.7) and

sharp morphology (0.7 to 1.0) and high morphology (>1.0) refers to the high erosion-prone area. All subwatershed of Jamini basin except Jamrar subwatershed are showing ruggedness value from 0.12 to 0.27 (Table 1). It indicates that all subwatershed except Jamrar are less susceptible to erosion and are quite smoother. The Jamar watershed is showing rugged and sharp terrain and is more prone to erosion. Overall the value of ruggedness of Jamini basin is 0.34 (Table 1). It infers that the Jamini basin is slightly rugged and less prone to erosion and sediment transport.

5.4 Hypsometric Curve

Hypsometry is defined as the overall slope and the forms of drainage basin (Strahler 1952). These curves are related to the volume of the soil mass in the basin and the amount of erosion that had occurred in a basin against the remaining mass (Hurtrez et al. 1999). It is also used to differentiate between erosional landforms evolved at different cycles of drainage (youth, mature and old stages). Apart from erosional stages of landform, the hypsometric data can be used to determine the influence of tectonic, climatic and lithological factors on the evolution of drainage (Schumm 1956; Strahler 1956; Lifton and Chase 1992; Chen et al. 2003; Huang and Niemann 2006).

It can also explore the level of erosion of soil that has occurred in the past geological time (Bishop et al. 2002). The hypsometric curves have been classified into three types of landforms based on the shape of the curve; (1) young stage, (2) mature stage, and (3) old stage (Strahler 1952). The convex curves associated to the youth stage are indicating that the terrain is slightly eroded and undissected. The S-shaped curves matching with the mature stage are concave
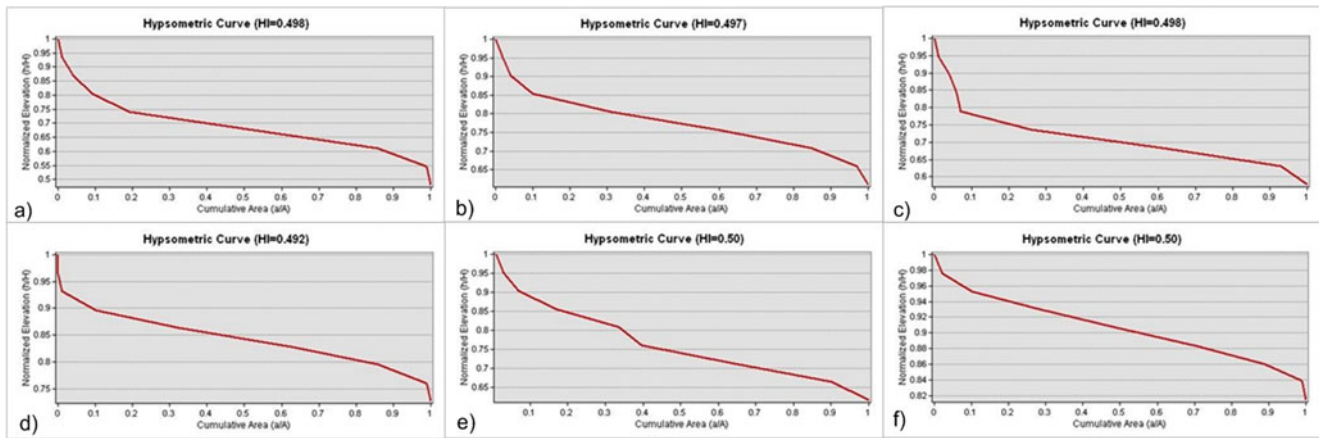
Fig. 10 **a** Hypsometric curve of Jamni basin; **b** Shahjad watershed; **c** Sajnam watershed; **d** Baragl watershed; **e** Onri watershed; **e** Jamrar watershed

upward at a higher altitude and convex downward at relief at a lower height and indicative of the occurrence of moderately eroded regions. The intensively eroded and deeply dissected landforms associated to concave curves are indicating the old stage of drainage.

In the present paper, all hypsometric curves resemble to S-shaped curve (Figs. 10a–f). It infers that all subwatershed of Jamini basin showing S-shaped curves have experienced moderate erosion activities during the development of the landscape. The hypsometric index value of all subwatersheds of Jamini basin ranging from 0.492 to 0.500 (Table 1) implies that the landscapes have reached the matured stage of evolution.

