

# Morphotectonics of the Jamini River basin, Bundelkhand Craton, Central India; using remote sensing and GIS technique

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**Abstract** Morphological and morphotectonic analyses have been used to obtain information that influence hydrographic basins, predominantly these are modifications of tectonic elements and the quantitative description of landforms. Discrimination of morphotectonic indices of active tectonics of the Jamini river basin consists the analyses of asymmetry factor, ruggedness number, basin relief, gradient, basin elongation ratio, drainage density analysis, and drainage pattern analysis, which have been completed for each drainage basin using remote sensing and GIS techniques. The Jamini river is one of the major tributaries of the Betwa river in central India. The Jamini river basin is divided into five subwatersheds viz. Jamrar, Onri, Sainam, Shahzad and Baragl subwatershed. The quantitative approach of watershed development of the Jamini river basin, and its four sixth (SW1–SW4) and one fifth (SW5) order subwatersheds, was carried out using Survey of India toposheets (parts of 54I, 54K, 54L, 54O, and 54P), Landsat 7 ETM+, ASTER (GDEM) data, and field data. The Jamini river has low bifurcation index which is a positive marker of tectonic imprint on the hydrographic network. The analyses show that the geomorphological progression of the study area was robustly influenced by tectonics. The analysis demonstrates to extensional tectonics system with the following alignments: NE–SW, NW–SE, NNE–SSW, ENE–WSW, E–W, and N–S. Three major trends are followed by lower order streams viz. NE–SW, NW–SE, and E–W directions which

advocate that these tectonic trends were active at least up to the Late Pleistocene. The assessment of morphotectonic indices may be used to evaluate the control of active faults on the hydrographic system. The analysis points out westward tilting of the drainage basins with strong asymmetry in some reaches, marked elongation ratio of sub-watersheds, and lower order streams having close alignment with lineaments (active faults). The study facilitated to considerate the function of active tectonism in the advancement of the basin.

**Keywords** Jamini river · Morphotectonics · Remote Sensing and GIS technique · Central India

## Introduction

The Ganga and Yamuna are the two major rivers of the world (Singh and Singh 1992; Sinha 1996) and the tectonic control of their courses is well documented for the main channels (Tangri 1986; Jain and Sinha 2005; Singh 2015; Prakash et al. 2016a, b). The effects of tectonic control of major rivers are not readily identified as large discharge rate masks the overall change but the imprints of tectonics become obvious in tributaries associated with major rivers (Schumm et al. 2000). The tributaries of Ganga River have been extensively studied pertaining to their morphotectonics (Tangri 1992; Shukla et al. 2012). However, the tributaries of Yamuna river, especially those draining the Bundelkhand craton, have not been studied in detail although it is well accepted that there is a strong structural anisotropy in the basement of Bundelkhand craton which controls various tectonic and geomorphic landforms on the surface and these basement structures depict episodic reactivation (Godin and Harris 2014). To establish the role

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of basement tectonics and possible reactivation of subsurface structures, a judicious blend of morphometric analysis of river basin and field investigations with select field checks are extremely useful (Pati et al. 2006). The study of drainage basin analysis has clearly established the inherent control of lithology and tectonics of an area in the development of fluvial landforms (Ritter, 1986; Pati et al. 2006, 2008). It also helps in evaluation of geometric characteristics of the fluvial landscape (Pophare and Balpande, 2014; Prakash et al. 2016a, b). The emerging trends in the space technology and applications of spatial data become very useful for surface characterization, interpretation, and management of the quantitative data sets (Magesh et al. 2012).

In Indian scenario, the morphotectonic analysis was implemented by various workers for many purposes especially for watershed analysis and prioritization of micro-watersheds (Raj et al. 1999; Raj 2004; Thomas et al. 2010; Mishra et al. 2011; Prabu and Baskaran 2013; Singh 2014; Withanage et al. 2014). The evolution of landscape and tectonically produced slopes are further modified by the external forces through the process of erosion and deposition with the development of new deformational structures (Singh and Singh 1992). Drainage system became accustomed to any small amends of surface morphology and witness in order about any structural deformations (Leeder and Jackson 1993; Raj 2007; Kale and Shejwalkar 2008; Pati et al. 2008; Singh 2014; Prakash et al. 2016a, b).

Of the three major tributaries (Chambal, Betwa, and Ken) of river Yamuna in the peninsular India having SW to NE flow direction, the Jamini river is a tributary of Betwa river and its watershed lies in the central part of the Bundelkhand craton. It drains the granitoids and related rocks of Bundelkhand craton, the terrigenous sediments belonging to Vindhyan Supergroup and the basaltic rocks of Deccan Trap. Since major part of the Jamini river basin comprise granitic rock as subsurface lithology, the primary porosity is relatively low and consequently the groundwater recharge is meager.

The geomorphological and morphotectonic study of drainage systems can provide useful indicators about the recent tectonic regime of a region (Argyriou et al. 2016; Singh 2014, 2015). The analysis of linear features has several applications. The linear structures of tectonic origin offer valuable information concerning the seismic hazards and (neo) tectonics in the terrain (Macenzie 1978; Rastogi 2001). Further these features are also very significant in the structural analyses of global tectonics (Molnar and Tapponnier 1975; Boccaletti et al. 1990), hydrogeological investigations (Vincent et al., 2010). The study area cover regions of poor socio-economic conditions, low rainfall, draught affected poor drainage density, meager agricultural outputs, and largely unexplored natural resources. The

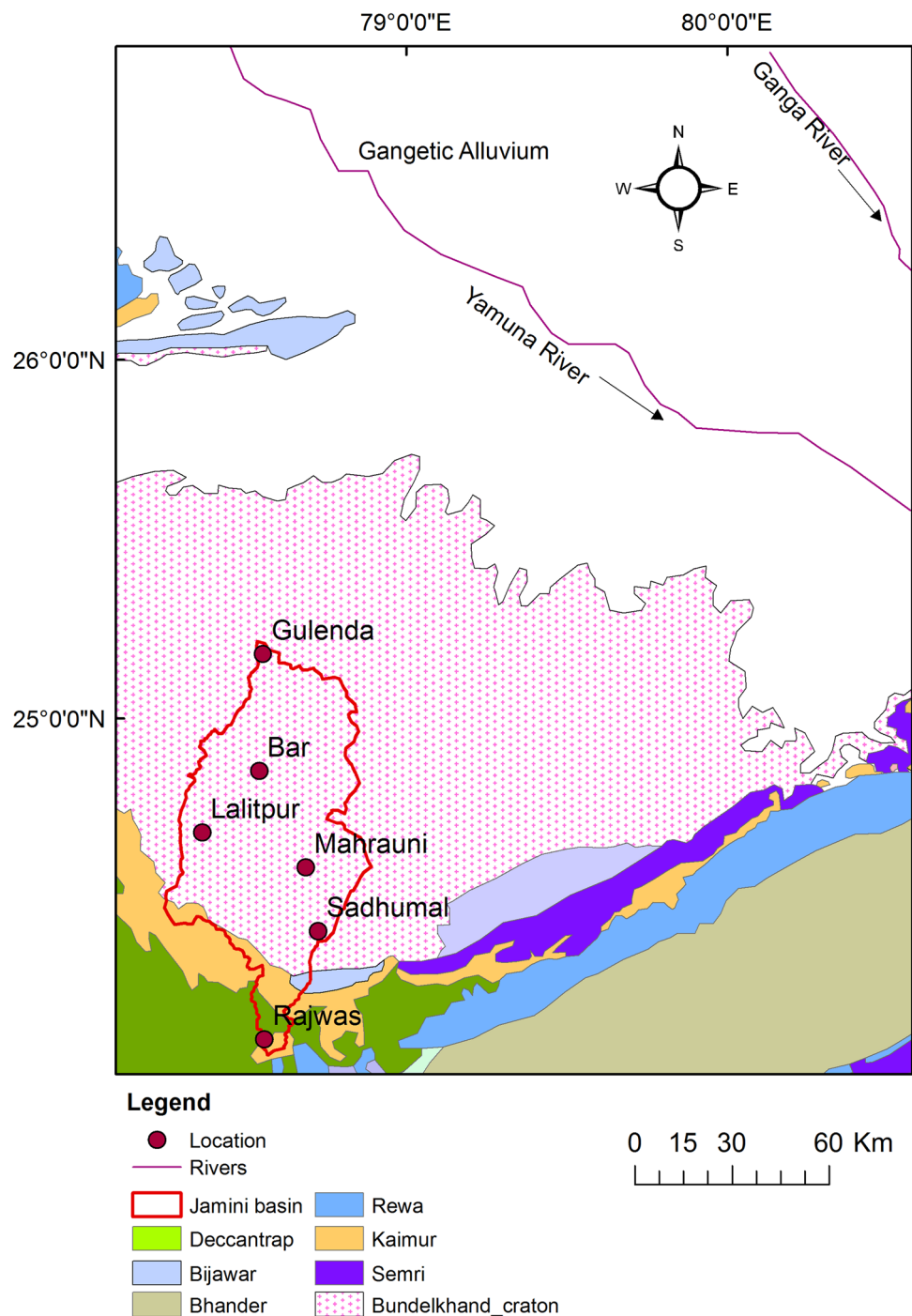
current study is aimed to broaden its scientific conclusions to various user communities so that some of these problems are precisely addressed.

