Geomorphological Analysis of the Ukhma River Basin from the Northern Foreland of Peninsular India

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1 Introduction

Fluvial landforms are primarily shaped by river systems (Vandenberghe, 2002; Corenblit et al., 2007). Previous studies have concentrated on geometric characteristics and practices, including quantitative investigation of the drainage basin's texture, shape, pattern, relief, and topography (Schumm, 1986; Burbank et al., 2000; Huggett & Cheesman, 2002; Rai, 2017).

The drainage pattern reflects the surface expression of underlying lithology and typical physiographic features (Pophare et al., 2014). Any hydrological investigation, including groundwater efficiency estimation and management, requires its morphometric analysis of the river basin (Waikar, 2014; Mustafa, 2016).

The morphometric analysis, with the support of the digital elevation model (DEM) and remote sensing data, ensures accurate information on the stream network. It also helps to understand the geomorphological and geology of the basin (Kumar et al., 2011; Rai, 2017). The morphometric variables such as slope, area, altitude, volume, profile, and texture of landforms include important study parameters (Rai et al., 2014; Singh et al., 2018a, b; Kanhaiya et al., 2019a, b, c; Prakash et al., 2019; Singh et al., 2020).

The morphometric investigation estimates the channel's relief, aerial, linear, and gradient (Singh et al., 2018a, b). Numerous researchers have utilized GIS and

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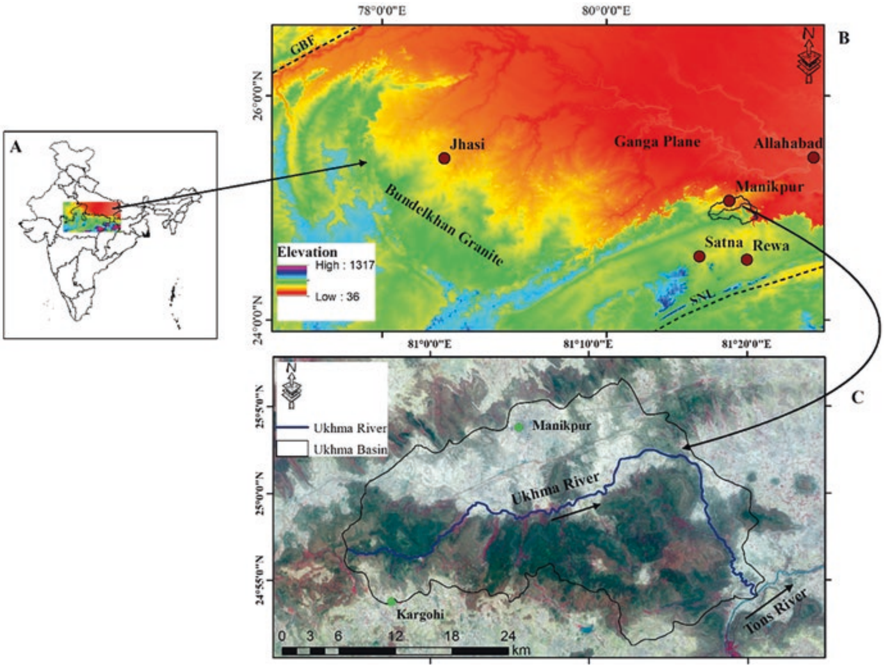

Fig. 1 The map shows the location of the Ukhma river basin (Singh et al., 2022)

remote sensing techniques to investigate the morphometric analysis of river basins in recent and previous years (Horton, 1945; Strahler, 1957; Babar & Kaplay, 1998; Kaplay et al., 2004; Babar, 2001, 2002, 2005; Sreedevi et al., 2009; Singh et al., 2013; Jadhav & Babar, 2014; Singh & Kanhaiya 2015; Rai, 2017; Prakash et al., 2019; Solangi et al., 2019a, b, Singh et al., 2021).

The present study focuses on the characterization of the Ukhma river basin using GIS and remote sensing techniques (Fig.1a–c). The morphometric parameters, in conjunction with morphotectonics, have undergone comprehensive analysis and discussion to delineate the river basin's structure. This exploration aims to ascertain its effectiveness in water harvesting and groundwater management.

2 Geology of the Area

The Ukhma river is the tributary of the Tons River. It flows through districts such as Rewa and Satna of Madhya Pradesh, Central India (Fig. 1a–c). A typical seasonal river, the river Ukhma, joins the Tons River near Deokhar Village in the Satna district and originates from Ledari Village. The area of the Ukhma basin lies on Vindhyan rocks, covering an area of about 745 km^2.

The Ukhma basin covers one of the most dominant stratigraphic horizons in Central India, viz., Vindhyan Supergroup. Two distinct groups within the Vindhyan Supergroup are distinguished by distinct regional unconformity: Kaimur, Rewa, and Bhander Groups make up the Upper Vindhyan and the Lower Vindhyan (Semri Group) (Auden, 1933; Chakraborty & Chaudhuri, 1990; Chakraborty et al., 1998; Chakraborty, 2006; Shukla et al., 2014; Verma & Shukla, 2020). The maximum part of the study area is covered by the Rewa Group of rock, which consists of sandstone and shale, followed by the Kaimur Group.