5.5 Correlation of Linear, Areal and Relief Parameters of Each Watershed of Jamini Basin

Inspection of the correlation matrix is important because it can point out the association among the variables that can show the overall coherence of the data set and indicate the participation of the individual parameter in several influencing factors. Inter parameter relationship also provide information on drainage behaviour and pathway of variables in a river system. Multiple regression analysis was carried and their results are given in Tables 2, 3 and 4 (Figs. 11, 12 and 13). Among the linear parameters shown in Table 2

Table 2 Correlation matrix of selected linear parameters

	Lurm	**Luwm**	**Rf**	**Rw**	**Rbm**	**Rbwm**	**ρ**	**Lar**	**k**	**Sf**	**Rt**	**S**
Lurm	1											
Luwm	0.980	1										
Rf	0.692	0.770	1									
Rw	−0.161	−0.132	−0.544	1								
Rbm	0.690	0.803	0.799	0.052	1							
Rbwm	0.042	0.010	−0.183	−0.097	−0.392	1						
ρ	0.847	0.733	0.308	−0.190	0.206	0.293	1					
Lar	0.058	0.166	−0.073	0.856	0.498	−0.223	−0.246	1				
k	0.686	0.711	0.939	−0.754	0.564	0.011	0.456	−0.379	1			
Sf	0.686	0.711	0.939	−0.754	0.564	0.011	0.456	−0.379	1.000	1		
Rt	0.003	0.114	−0.108	0.864	0.462	−0.221	−0.294	0.998	−0.414	−0.414	1	
S	0.068	−0.075	−0.480	0.050	−0.468	0.196	0.495	−0.379	−0.304	−0.304	−0.386	1

Lurm: Stream length used in the ratio; **Luwm:** weighted mean stream length ratio; **Rf:** Fitness ratio; **Rw:** wandering ratio; **Rbm:** mean bifurcation ratio; **Rbwm:** weighted mean bifurcation ratio; **ρ:** Rho coefficient; **Lar:** length area relation; **k:** lemniscate's; **Sf:** shape factor; **Rt:** texture ratio; **S:** Sinuosity (higher order)

Table 3 Correlation matrix of selected areal parameters

	Pr	Fs	Dd	Di	If	Re	Rc	Rcn	Cc	Ff	Lg	C	Rt
Pr	1												
Fs	–0.544	1											
Dd	–0.690	0.282	1										
Di	–0.172	**0.804**	–0.296	1									
If	–0.648	**0.943**	**0.577**	**0.577**	1								
Re	**0.552**	–0.277	–0.874	0.335	–0.539	1							
Rc	–0.403	0.360	–0.384	**0.614**	0.117	0.401	1						
Rcn	**1.000**	–0.544	–0.690	–0.172	–0.648	**0.552**	–0.403	1					
Cc	0.329	–0.331	0.454	–0.631	–0.071	–0.486	–0.995	0.329	1				
Ff	**0.612**	–0.324	–0.873	0.286	–0.573	**0.996**	0.322	**0.612**	–0.410	1			
Lg	**0.616**	–0.213	–0.966	0.381	–0.509	**0.873**	0.434	**0.616**	–0.493	**0.864**	1		
C	**0.690**	–0.282	–1.000	0.296	–0.577	**0.874**	0.384	**0.690**	–0.454	**0.873**	**0.966**	1	
Rt	**1.000**	–0.524	–0.687	–0.155	–0.629	**0.548**	–0.406	**1.000**	0.332	**0.608**	**0.612**	**0.687**	1

Pr: Relative perimeter; **Fs:** Stream frequency; **Dd:** Drainage density; **Di:** Drainage intensity; **If:** Infiltration number; **Re:** Elongation ratio;**Rc:** Circularity ratio;**Rcn:** Circularity ratio; **Cc:** Compac**Pr:** Relative perimeter; **Fs:** Stream frequency; **Dd:** Drainage density; **Di:** Drainage intensity; **If:** Infiltration number; **Re:** Elongation ratio;**Rc:** Circularity ratio;**Rcn:** Circularity ratio; **Cc:** Compactness coefficient; **Ff:** Form factor; **Lg:** Length of overland flow; **C:** Constant of channel maintenance; **Rt:** Drainage texture