## Geology of the area

The basin of Jamini river spread over parts of Bundelkhand craton, Bijawar Group, Vindhyan Supergroup and Deccan trap in central India. The Bundelkhand craton is surrounded by Vindhyan Supergroup by east, south, and west margin while northern part is covered by the Indo-Gangetic alluvium. Its south-western fringe is spotted by small outcrops of the Bijawar Group (Fig. 1). Bundelkhand Tectonic zone with E–W trends occurs as tectonic slivers in supracrustal rocks. The occurrence of corundum-bearing schists (Saha et al. 2011) in Bundelkhand craton is reflected as explicit indication of Archean subduction processes (Moyen and Martin 2012). The Bundelkhand craton comprises in addition to the granitoids; syenites, amphibolites, Banded iron formation, tonalite–trondhjemite–granodiorite (Pati et al. 2007), gneisses, calc-silicate rocks, quartzites, pillow lavas (Pati and Raju 2001), basaltic komatiites of boninitic affinity-volcaniclastic metasediments (Malviya et al. 2006), giant quartz veins (Pati et al. 2007), and volcanics (rhyolites) occur in the Archean Craton. PGE-bearing Mafic-ultramafic rocks is also exposed in southern margin of the craton (Pati et al. 2005). Most of quartz veins of varied size with mainly NNE–SSW and NE–SW trends are observed in parts of the Bundelkhand craton representing an episodic tectonic controlled hydrothermal activity (Pati et al. 2007) which are later on intruded by mafic dykes in some places. Mafic dykes represent the youngest intrusive phase (Pati et al. 2005) with NW–SE trend.

The Bijawar group is the Meso-proterozoic formations deposited over the Archean Bundelkhand craton and it is exposed along its southeastern (Hirapur and Sonarai Basins) and northwestern (Gwalior Basin) margins. The Bijawar group consists in succession of a basal conglomeratic horizon and quartzite overlain by hornstone breccias, limestone, phyllitic shales, red jaspers, and dioritic traps (Pati et al. 2007). These rocks are again well exposed along the southeastern edges of the Vindhyan Syncline where they dip under the Semri Group of the Vindhyan supergroup (Ray 2006). The Vindhyan Supergroup, is one of the biggest and widest Precambrian sedimentary successions of the world, occupying an area of 1,04,000 km<sup>2</sup> in central peninsular India. The basin, spread over Rajasthan, Madhya Pradesh, Uttar Pradesh, Jharkhand, and Bihar. The Vindhyan Basin is bordered to the south by the ENE–WSW trending Narmada-Son lineament. The western margin is delimited by the NE–SW trending Great

**Fig. 1** Location map showing the position of Jamini River Basin in different cratons of India



Boundary Fault closest to the northwest trending Aravalli–Delhi Fold Belt (Venkatachala et al. 1996) and Indo-Gangetic alluvium towards north and east but the basin is deemed to persist underneath of the Gangetic alluvial (Chakraborty 2006). The Vindhyan Supergroup is subdivided into the upper Vindhyan (Kaimur, Rewa, and Bhandar Groups) and the lower Vindhyan (Semri Group). The Vindhyan rocks are well exposed in three diverse sectors: the Rajasthan sector, the Bundelkhand sector, and

the Son Valley Sector. The study area extends over the Bundelkhand sector which consist the Semri, Kaimur and Rewa group.

The Deccan Traps reside in peninsular India between longitude 69°–79°E and latitude 16°–22°N and comprises one of the biggest volcanic provinces on the earth (Mahoney et al. 2002; Courtillot et al. 1988; Bose 1995; Ghosh et al. 2006). The Deccan traps also have severe problem in groundwater abundance (Limaye 2010). Lithology, degree

of deformation, and intensity of precipitation are controlling factor of hydrological deeds in this volcanic province.