The Aravalli-Delhi orogenic belt confines the Vindhyan Basin to the west and the Satpura orogenic belt to the south. According to Roy and Bandyopadhyay (1990), Verma (1991), and Verma (1996), the Mahakoshal Supergroup and the Bijawar Supergroup are low-grade metamorphic rocks to the east. The Vindhyan Basin's southern tectonic boundary is marked by the Son-Narmada lineament. It is accepted that this structural design appeared during the Archean and has stayed dynamic all through its geologic past (Naqvi & Rogers, 1987; Kaila, 1986; Kaila et al., 1989) (Fig. 1b). A southerly dipping reverse fault separates the Vindhyans from the Satpura mobile belt further south of this lineament (Tewari et al., 2001).

This fault appears to have generated deformations in the sedimentary rocks occurring immediately to its North in the Son Valley. However, these deformations are untraceable to the west, possibly due to the cover of younger rocks (Rogers, 1986). It is believed that the mountain-building activity in the Satpura was underway during the early phases of deposition in the Vindhyan Basin. At a later stage, the folded rocks of the Satpura were transported onto the Vindhyan (Naqvi & Rogers, 1987). The Great Boundary Fault (GBF) at the western margin in Rajasthan roughly separates the Vindhyan from the Archean/Paleoproterozoic Aravalli/Delhi Foldbelt (Fig. 1b). Although it was earlier believed that the GBF was purely a pre-Vindhyan fault that bounded the Vindhyan from the pre-Vindhyan rocks, there is sufficient field evidence that indicates that it had abundant reactivations after the deposition of the Vindhyan (Banerjee & Singh, 1981; Kaila, 1986; Kaila et al., 1989; Srivastava & Sahay, 2003).

3 Methodology

The Ukhma Basin boundary has been delineated using Survey of India (SOI) topographical maps No. 63C/16, 63D/13, 63G/8,4, and 63H/1,5 at a 1:50,000 scale. The Universal Transverse Mercator (UTM) projection WGS 1984, Zone 44 North, serves as a georeference for the topographical maps. Arc GIS 10 software uses SOI topographical maps to extract the streams of the Ukhma Basin. The entire high-resolution advanced topographic database of the Earth's surface was created by the Shuttle Radar Topography Mission (SRTM), which collected elevation (height) data from all over the world. Geomorphological parameters like slope aspect and gradient were identified using the SRTM DEM. Deformation (structural) features like

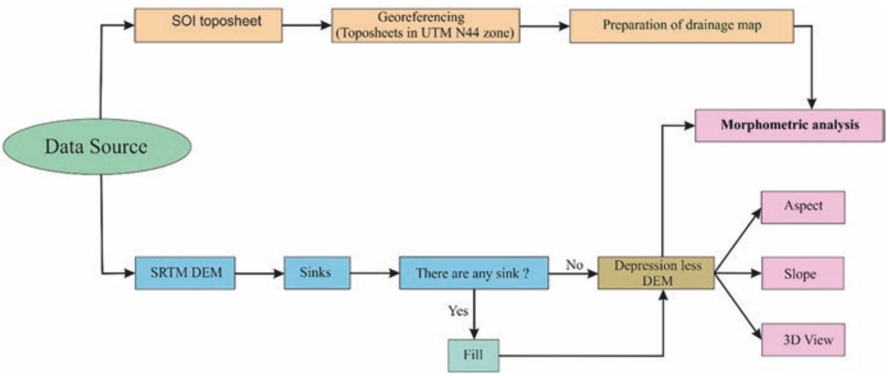

Fig. 2 The flowchart depicts the in-depth methodology

joints, fractures, and drainage offset (linear features or lineaments) were determined

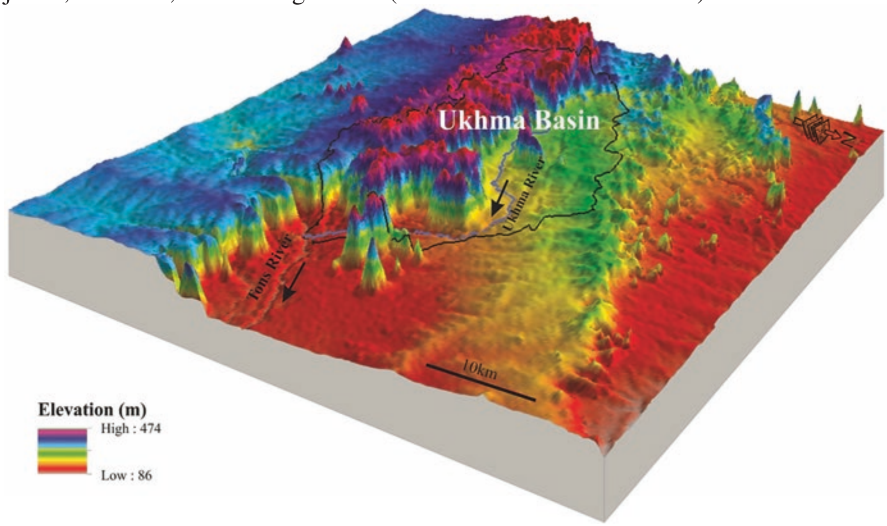

Fig. 3 The digital elevation model of the Ukhma river basin drove from SRTM data. The elevation varies between 86 to 474 m in the study area