Table 4 Correlation matrix of selected relief parameters

|	H	Rh	Rhp	Dis	Rg	Sw	Rn	MRn	H I
H	1								
Rh	0.244	1							
Rhp	0.141	0.495	1						
Dis	**0.982**	0.319	0.140	1					
Rg	0.244	**1.000**	0.495	0.319	1				
Sw	0.244	**1.000**	0.495	0.319	**1.000**	1			
Rn	–0.430	–0.723	–0.604	–0.548	–0.723	–0.723	1		
MRn	0.242	0.419	**0.979**	0.226	0.419	0.419	–0.618	1	
HI	0.266	–0.707	–0.164	0.105	–0.707	–0.707	**0.596**	–0.048	1

H: Total basin relief; **Rh:** Relief ratio; **Rhp:** Relative relief ratio; **Dis:** Dissection ratio; **Rg:** Gradient ratio; **Sw:** Watershed slope; **Rn:** Ruggedness number; **MRn:** Melton ruggedness number; **HI:** Hypsometric integral

(linear parameters): Lurm, Luwm, Rf, Rbm, k and Sf bear a positive correlation among each other. P shows positive correlation with Lurm, Luwm; Lar, Rw and Rt are positively correlated among each other; while Sf shows strongest positive correlation with k. Rbwm, and S show the partial positive correlation or inverse correlation with the rest of the parameters which do not show the dependency on any other linear parameter.

In Table 3 (areal parameters): Pr, Re, Rcn, Ff, Lg, C and Rt are positively correlated among each other; Dd and Rc show positive correlation with If and Di, respectively; while Fs, Di and If are positively correlated among each other. Pr, Rcn and Rt show the strongest positive correlation among

each other. Cc shows the partial positive correlation or inverse correlation with the rest of the areal parameters which do not show the dependency on any other parameter.