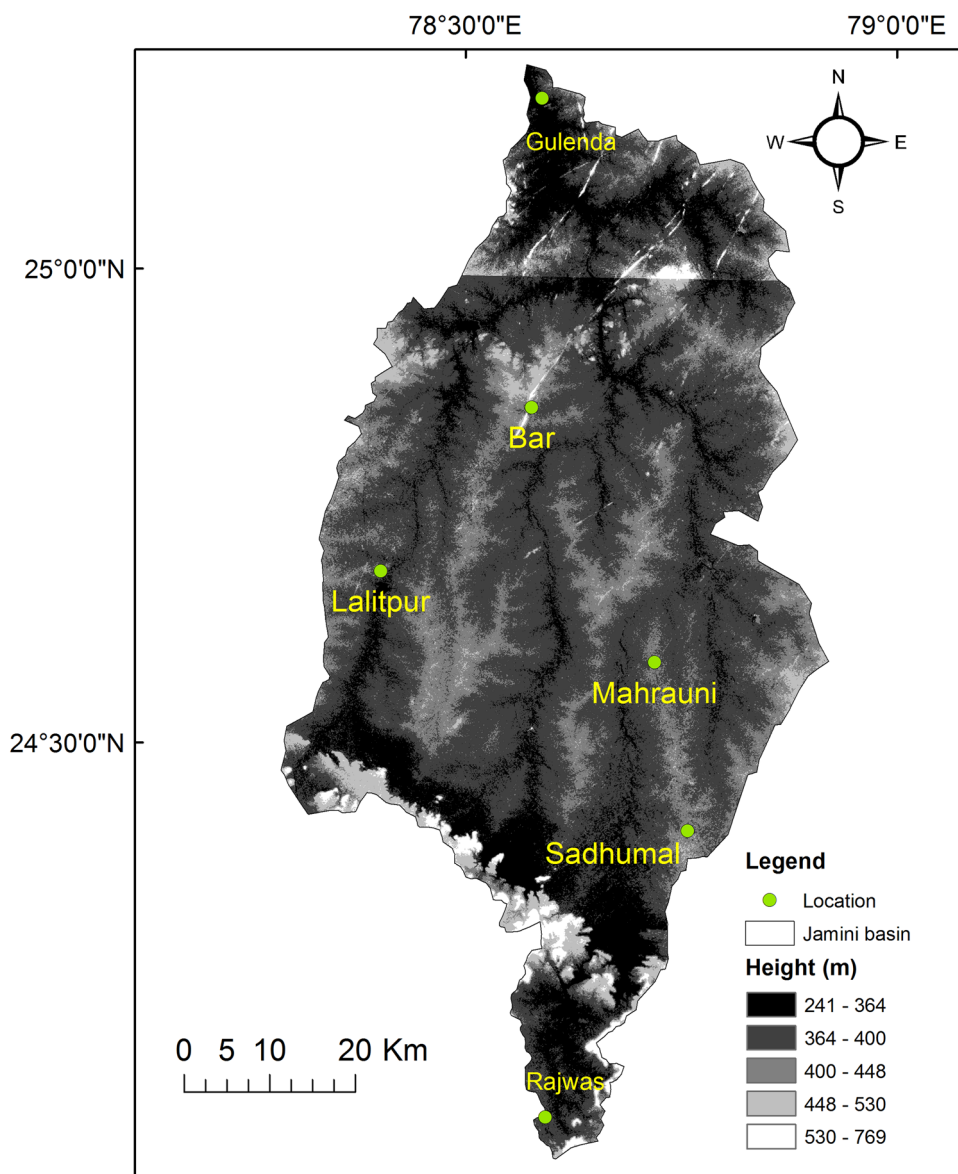
## Methodology

Advanced spaceborne thermal emission and reflection (ASTER G-DEM) (date of acquisition—2006-09-30), included elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of the study area (Fig. 2). The ASTER data of WRS-2 satellite with capture resolution of 3 arc second and pixel resolution of 30 m was used for this study. The ASTER data were used to delineate the drainage network through digital elevation model technique. Thematic Mapper (ETM+) data and SOI (Survey of India)

topographic maps (1:50,000) are used for delineation and corroboration of the drainage networks, lineaments and demarcation of subwatershed of the study area. The ASTER and ETM+ data were obtained from global land cover facility (<http://www.landcover.org>). The ETM+ is a cross-track scanner providing seven multispectral channels (3 visible, 1 near-infrared, 2 mid-infrared, 1 thermal-infrared) at 30-meter resolution while 15 m spatial resolution in panchromatic mode (120-meter resolution for the thermal-infrared band) and orthorectified data with moderate resolution 30–90 m of Date 2000/11/20. The LANDSAT data are used for identification of structural deformation like fractures, joints, and offset of drainages in form of lineaments of the basin.

Watershed and drainage network was analyzed using Horton's (1945) scheme while in stream ordering Strahler

**Fig. 2** Digital elevation model of the Jamini river basin. The elevation varies from 241 to 769 m in the study area



(1964) methods were adopted. The basic parameters like length of individual stream, basin area, and perimeter of the basin were extracted from the Arc GIS-10 geodatabase and further used for calculating morphometric parameter such as linear, areal, relief, and tectonic aspects by means of various equations (Table 1).

## Results and discussion

The morphometric investigation incorporates measurement and mathematical analysis of the area, altitude, volume, slope, profiles of the land, and drainage basin characteristics of the catchment area concerned (Clarke 1966).

In the present study, catchment area of the Jamini river with stream network and 4 sixth order and 1 fifth order subwatersheds viz. Jamrar, Onri, Sainam, Shahzad, and Baragl subwatershed as shown in Fig. 3 has been thoroughly examined in the field as well as in the laboratory. The parameters of linear, areal, relief, and tectonic aspects have been examined and described under following heads along with their relevant significance.

### Drainage pattern

The drainage orientations of the Jamini watershed (JW) show poly-modal distribution (NE–SW, NW–SE, N–S, and E–W). The NE and SW trend of the streams is highly conspicuous (Fig. 3). The drainage patterns are trellised in general; while rectangular, dendritic and parallel pattern has also been noted. The trellis drainage patterns are formed by the network of tributaries and consequently the Jamini river which follow the regional slope is well adjusted to the different geological structures (like shear zones, orientation of quartz reefs and mafic dykes). Dendritic or tree-shaped drainage pattern is the most common and widespread pattern to be found in the study area. The dendritic patterns resemble the area of homogeneous lithologies and horizontal or very gentle dipping strata. Some parts of the study area are characterized by centripetal drainage pattern, which may be caused by the localized exhumation due to tectonic activity.

### Linear aspects

#### Perimeter (P)

The Jamini watershed with perimeter 380.3554 km is divided into four 6th order and one 5th order subwatersheds, which are given in the Table 2. Among the 5 subwatersheds, the Onri subwatershed has the largest

**Table 1** Different parameters implemented for morphometric and morphotectonic analysis

Parameters	Definition
<b>Linear aspects</b>	
Perimeter (P) (km)	
Basin length (Lb) (km)	
Stream order (Nu)	Strahler (1957)
Stream length (Lu) (km)	Horton (1945)
Bifurcation ratio (Rb)	$Rb = Nu/N(u + 1)$ , Horton (1945)
Stream length ratio (Rl)	$Rl = Lu/L(u - 1)$ , Horton (1945)
<b>Areal aspects</b>	
Rho coefficient (R)	$R = Rl/Rb$ , Horton (1945)
Area (A) (km <sup>2</sup> )	
Drainage density (Dd) (km km <sup>-2</sup> )	$Dd = \sum Lt/A$ , Horton (1945)
Stream frequency (Fs) (Km <sup>-2</sup> )	$Fs = Nt/A$ , Horton (1945)
Drainage texture (T) (Km km <sup>-4</sup> )	$T = Dd \times Fs$ , Smith (1950)
Length of overland flow (Lg) (km)	$Lg = 1/2Dd$ , Horton (1945)
Constant of channel maintenance (C) (km)	$C = 1/Dd$ , Schumm (1956)
Form factor (Ff)	$Ff = A/Lb^2$ , Horton (1945)
Circularity ratio (Rc)	$Rc = 4\pi A/P^2$ , Miller (1953)
Elongation ratio (Re)	$Re = 1.128\sqrt{A/Lb}$ , Schumm (1956)
<b>Relief aspects</b>	
Shape index (Sw)	$Sw = 1/Ff$ , Horton (1932)
Basin relief (r) (km)	$R = H - h$ , Schumm (1956)
Relief ratio (Rr)	$Rr = R/Lb$ , Schumm (1956)
Ruggedness number (Rn)	$Rn = R \cdot Dd$ , Strahler (1958)
Gradient ratio (Rg)	$Rg = Es - Em/Lb$ , Sreedevi et al. (2004)
Melton ruggedness ratio (MRn)	$MRn = H - h/A^{0.5}$ , Melton (1965)