using Sentinal-2 images. The flowchart (Fig. 2) depicts the in-depth methodology.

The data from the SRTM DEM (Fig. 3) is used to highlight important geomorphological parameters like slope aspect and gradient (Fig. 4). This study used Strahler's (1964) stream order method. A mathematical approach and formula for calculating the basin morphometric parameters are presented in Table 1.

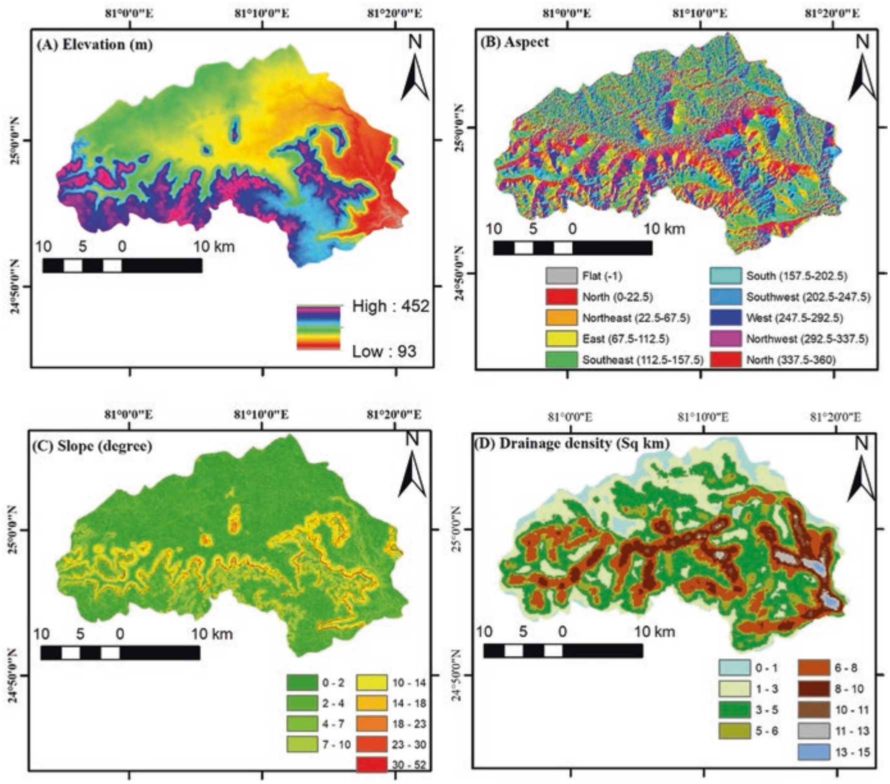

Fig. 4 (**a**) Relief map, (**b**) aspect map, (**c**) slope map, and (**d**) drainage density map of the Ukhma river basin

4 Results

The morphometric analysis involves the measurement and analytical study of the river basin. Morphometric studies include basin area, altitude, volume, slope, profiles of the River, and drainage basin characteristics of the catchment zone concerned (Clark, 1966). Ukhma river basin is a six-order basin with fifth-order 10 subbasins, viz., Jiro, Gularha, Chhatan, Baridari, Bedhak, Dharkundi, Kakarhai, Terhwa, Jarera, and Karibarah subbasin are, shown in Fig. 5.

The characteristics of linear, areal, and relief perspectives have been examined and illustrated in the accompanying results, along with their respective features.

4.1 Drainage Pattern and Morphometric Aspects

The drainage orientations (direction) of the Ukhma River basin (UW) show polymodal distribution (NE–SW, NW–SE, N–S, and E–W) (Fig. 5). The dendritic drainage pattern is primarily found in the lower part of the Ukhma river basin. The