Relief parameters are also strongly correlated with each other which are shown in Table 4 (relief parameters), where: Dis positively correlated with H; Rg, Sw and Rh show strongest correlation among each other; MRn and HI bear a positive correlation with Rhp and Rn respectively; HI positively correlated with Rn. The relationship of linear, areal and relief parameters of Jamini basin and its subwatersheds were correlated in Figs. 13a, b and c. The uniform trends of these parameters imply that the basin was evolved in a geologically and geomorphologically homogenous terrain.
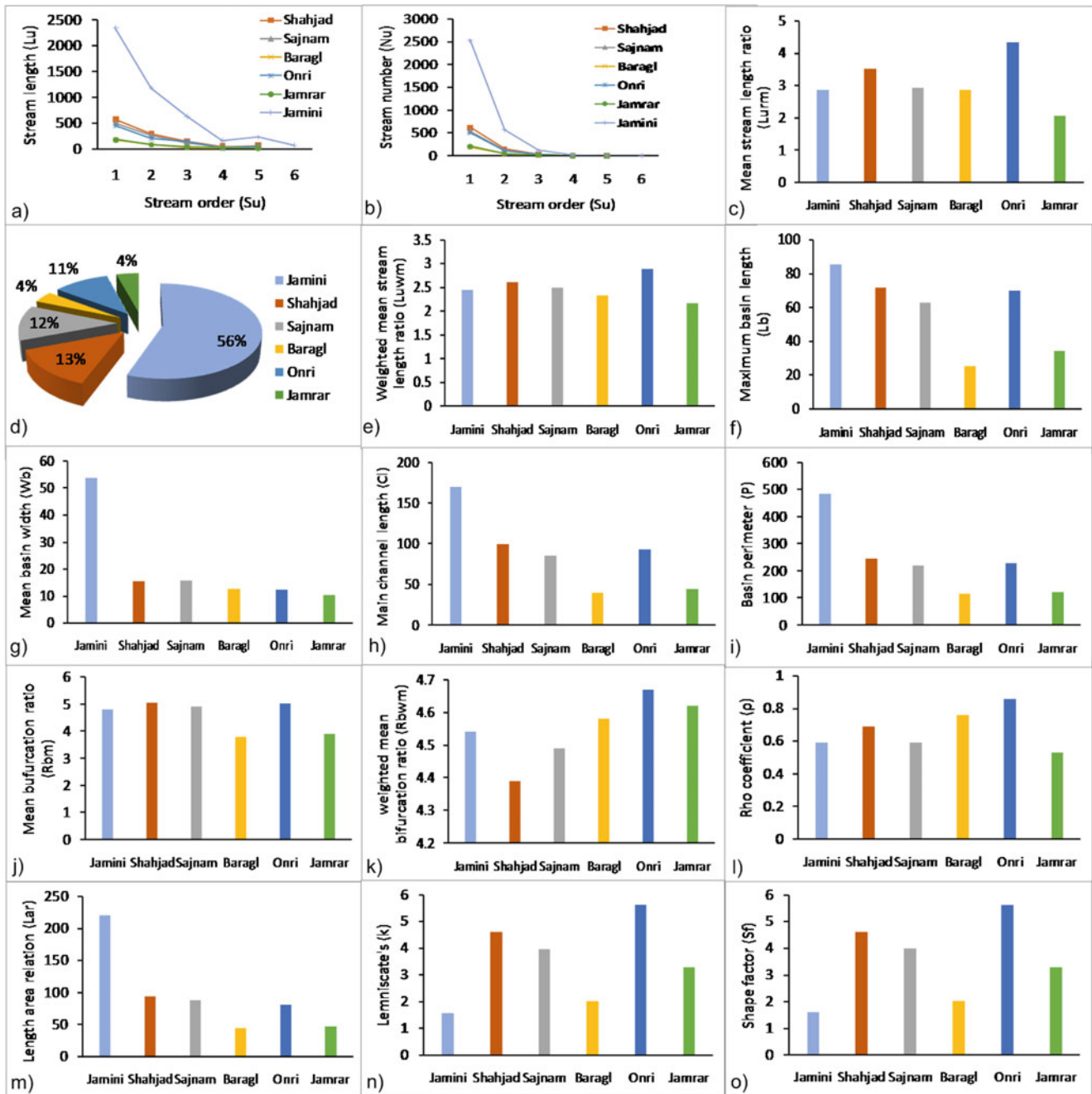
Fig. 11 shows the relationship between stream number versus stream order (**a**) and stream length versus stream order (**b**). It also shows the area percentage of Jamini river and its subwatersheds (**c–o**)