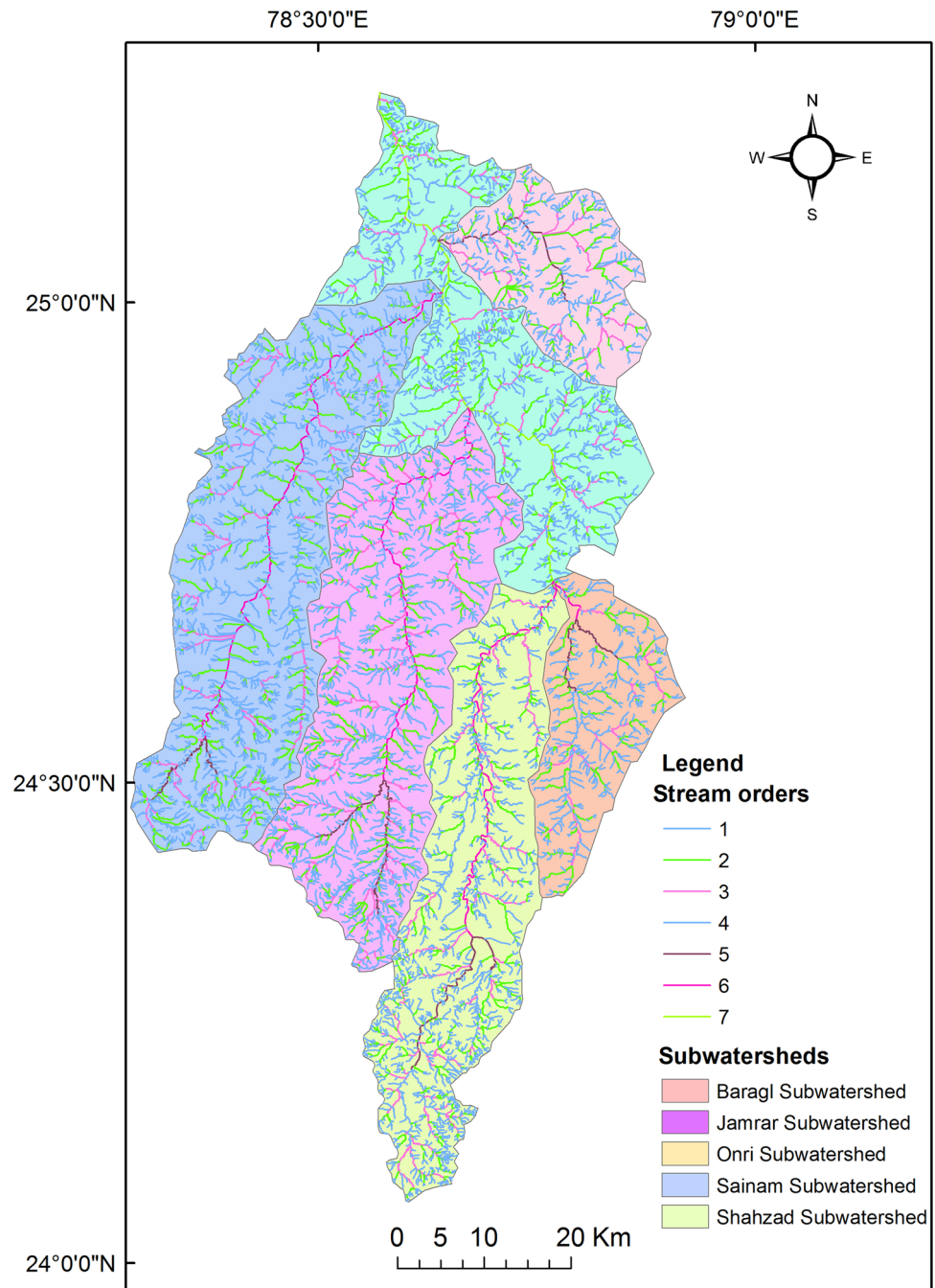
perimeter, i.e., 179.6161 km and Baragl subwatershed has smallest perimeter i.e. 84.67177 km.

#### Stream order (Nu)

“Stream order is defined as a measure of the position of a stream in the hierarchy of tributaries.” (Leopold et al. 1964). The classification of streams based on the number and type of tributary junctions has proven to be useful indicator of stream size, discharge, and drainage area (Strahler 1957). The JW is allocated as seventh order stream. The subwatersheds are divided on the basis of sixth and fifth order stream. According to Horton’s laws of stream numbers, there is an inverse geometric sequence with stream order and number of stream segments. This



**Fig. 3** Drainage with subwatersheds in which the main watershed is divided into five subwatersheds (Jamrar, Onri, Sainam, Shahzad, and Baragl subwatershed) on the basis of 6th order stream and 5th order stream



signifies that the number of streams generally decreases in geometric progression as the stream order increases.

### Bifurcation ratio (Rb)

According to Strahler (1957, 1964), the bifurcation ratio is defined as a ratio of the number of streams of a given order ( $N_u$ ) to the number of streams of the next higher order ( $N_{u+1}$ ). The values of the bifurcation ratio vary from 4.68 and 2.39 (Table 2). The average bifurcation ratio shows a linear trend between subwatershed (Fig. 4a),

inferring that the geological and structural have control on the drainage pattern. The elongated basin of the Baragl subwatershed with high Rb value would yield a low, but extended peak flow and the rotund basin of Jamrar subwatershed with low Rb value would produce a squat peak discharge (Strahler 1964).

### Stream length (Lu)

Stream length is an important hydrological feature of the basin as it reveals surface runoff character and streams of

**Table 2** Linear aspects, areal aspects, relief aspects, and tectonic parameters of Jamini river basin and its five subwatersheds

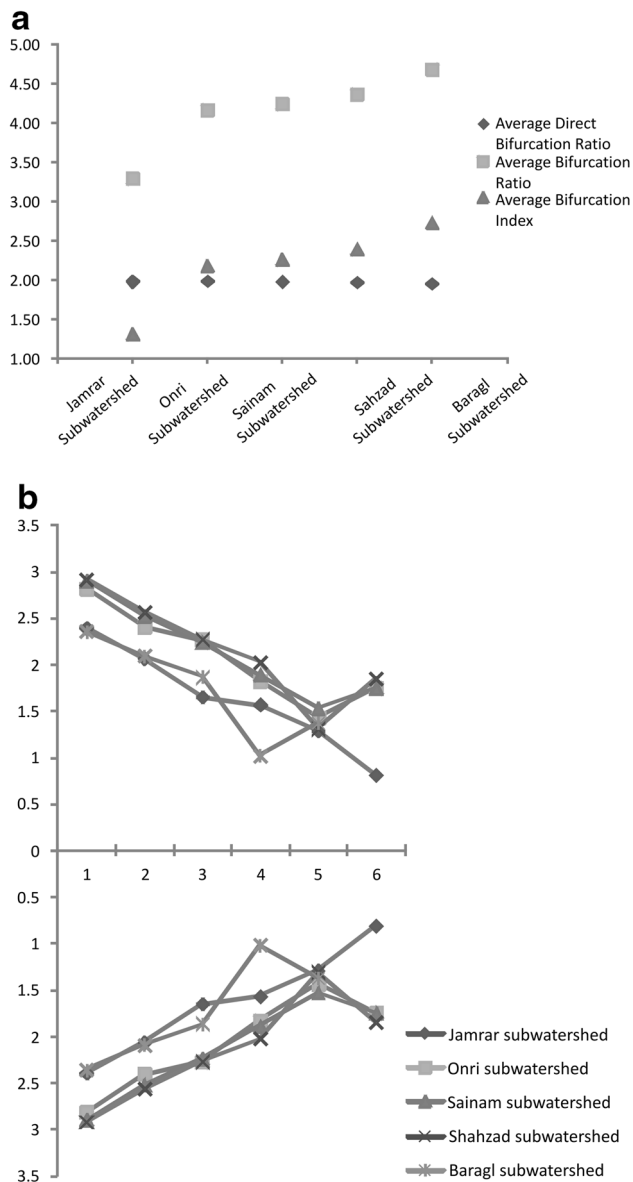
	Jamrar subwatershed (SW1)	Onri subwatershed (SW2)	Sainam subwatershed (SW3)	Shahzad subwatershed (SW4)	Baragl subwatershed (SW5)	Main watershed
<b>Linear parameters</b>						
Perimeter (P, km)	93.933	179.616	174.003	189.946	84.671	380.355
Basin length (Lb, km)	37.324	73.180	66.018	73.006	26.737	124.342
Average stream length ratio (Avg RI)	0.50	0.78	0.69	1.03	0.88	0.611
Average bifurcation ratio (Avg Rb)	3.293	4.170	4.239	4.366	4.686	4.218
Rho coefficient (R)	0.154	0.189	0.163	0.236	0.188	0.145
<b>Areal parameters</b>						
Area (A, km <sup>2</sup> )	368.09	828.661	982.25	1071.24	345.356	4398.084
Drainage density (Dd)	1.28	1.49	1.49	1.47	1.32	1.43
Stream frequency (Fs)	1.01	1.50	1.35	1.38	1.15	1.35
Drainage texture (T)	1.29	2.26	2.03	2.04	1.53	1.94
Length of overland flow (Lg)	0.30	0.33	0.33	0.34	0.37	0.34
Constant of channel maintenance (C)	0.78	0.66	0.67	0.67	0.75	0.69
Form factor (Ff)	0.26	0.15	0.22	0.20	0.48	0.28
Circulatory ratio (Rc)	0.52	0.32	0.40	0.37	0.60	0.38
Shape index (Sw)	3.78	6.46	4.43	4.97	2.06	3.51
<b>Relief and tectonic parameters</b>						
Elongation ratio (Re)	0.57	0.44	0.53	0.50	0.78	0.60
Basin relief (r)	0.065	0.222	0.229	0.183	0.084	0.307
Relief ratio (Rr)	0.0017	0.0030	0.0034	0.0025	0.0031	0.0024
Ruggedness number (Rn)	0.08	0.33	0.34	0.26	0.11	0.44
Gradient ratio (Rg)	0.0017	0.0027	0.0025	0.0017	0.0027	0.0022
Melton ruggedness ratio (MRn)	0.0033	0.0077	0.0073	0.0055	0.0045	0.0046
Average direct bifurcation ratio (Avg Rdb)	1.98	1.98	1.97	1.97	1.95	
Bifurcation index (R)	1.31	2.18	2.26	2.39	2.73	
Asymmetry factor (AF)	69.57	56.08	42.26	51.18	58.46	