Table 1 Different parameters implemented for morphometric analysis

	Parameter	Definition
Linear aspects		
	Perimeter (P) (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)
	Rho coefficient(R)	$R = Rl/Rb$, Horton (1945)
Areal aspects		
	Area (A) (km^2)	
	Drainage density (Dd) (km km-2)	$Dd = \sum Lt/A$, Horton (1945)
	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)	$Ff = A/Lb2$, Horton (1945)
	Circularity ratio (Rc)	$Rc = 4\prod A/P2$, Miller (1953)
	Elongation ratio (re)	$Re = 1.128\sqrt{A}/Lb$, Schumm (1956)
Relief aspects		
	Basin relief (R) (km)	$R = H-h$, Schumm (1956)
	Relief ratio (Rr)	$Rr = R/Lb$, Schumm (1956)
	Relief ratio (Rr)	$Rr = R/Lb$, Schumm (1956)
	Gradient ratio (Rg)	$Rg = Es-Em/Lb$, Sreedevi et al.(2004)
	Melton ruggedness ratio (MRn)	$MRn = H–h/A^{0.5}$, Melton (1965)

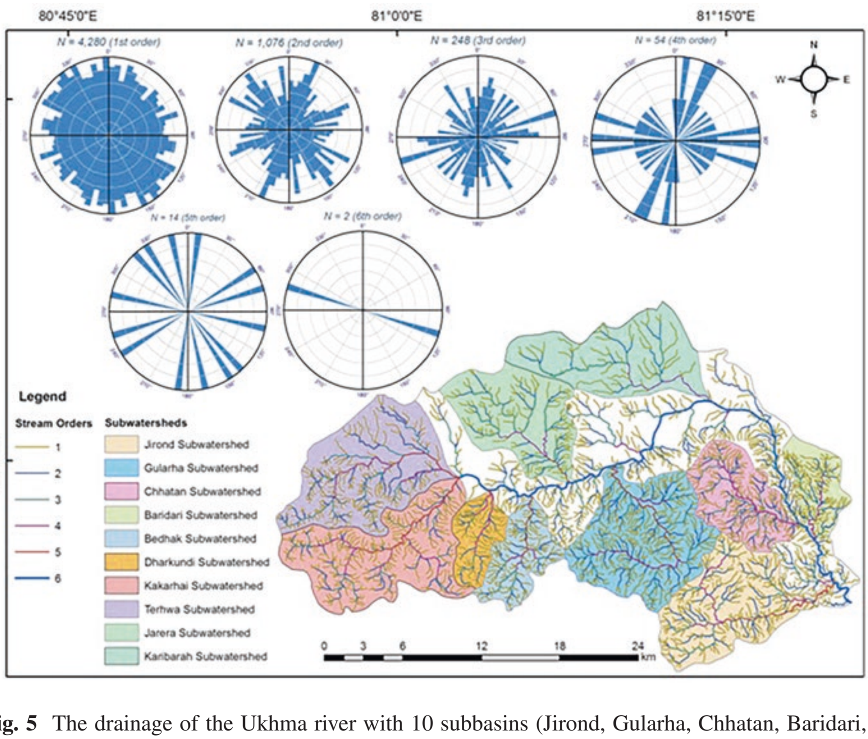

Fig. 5 The drainage of the Ukhma river with 10 subbasins (Jirond, Gularha, Chhatan, Baridari, Bedhak, Dharkundi, Kakarhai, Terhwa, Jarera, and Karibarah)

dendritic patterns resemble a zone of similar lithologies. The elevation, aspect, slope, and drainage density map also have been prepared and shown in Fig. 4a–d. The elevation, aspect, slope, and drainage density map are beneficial to determine the distribution of vegetation, biodiversity in the basin area, morpho-conservation practices, etc. (Sreedevi et al., 2004).

4.2 *Linear Characteristics of the Basin*

From head to mouth, stream network reveals the behavior of a stream and its tributaries and reflects the structural and lithological controls on the drainage basin. A drainage basin's perimeter, stream order, length, bifurcation ratio, stream length ratio, and rho coefficient are all important linear properties.

The Ukhma River basin is divided into ten 5th-order stream subbasins and has a perimeter of 139.74 kilometers (Table 2). The Dharkundi subbasin has a minimum perimeter of 20.31 km, while the Kakarhai subbasin has a maximum perimeter of 50.52 km. According to Leopold (1969), stream order demonstrates a stream's distinct position within a drainage basin. The Ukhma river basin is designated as the sixth-order stream in accordance with Strahler's stream ordering (Strahler, 1957, 1958).

For a given order, the length of the stream indicates the basin's contributing region (Horton, 1945). The length of stream segments is inversely proportional to the order of the streams (Fig. 6). It indicates that stream length increases with stream order and decreases in first-order streams (Fig. 7). Table 2 displays the average and total lengths of each stream. Hack (1957) depicts the relationship between basin territory and stream length, stating that head-ward erosion is the predominant river for drainage system expansion and improvement. The Dharkundi subbasin has the highest stream length ratio (0.66), indicating that structures and rock types influence the development of drainage patterns.

The bifurcation ratio is the proportion between the number of following higher-order streams and the number of streams of a given order (Strahler, 1964).

The bifurcation ratio ranges from 3 to 7, by which the geological structures control the drainage pattern. The typical Rb of the Ukhma Bowl is 4.75 (Table 2), which shows the undulating region with high surface runoff and moderate permeability of litho-units.