6 Conclusions

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

high elevated area. The S-shaped hypsometric curve indicates that the terrain has experienced moderate erosion process during landscape development. The hypsometric index value is indicative of the maturity stage of landscapes development. A statistical tool like correlation matrix analysis can be an effective method for characterization of correlation among multiple parameters, which determine the behavior of river basin. In this study, linear, areal and relief parameters are tabled in distinct correlation matrices and are
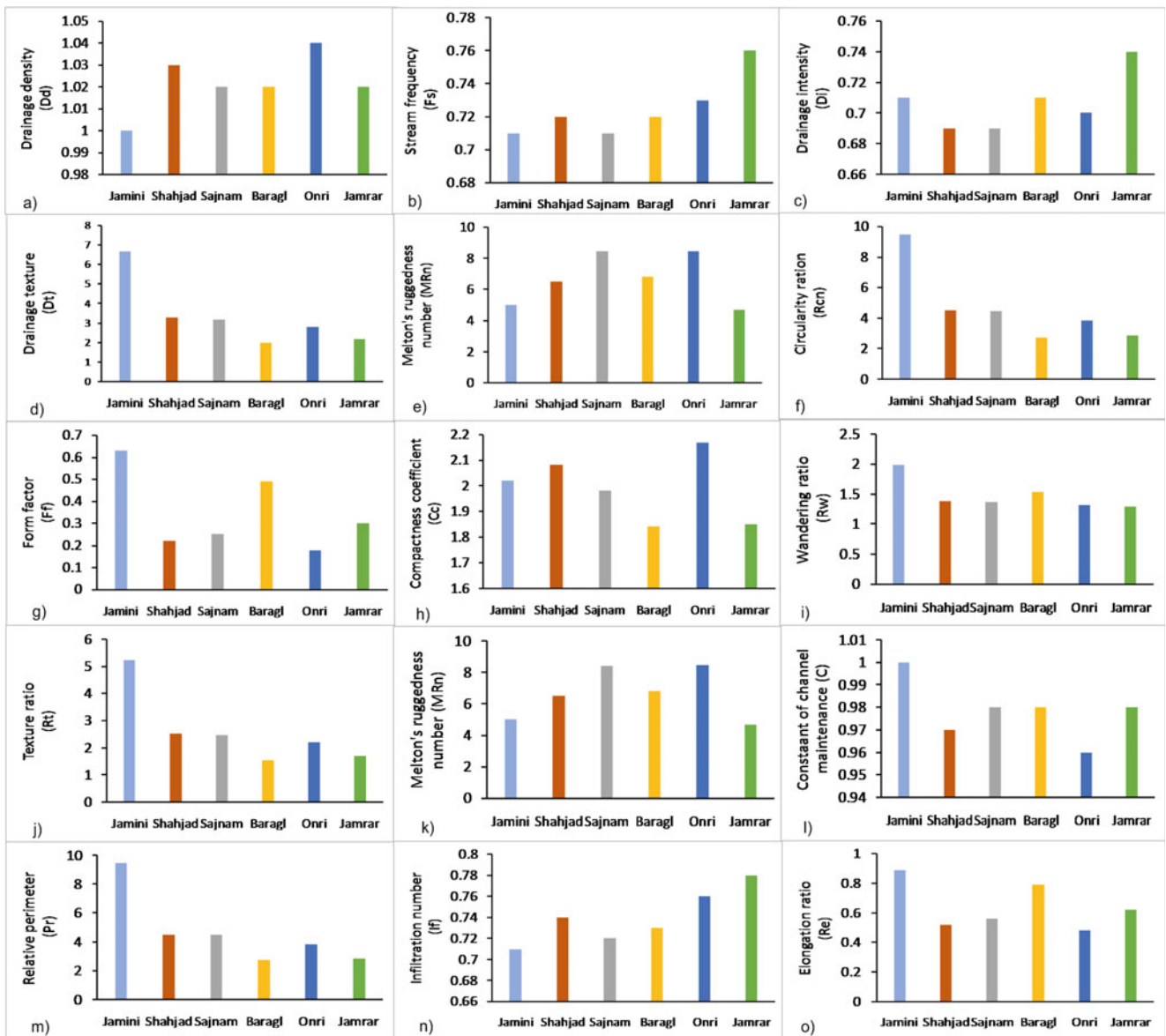
Fig. 12 The relationship of areal and relief parameters of each subwatershed of Jamini basin is represented by various trends
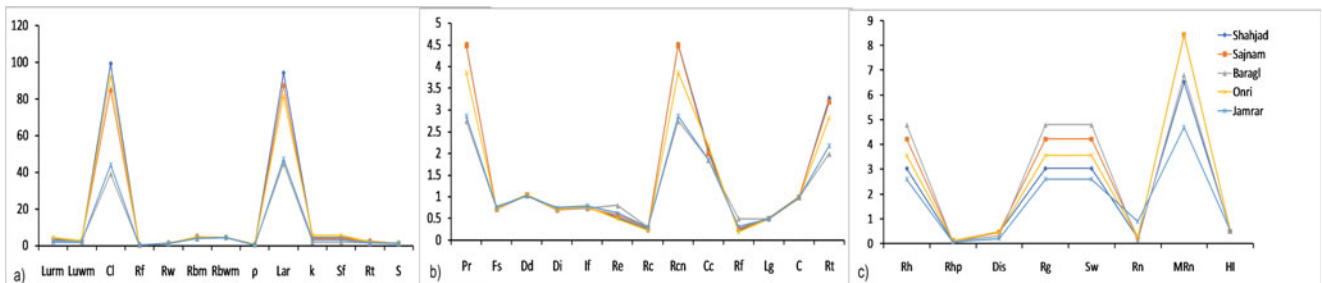

Fig. 13 shows the relationship between linear (**a**), areal (**b**), and relief parameters (**c**)

showing strong correlation among the cluster. This statistical outcome further reasserted with the graphical method and uniform trends of these parameters infer that the Jamini basin was evolved in a homogenous geological and geomorphological terrain.

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