relatively smaller lengths exemplify the larger slope and finer texture of the area. The streams having relatively long length are suggestive of flat topography with small gradients. The total length of stream segment is higher in first order streams and decreases as the stream order increases, pursuing the Horton's (1945) law of stream length. The mean and total stream length of each stream order is given in Table 2. The relationship between watershed area and stream length is characterized by Hack (1957) as the headward erosion is the predominant driver for the drainage network development and expansion. The rapid boost up from average stream length ratio is observed in the SB5 watershed, i.e., 1.03, symptomatic the influence of rock types variation and structural control in the development of drainage networks.

Plot of the logarithm of stream length versus stream order (Fig. 4b) showed the linear pattern which indicates the homogenous rock material subjected to weathering erosion characteristics of the basin. Deviation from its general behavior indicates that the terrain is characterized by variation in lithology and topography.

#### Stream length ratio (RI)

The stream length ratio, among 5 subwatersheds, varies from 0.50 to 1.03 (Table 2). The variability in RI is an indication of differences between slope and topography and hence it has an important control on discharge and different erosion stages of the watershed (Sreedevi et al. 2004). Higher stream length ratio indicates high erosion



**Fig. 4** **a** Scatter diagram between average bifurcation ratio, average direct bifurcation ratio, and average bifurcation index of the Jamini subwatersheds. **b** Smooth line scatter diagram between stream order versus logarithm of number of stream (LogNu) and logarithm of stream length (LogLu)

activity. The increase of RI from lower to higher orders is exemplified by the attainment of geomorphic maturity (Thomas et al. 2010).

### Rho coefficient (R)

The rho coefficient varies between 0.15 and 0.23 (Table 2) for the subwatersheds. The Rho coefficient is an important parameter relating drainage density to physiographic development of a watershed. It also assist evaluation of storage capacity of drainage network and hence, a

determinant of critical degree of drainage development in a given watershed (Horton 1945). All subwatersheds from SW1 to SW5 show lower values (0.15 and 0.23 i.e.  $R < 0.50$ ), suggesting lower hydrologic storage during floods.

### Areal aspects

The Jamini watershed occupies 4398.08 km<sup>2</sup> areas in central India and spread over parts of Uttar Pradesh and Madhya Pradesh. The areas of other subwatersheds are tabulated in the Table 2.

### Drainage density (Dd)

Drainage density (Dd) is described as an expression of the closeness of spacing of channels and quantitatively obtained by the ratio of total channel segment lengths within a basin over the basin area (Horton 1945; Strahler 1964). The Dd of the Jamini watersheds is 1.43 (Table 2). Low drainage density (1.28) of the Jamrar subwatershed is favored of resistant lithology or highly permeable subsoil materials, under dense vegetations while high drainage density (1.49) of the Onri and Sainam subwatershed is favored in regions of weak or impermeable materials with sparse vegetation cover (Strahler 1964).

Schumm (1956) used the inverse of drainage density as a property termed constant of channel maintenance. The C of JW is 0.69 (Table 2). Large value of C signifies higher infiltration rate and mature to old stage of the river.

### Drainage texture (T)

Smith (1950) suggested that drainage texture is a measure of relative channel spacing in a fluvial-dissected terrain, which is greatly influenced by climate, vegetation, lithology, soil type, relief, and stage of development of a watershed. According to Smith (1950) classification, the study area is falling under very coarse drainage texture because of the low drainage density ( $< 2$ ).

### Length of overland flow (Lg)

Horton (1945) defined length of overland flow (Lg) as the length of flow path, projected to the horizontal of non-channel flow from a point on the drainage divide to a point on the adjacent stream channel. Length of overland flow is also affected by other factors viz. rainfall intensity, infiltration rate, soils, vegetations covers, etc. In the study area, Lg varies from 0.33 and 0.39 (Table 2). Youth stage is marked with maximum length of overland flow and old stages spotted as reduction in Lg.



### Form factor (Ff)

Form factor is used to predict the flow intensity of a watershed of a defined area and this has a direct linkage to peak discharge (Horton 1945, Gregory and Walling 1973). Ff of JW is 0.28 (Table 2). The Ff of other subwatersheds is given in the Table 2. Relatively larger values of Ff ( $>0.30$ ) for Baragl and Jamrar subwatersheds are indicating higher flow peak for shorter duration.

### Circulatory ratio (Rc)

Miller (1958) used a dimensionless circulatory ratio Rc, defined as, the ratio of basin area to the area of a circle having the same perimeter as the basin. Rc of JW is 0.38 (Table 2). Low (Onri subwatershed), i.e., 0.32 and high (Baragl subwatershed), i.e., 0.60 value of Rc corresponds to youth and mature stages of watershed development.

The shape index of JW is 3.51, while the values of the subwatersheds range between 2.06 and 6.46 (Table 2). The shape index refers to elongated basin with high peak discharge.

### Relief aspect

#### Basin relief (R)

Basin relief is a parameter that determines the stream gradient and influences flood pattern and volume of sediment that can be transported (Hadley and Schumm 1961). It is also an important factor to understand denudational characteristics of the basin (Sreedevi et al. 2004). The basin relief values are tabulated in Table 2.

The larger  $R$  values (0.229 of Sainam subwatershed) are a result of the paleo and neo tectonic regimen of the the Jamini River.

#### Relief ratio (Rr)

Relief ratio is a dimensionless ratio between basin relief and basin length and widely accepted as an effective measure of gradient aspects of the watershed (Schumm 1956; Vittala et al. 2004). The Rr values of all subwatersheds are less than 0.5 (Table 2), signifying the presence of steeper slope and low permeability of surface.