As defined by Horton (1945), the stream length ratio is the proportion of the stream's mean length to the following lower order of the stream segments. The stream length proportion among 10 subbasins varies from 0.49 to 0.66. According to Sreedevi et al. (2004), the RL values' variations are directly related to the topography and lithology. The high erosion activity indicates a higher stream length ratio. The stream length ratio increases from lower- to higher-order and is represented as an achievement of geomorphic development (Thomas et al., 2010; Prakash et al., 2016a, b, 2017; Singh et al., 2018a, b, 2020, 2021).

Table 2 Morphometric parameters of the Ukhma river basin and its subbasins

Linear aspects	Jirond subwatershed	Gularha subwatershed	Chhatan subwatershed	Baridari subwatershed	Bedhak subwatershed	Dharkundi subwatershed	Kakarhai subwatershed	Terhwa subwatershed	Jarera subwatershed	Karibarah subwatershed	Main watershed
Perimeter (P) (km)	41.74	40.16	27.99	21.44	27.63	20.31	50.52	42.28	33.82	40.61	139.74
Stream order (Nu)	294	405	273	167	166	104	347	291	151	62	2837
Stream length (Lu) (km)	206.79	268.11	167.49	93.02	101.05	67.62	222.46	197.81	122.92	91.59	1995.38
Bifurcation ratio (Rb)	3.93	4.38	6.58	5.11	3.34	3.21	4.03	3.96	3.36	3.54	4.75
Stream length ratio (Rl)	0.601	0.558	0.499	0.585	0.627	0.667	0.582	0.497	0.491	0.625	0.562
Rho coefficient(R)	0.152	0.127	0.075	0.114	0.187	0.207	0.144	0.125	0.146	0.176	0.118
Areal aspects											
Area (A) (km^2)	69.91	81.51	43.79	24.01	30.19	20.96	82.21	84.89	60.17	66.74	745.84
Drainage density (Dd) (km km^2)	2.95	3.28	3.82	3.87	3.34	3.22	2.71	2.33	2.04	1.37	2.67
Length of overland flow (Lg) (km)	1.47	1.64	1.91	1.93	1.67	1.61	1.35	1.16	1.02	0.68	1.33
Constant of channel maintenance (C) (km)	0.33	0.3	0.26	0.25	0.29	0.31	0.36	0.42	0.48	0.72	0.37
Form factor (Ff)	0.34	0.61	0.5	0.37	0.38	0.38	0.4	0.41	0.4	0.26	0.4
Circularity ratio (Rc)	0.5	0.63	0.7	0.65	0.49	0.63	0.4	0.59	0.66	0.5	0.47

Elongation ratio (Re)	0.66	0.88	0.8	0.68	0.7	0.7	0.71	0.72	0.71	0.57	0.71
Relief aspects											
Basin relief (R) (km)	0.311	0.243	0.295	0.183	0.215	0.218	0.193	0.213	0.069	0.093	0.312
Relief ratio (Rr)	0.021	0.021	0.031	0.022	0.024	0.029	0.013	0.014	0.005	0.005	0.007
Gradient ratio (Rg)	0.021	0.02	0.031	0.021	0.023	0.029	0.013	0.014	0.005	0.005	0.007
Melton ruggedness ratio (MRn)	0.037	0.026	0.044	0.037	0.039	0.047	0.021	0.023	0.008	0.011	0.011