#### Ruggedness number (Rn)

The ruggedness number is expressed as the product of basin relief and drainage density (Strahler 1958; Vijith and Sathesh 2006). The high ruggedness value (Table 2) of the Jamini watershed implies that the tract is more prone to

soil erosion and have structural deformation in association with relief and drainage density.

### Gradient ratio (Rg)

Gradient ratio is a marker of channel undulation which assists the assessment of the runoff volume (Sreedevi et al. 2004; Thomas et al. 2010). The large Rg values 0.00273 of Baragl subwatershed. (Table 2) of SB5 subwatershed reflects the elevated and rugged nature of the terrain.

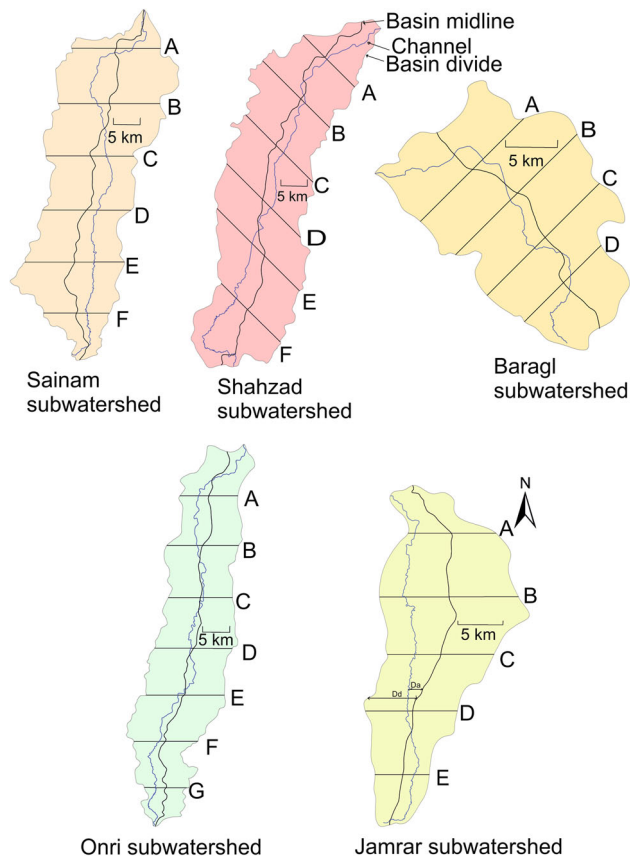
### Tectonic parameter

#### Elongation ratio (Re)

Schumm (1956) used an elongation ratio Re, defined as the ratio of diameter of a circle of the same area as the basin to a maximum basin length. The ratio in general varies between 0.40 and 1.0 over an ample diversity of climate and geology. Values close to 1.0 are distinctive of the regions characterized by very low relief, whereas values in the range 0.6–0.8 (Table 2) are generally associated with strong relief and steep ground slant. The elongated drainage basins tend to become more circular with the termination of uplift (Bull and McFadden 1977, Singh 2015) in the tectonically control areas.

#### Asymmetry factor (AF)

The Asymmetry factor permits to establish the lateral tilting of a basin with respect to the main water course (Hare and Gardner 1985; Cox 1994; Cuong and Zuchiewicz 2001; Mohan et al. 2007; Singh and Srivastava 2011; Raj 2012). This index also includes directions of possible differential tectonic (neo) activity and is also sensitive to uplift and subsidence of discrete blocks versus broad tilting (Pinter 2005). The asymmetric factor (AF) is defined as  $AF = 100 (A_r/A_t)$ , where  $A_r$  = Area of the right (facing downstream) of the trunk stream, and  $A_t$  = Total area of the drainage basin. According to Molin et al. (2004) the channel has shifted toward the left side of the drainage basin (if  $AF > 50$ ) and the channel has shifted toward the downstream right side of the drainage basin when the AF value is less than 50. Jamrar, Onri, Shahzad, and Baragl subwatersheds have  $AF > 50$  and showing that channel has shifted westward while SB3 (Sainam subwatershed) has  $AF < 50$  pointing toward their shift in the right side (eastward) of the drainage basin. The channel shift is marked by paleochannels, meander scars, and meander cutoffs.



**Fig. 5** Transverse topographic asymmetry ( $T$ ) of drainage basins of Jamrar, Onri, Sainam, Shahzad, and Baragl.  $T = Da/Dd$ , where  $Da$  is the distance from stream channel to the middle of its drainage basin and  $Dd$  is the distance from the basin margin to the middle of the basin as shown in the figure of Jamrar subwatershed

### Direct bifurcation ratio

The bifurcation ratio is the measure of the degree of branching within the hydrographic network (Horton 1945; Strahler 1952). Direct bifurcation ratio  $Rdb = Ndu / Nu + 1$ , where  $Ndu$  represents the number of fluvial segments of a given order that flows in segments of the next higher order (Guarnieri and Pirrotta 2008);  $Nu + 1$  is the number of segments of next higher order. This ratio describes the structure of the hydrographic network without considering hierarchical anomalies. Bifurcation index  $R = Rb - Rdb$ . It can give useful information on the erosive processes and on the degree of evolution of the basin (Guarnieri and Pirrotta 2008). The parameters relative to this analysis demonstrated that SB5 sub-watershed had an inadequate association of the hydrographic network due to active tectonics. SB1 subwatershed shows low bifurcation index which are sure indicators of notable tectonic imprint on the drainage network.

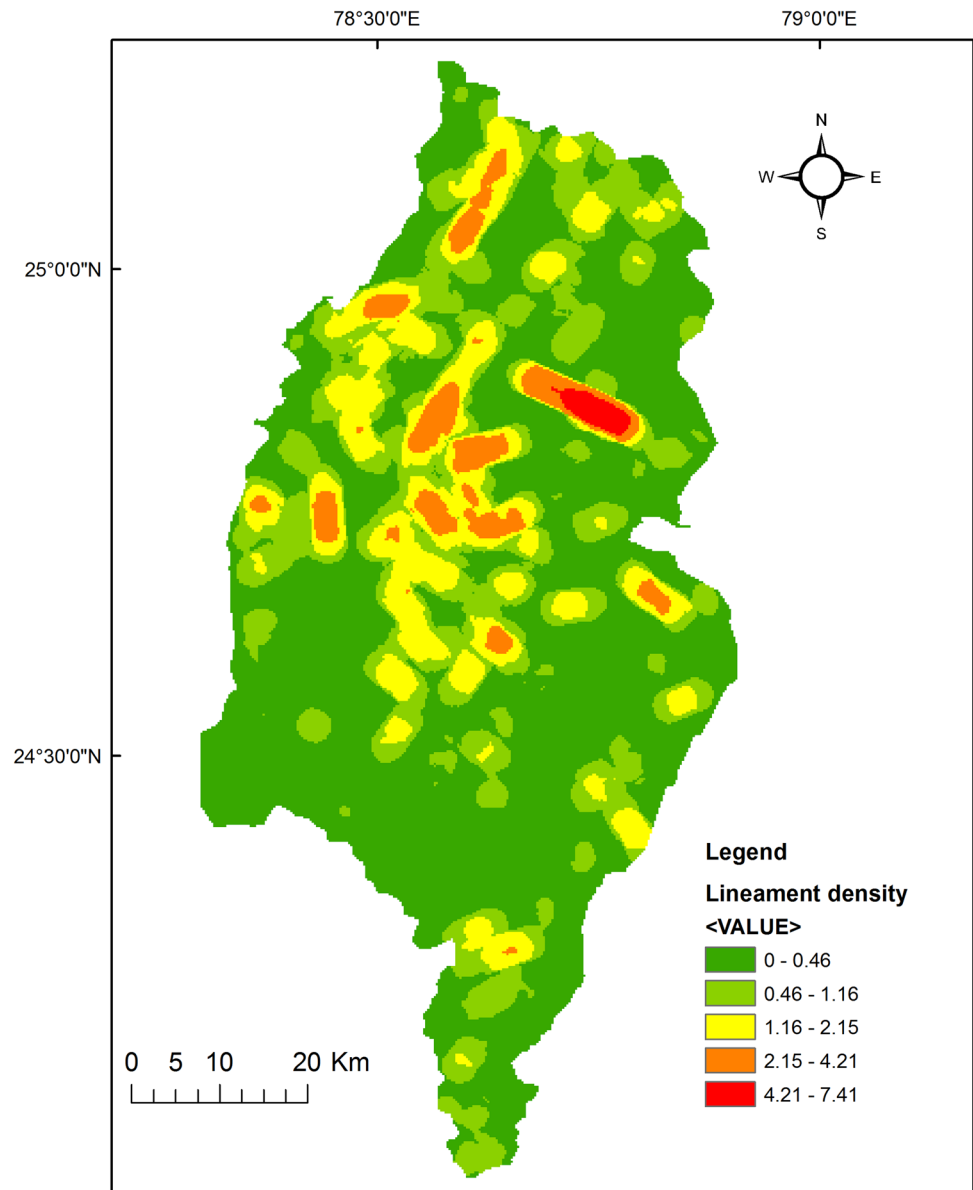
A scatter diagram of bifurcation index, average bifurcation ratio, and average direct bifurcation ratio is