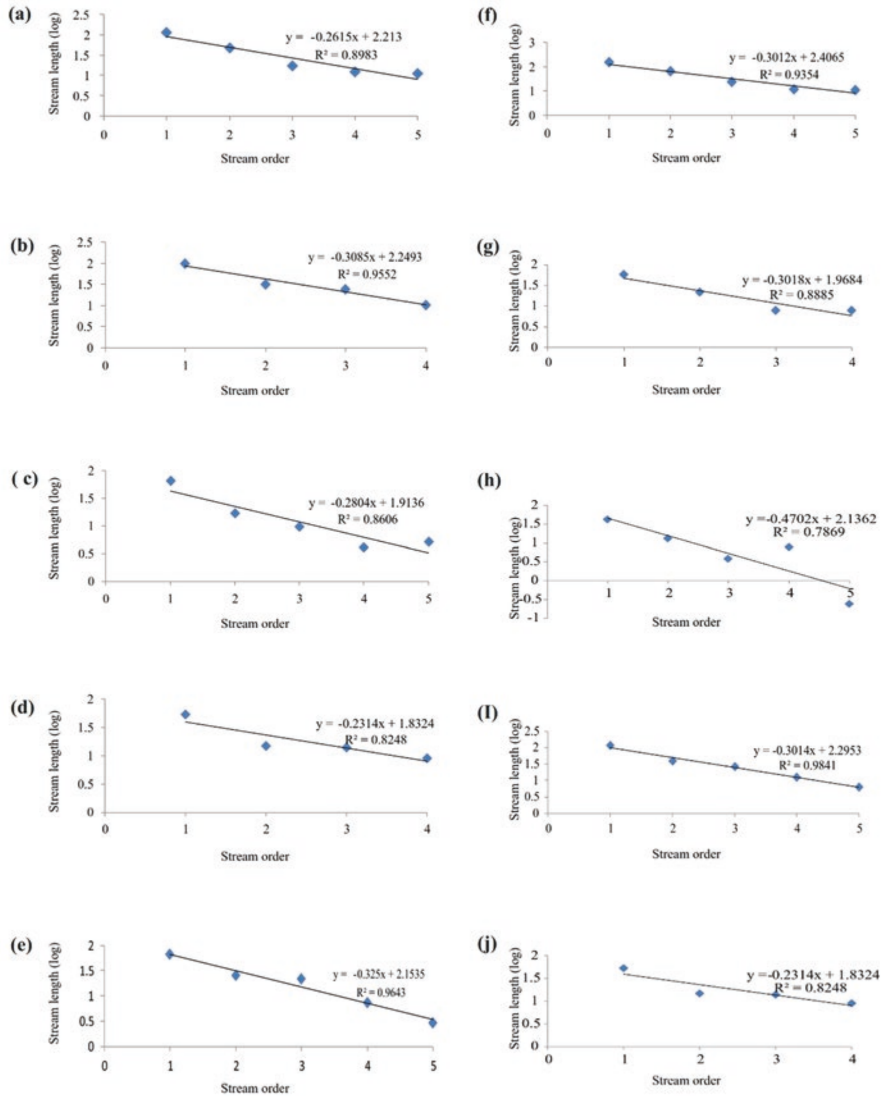

Fig. 6 The relation between stream order and stream length (**a**) Jirond subbasin (**b**) Chhatan subbasin (**c**) Bedhak subbasin (**d**) Kakarhai subbasin (**e**) Jarera subbasin (**f**) Gularha subbasin (**g**) Baridari subbasin (**h**) Dharkundi subbasin (**i**) Terhwa subbasin (**j**) Karibar

The Rho coefficient is characterized as the proportion of the stream length ratio to the bifurcation ratio. For the subbasins, the rho coefficient varies between 0.07 and 0.21. It is an essential parameter relating drainage density to the physiography maturity of a basin. It is a crucial parameter that links drainage density to a basin's physiography maturity. The Rho coefficient is a valuable parameter for assessing the storage capacity limit of the drainage system (Horton, 1945). Higher hydrologic