**Table 3** Transverse topographic asymmetric ( $T$ ) of the Jamini and its subwatersheds

Transverse topographic asymmetry ( $T$ )	
$T = Da/Dd$ (segment wise)	
Jamrar subwatershed	
A	0.84
B	0.63
C	0.49
D	0.10
E	0.42
Onri subwatershed	
A	0.35
B	0.15
C	0.08
D	0.06
E	0.15
F	0.19
G	0.49
Sainam subwatershed	
A	0.37
B	0.23
C	0.35
D	0.24
E	0.40
F	0.32
Shahzad subwatershed	
A	0.07
B	0.14
C	0.20
D	0.22
E	0.26
F	0.43
Baragl subwatershed	
A	0.19
B	0.12
C	0.18
D	0.18

tabulated in Table 2. The linear resemblance (Fig. 4a), demonstrating the control of the lithology and geological structures on distorted trellis and dendritic drainage pattern. A scatter diagram with smooth line and marks (Fig. 4b) of stream order (on abscissa) and logarithm of number of streams and logarithm of stream length is constant throughout the successive order of basin and advocating the preserved geometrical similarity in ascending order. The parameters relative to this analysis show that Onri, Sainam, Shahzad, and Baragl show a scant organization of the hydrographic network due to active tectonics. Jamrar rivers show low bifurcation index which are positive

**Fig. 6** Lineament density variation map of the study area



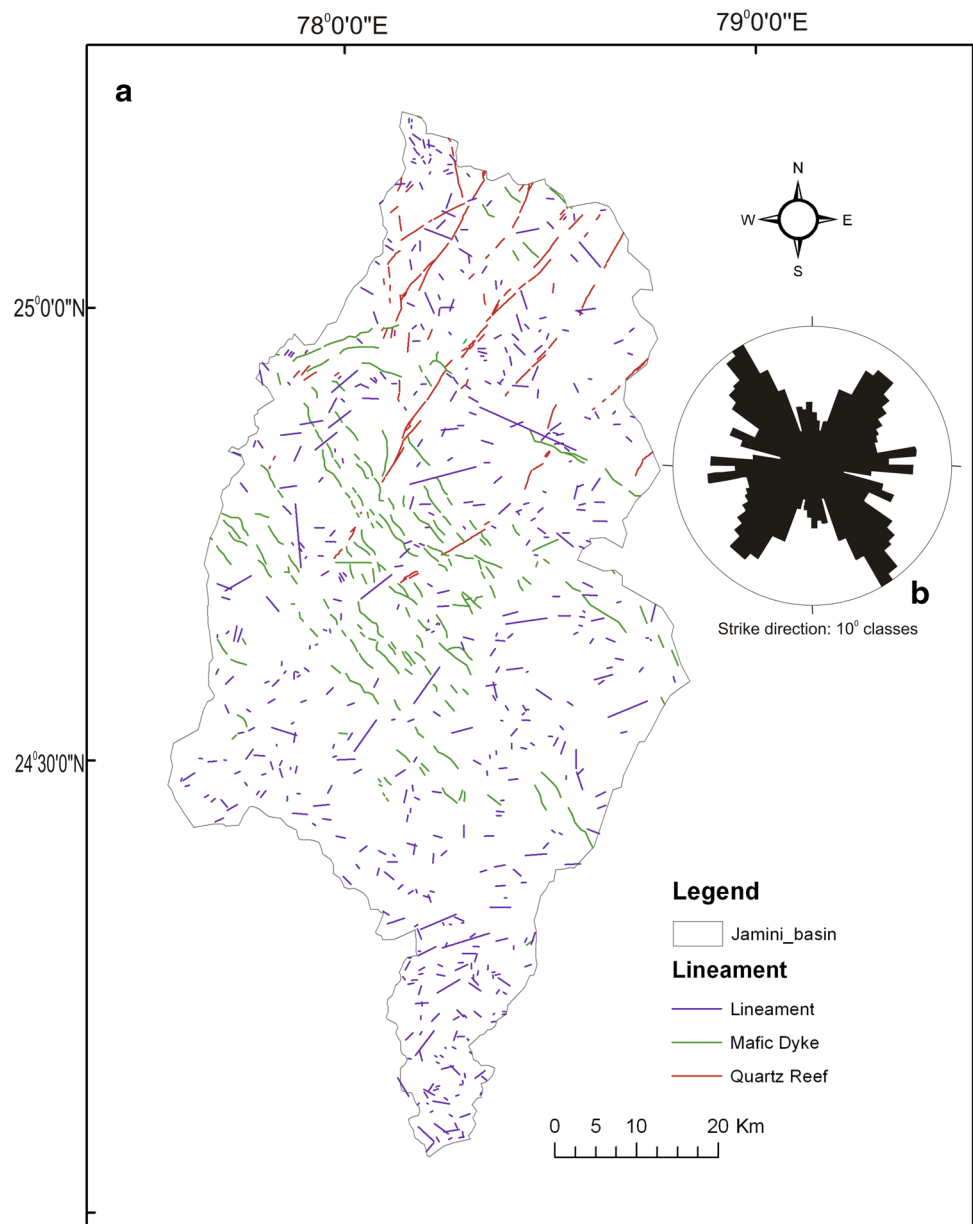
indicators of notable tectonic imprint on the drainage network (Table 2).

### Transverse topography asymmetry (T)

Transverse topographic asymmetry (T) is a reconnaissance tool for area, presenting lateral tilting (Cox et al. 2001). The cross valley asymmetry of its drainage basin for a specified sector of the stream is exemplified as a ratio of  $D_a$  and  $D_d$  (Fig. 5), where  $D_a$  is the distance from stream channel to the middle of its drainage basin and  $D_d$  is the distance from the basin margin to the middle of the basin (Fig. 5). If the value of  $D_a = 0$  and then the ratio  $D_a/D_d$  is also zero, signifying a symmetrical basin, representing that

the stream segment is in the middle of the drainage basin and inferring the non-tilted basin. As the value of  $D_a/D_d$  will tend toward 1, the stream migrates laterally away from the center of the basin toward the margin, representing the tilted basin. The values of transverse topography asymmetry (T) for the Jamini and its tributaries are tabulated in Table 3. The Jamrar subwatershed show strong asymmetry (average is 0.496) while the low topography asymmetry values (average is 0.17) of Baragl subwatershed explained by less tilt of the basin. From the values of topography asymmetry, we can construe the cause of asymmetry, which could depend on change in lithology, structural/tectonic disturbances, neotectonic structural features (e.g., pseudotachylite rocks).

**Fig. 7** **a** Spatial distribution of lineaments (823) in the Jamini river basin. **b** Rose diagram showing orientation of lineaments



### Orientations and lineament density

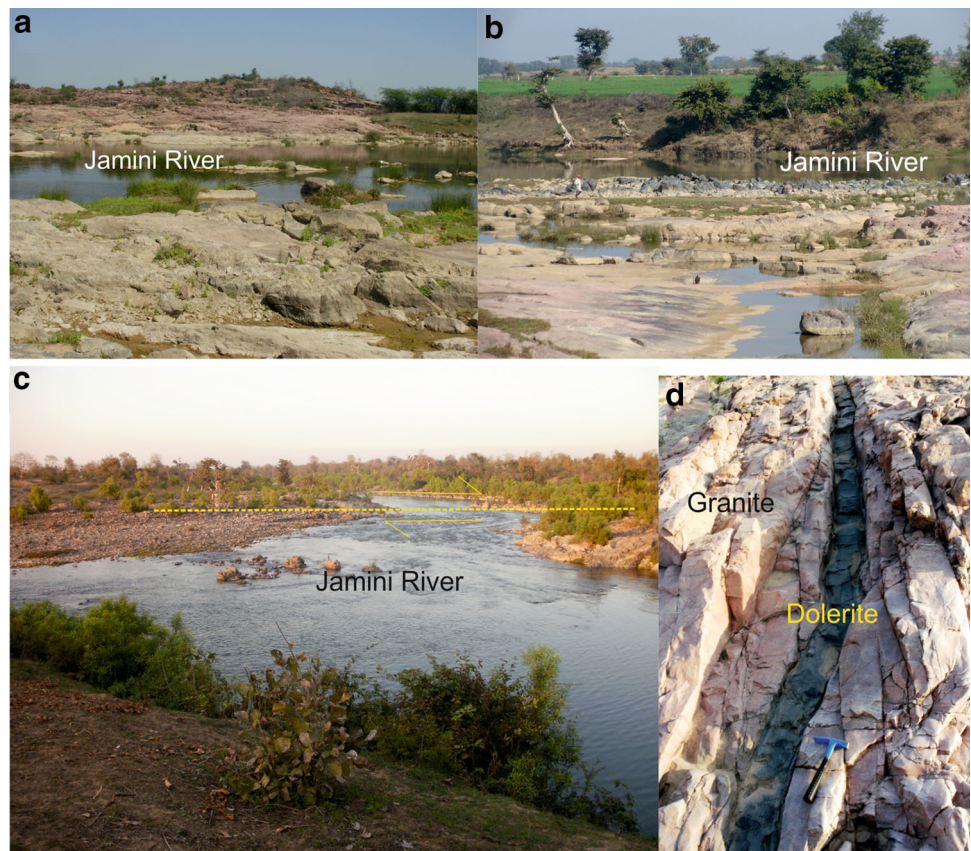
Orientation and extent of individual linear structure was calculated in Arc GIS 10.0 software. Some discontinuous linear structures continuing over hundreds of km in Bundelkhand craton, with similar orientation, were counted as one linear structure during the statistical analysis. The data so obtained was used to prepare lineament density (Fig. 6) plots in Arc GIS software. The orientation of various linear elements observed on the basis of Landsat ETM+ data and further validated by field studies has been shown in fig.7a.

According to Nur (1982), the lineaments are one of the important components of the earth's surface morphology and the lineament density is related to the intensity of

deformation. The orientations of linear structures have been shown in the form of a rose diagram (Fig. 7a, b) with a total number of 823 linear structures. The linear structures traced out from LANDSAT (ETM+) imageries and verified by selected field checks (Fig. 8a–d) indicate three main azimuthal frequencies in E-W, NE-SW, and NW-SE directions representing the three major deformation trends stratigraphically as shear zone, giant quartz veins, and basic dykes (youngest), respectively. The azimuthal frequency of NE-SW trending lineaments is comparatively low. In general, all these fractures can be formed either due to shear rupture or tensile failure. Shear failure (Hodgson, 1961) can very well explain the origin of lineament but rarely supported by in situ observations (Nur, 1982). It is



**Fig. 8** **a** The Jamini River flowing through confined valley setting in Bundelkhand Granitic Complex with occasional flood plain pockets having bedrock, boulder, and gravel. **b** Exposed Bundelkhand granite with mafic dyke intrusion along course of the Jamini River. **c** Sudden change of course of the Jamini River inferring to structural control of river. **d** Dolerite dyke intruding in Bundelkhand granite along the fracture present in granite



interesting to note that the maximum lineament frequency is found in the central part of Bundelkhand Craton (Fig. 6). Most of the lower order drainages of the Jamini river basin follow the NW–SE trend while higher order channels follow NE–SW trends.

## Conclusion

The study shows that GIS techniques have efficient tools for the assessment of drainage characteristics of the Jamini river watershed and its four, sixth order subwatersheds, and one fifth order sub-watershed to comprehend the significance of morphometry and morphotectonic studies in terrain characterization (such as nature of bedrock, infiltration capacity, surface run off, etc.) and expansion of the river basin.

Systematically organized and well-developed drainage network with large number of first and second order streams in the Jamini basin is validated through the homogeneous weathering and head-ward erosion. The area exhibits dendritic drainage pattern on the whole, however, sporadic trellis and centripetal pattern are also noticed in some region. Very high fraction of first and second order streams point out the structural deformation, mainly as

fractures, lineaments, and deformed litho units. The values of bifurcation ratio ( $R_b$ ) for the Jamini watershed illustrate dissected mountainous nature of watersheds having high drainage integration and mature topography. The numerical value of asymmetry factor ( $AF$ ) of the Sainam subwatershed pointed toward eastward shift in the channels. The paleochannels, meandercutoffs, and paleobars also correspond to the channel shift. Transverse topographic asymmetry ( $T$ ) values of five subwatersheds of the Jamini river have revealed that the subwatersheds are also influenced by the regional tilt. The low values of circulatory ratio and elongation ratio of the subwatersheds are also substantiating that the rivers drain a tectonically active area.

The trends of lineament and fault have good correlation with orientations of streams. The E–W oriented tectonic direction (shear zone trend) is likely to have controlled the drainage patterns in an early phase, followed by NW–SE and NE–SW trends. It advocates the probability that the NW–SE trending tectonic lines (trend of basic dyke) have been reactivated in recent times (late Pleistocene). The presence of E–W, NE–SW, and NW–SE stream trends in all illustrations recommends that the equivalent tectonic trends have been the main considerable tectonic events in the morphological advancement and hydrographic development of the basin. The stream trends pursue the



ascertained faults in the area which are mainly in E–W, NE–SW, and NW–SE directions. The present study indicates the active tectonics in various sectors of the area and their role in shaping the Jamini rivers basin.

Consequently, the morphotectonic analysis provides a better understanding for the status of land form and their processes, drainage management and evolution of groundwater potential for watershed planning and their management in water-deficient areas. The generated data may be used for various future projects in Jamini river basin management like ground water surveys by locating the zones of higher secondary porosity through lineament density data.

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