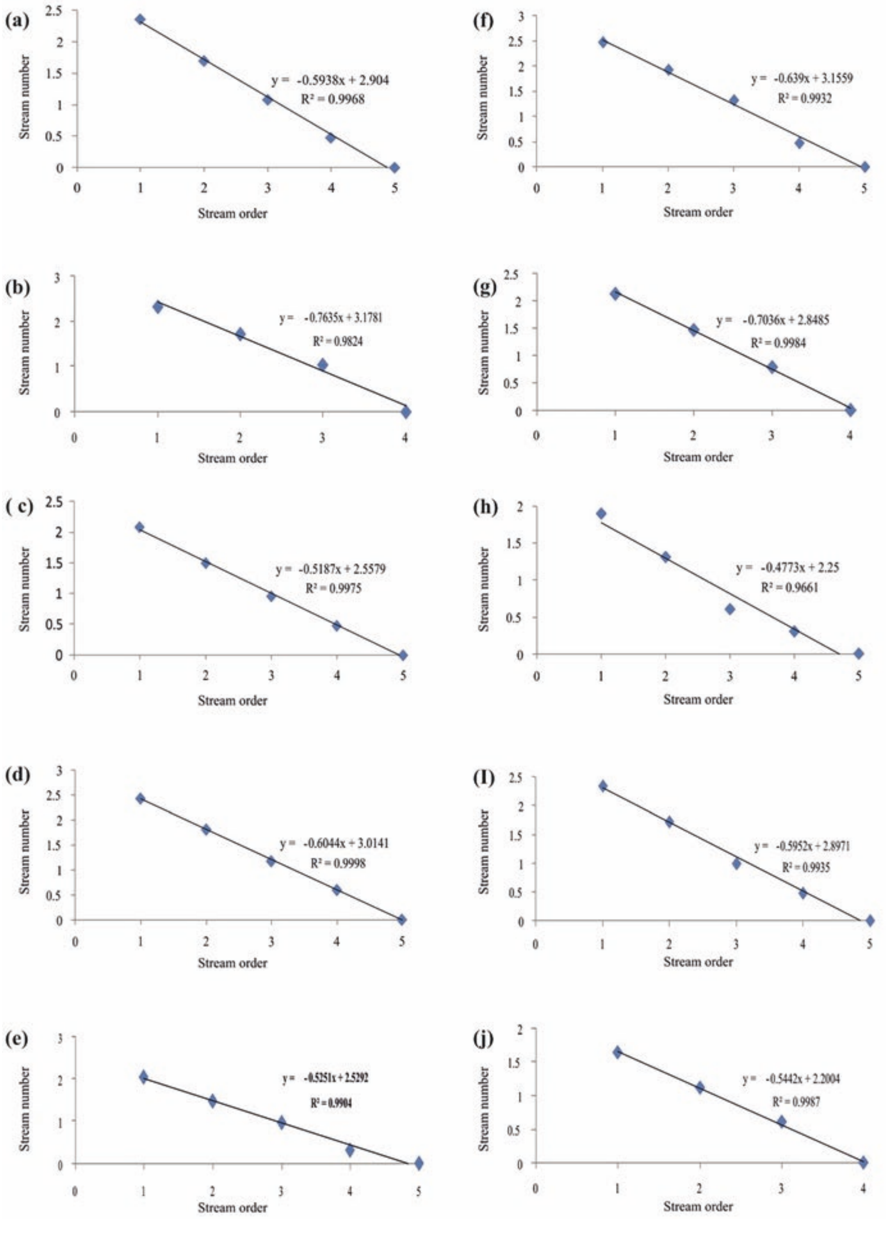

Fig. 7 The relation between stream order and stream number (**a**) Jirond subbasin (**b**) Chhatan subbasin (**c**) Bedhak subbasin (**d**) Kakarhai subbasin (**e**) Jarera subbasin (**f**) Gularha subbasin (**g**) Baridari subbasin (**h**) Dharkundi subbasin (**i**) Terhwa subbasin (**j**) Karibara subbasin

storage during floods and decreased erosion during high discharge explain the higher Rho coefficient values found in the Dharkundi and Bedhak subbasins.

4.3 Areal Aspects of the Basin

Geological structure, climatic conditions, lithology, and the basin's history of denudation are all revealed by the areal aspects of a drainage basin. Basin area, drainage density, overland flow length, constant channel maintenance, form factor, circulatory ratio, and elongation ratio are all aerial aspects of a drainage basin. The Ukhma basin occupies a 745.84 km^2 area in Central India. The areas of 10 subbasins are arranged and summarized in Table 2.

The ratio of total channel lengths within a basin to the basin's area is known as drainage density (Dd). It could also indicate how close the channels' spacing is (Strahler, 1964). Under dense vegetation and low relief, a low Dd is more likely to occur in a region with highly resistant and permeable subsoil. Mountainous relief, weak or impermeable subsurface material, and sparse vegetation all indicate a high drainage density. The Ukhma River basin has a drainage density of 2.67 per km, which indicates a moderate drainage density (Table 1). According to Rai (2017) and Thomas et al. (2010), the basin should have permeable subsoil and vegetative cover due to the moderate drainage density. Figure 4 depicts the Ukhma basin's drainage density map. The Karibarah subbasin's low drainage density is preferable to resistant lithology or extremely permeable subsoil beneath dense vegetation.

In contrast, the Baridari subbasin's high drainage density is supported in locations with weak or impermeable materials and minimal vegetation cover. The distance from the crest line at which the flow concentration occurs is used to calculate the overland flow length (Lg) (Horton, 1945, Rudraiah et al., 2008). According to Horton (1945), Lg is a significant parameter that influences the hydrological and physiographical developments of the drainage basin. Lg ranges between 0.68 and 1.93 in the study area (Table 2). The Baridari and Chhatan subbasins are characterized by an early stage of basin development, whereas other subbasins, such as the Ukhma basin, are assumed to have reached a mature stage.

Drainage density and the constant of channel maintenance (C) complement one another (Schumm, 1956). The basin's slope, permeability, climatic conditions, vegetation cover, erosional activity duration, and rock types influence the C. The C value of the Ukhma basin (UW) is 1.33 and differs from 0.25 and 0.72 for every 10 subbasins (Table 2). Subbasins with low C values are categorized as areas with few structural constraints. The stream's old saying is that a higher value of C indicates a higher invasion rate.

The drainage basin's shape and flow intensity are directly related to peak discharge by the form factor (Ff) (Gregory & Walling, 1973; Magesh et al., 2012). The higher Ff values of the Gularha and Chhatan subbasins (> 0.51) suggested that the peak flow was increased and lasted for a shorter time. In contrast, the Karibarah subbasin's lower value indicates shorter periods of insufficient peak flow.

According to Miller (1958), the circularity proportion (Rc) is the proportion of the basin area to the area of a circle with the same parameter as the basin. It is influenced by the basin's stream frequency (Fs), the land cover, the geological structures, the climate, the relief, and the steepness of the slope (Bali et al., 2012). Rc is a crucial parameter that indicates the stage of the basin (Sreedevi et al., 2004; Kumar & co., 2011). The Ukhma main basin has an Rc value of 0.47 (Table 2). The young and mature stages of basin development are represented by the Kakarhai subbasin's low Rc value of 0.41 and the Chhatan subbasin's high Rc value of 0.71, respectively.

The elongation ratio (Re), as defined by Schumm (1956), is the ratio of the basin's length to the diameter of a circle with the same area as the basin. The higher elongation ratio indicates the impervious surface's low relief. In contrast, the low value of the elongation ratio indicates similar geological materials that are strongly elongated and highly permeable (Reddy et al., 2004). The Re in the Ukhma basin ranges from 0.57 and 0.88 over a sufficient assorted atmosphere and topography with strong relief and steep slope.

4.4 Relief Aspects of the Basin

The basin relief, relief ratio, gradient ratio, and melton ruggedness number were all relief aspects of a drainage basin. According to Schumm (1956), basin relief is the difference in elevation between the basin's maximum and minimum elevations. Basin relief provides a better understanding of the basin's denudational description, reveals the stream's gradient, influences the channel's capacity for transportation, and reveals flood patterns (Sreedevi et al., 2004).

According to Schumm (1956), the relief ratio, defined as the ratio of basin relief to basin length, is widely accepted as a valid measure of the basin's gradient aspects (Vittala & co, 2004). A relief ratio with a high value represents the hilly region. In contrast, the valley and Pedi-plain areas are characterized by a low value (Kumar et al., 2011, Magesh et al., 2012). The Chhatan subbasin has a maximum Rr value of 0.031 (Table 2), indicating higher relief and a steeper slope supported by rugged rocks.

From source to mouth and basin length, the gradient ratio is the ratio of the various elevations. A measure of channel slant, the gradient ratio (Rg), aids in determining the runoff volume (Sreedevi et al., 2004; Thomas et al., 2010; Prakash et al., 2016, 2017; Singh et al., 2018b). The Chhatan subbasin's high Rg value indicates a steep slope and increased runoff. In contrast, the Karibarah subbasin's low Rg value indicates less surface runoff and a greater likelihood of infiltration.

The ratio of basin relief divided by the square root of the basin's area is the melton ruggedness number (Melton, 1965). The melton ruggedness number of the Ukhma Bowl is 0.011 (Table 2).

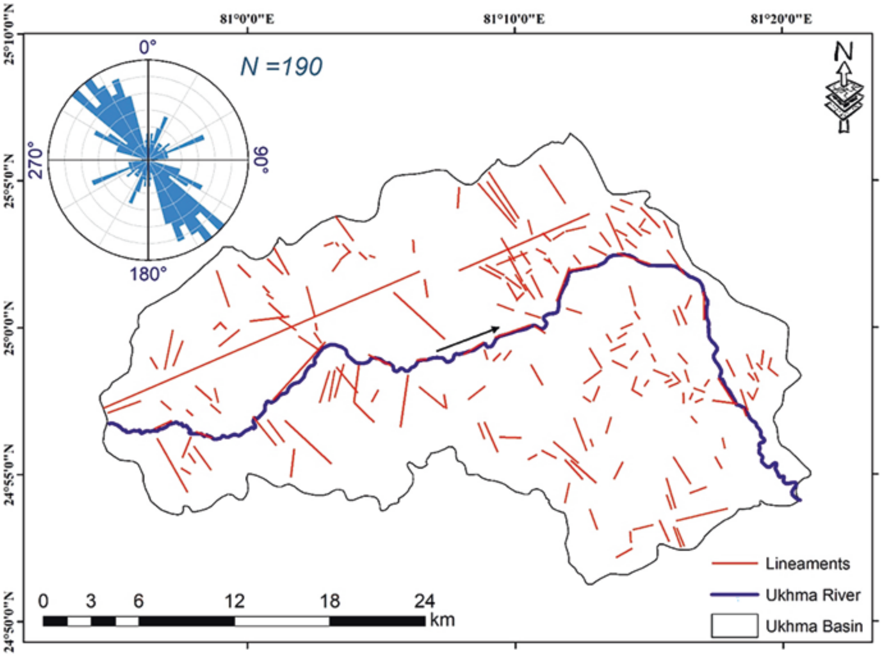

Fig. 8 Figure showing different lineament directions in the Ukhma river basin

4.5 *Lineaments Analysis*

According to Nur (1982), the lineaments are the essential components of the Earth's surface morphology and deformation. With the help of the Arc GIS-10 platform's sentinel-2 imagers, the lineaments were identified and further supported by in-depth field investigations. One hundred ninety lineaments have been mapped. Figure 8, a rose diagram, depicts the orientations of these lineaments. There are some NE–SW trending lineaments, and the NW–SE trending lineaments are relatively high. The fact that most lineaments do not follow the Son-Narmada lineament's regional trend suggests that secondary tectonics in and after the Son-Narmada lineament developed the basin. Figure 1b demonstrates that the faulting and fractures that occurred during the subsequent stage of basin development are distinct from the regional trend of the Son-Narmada lineaments.

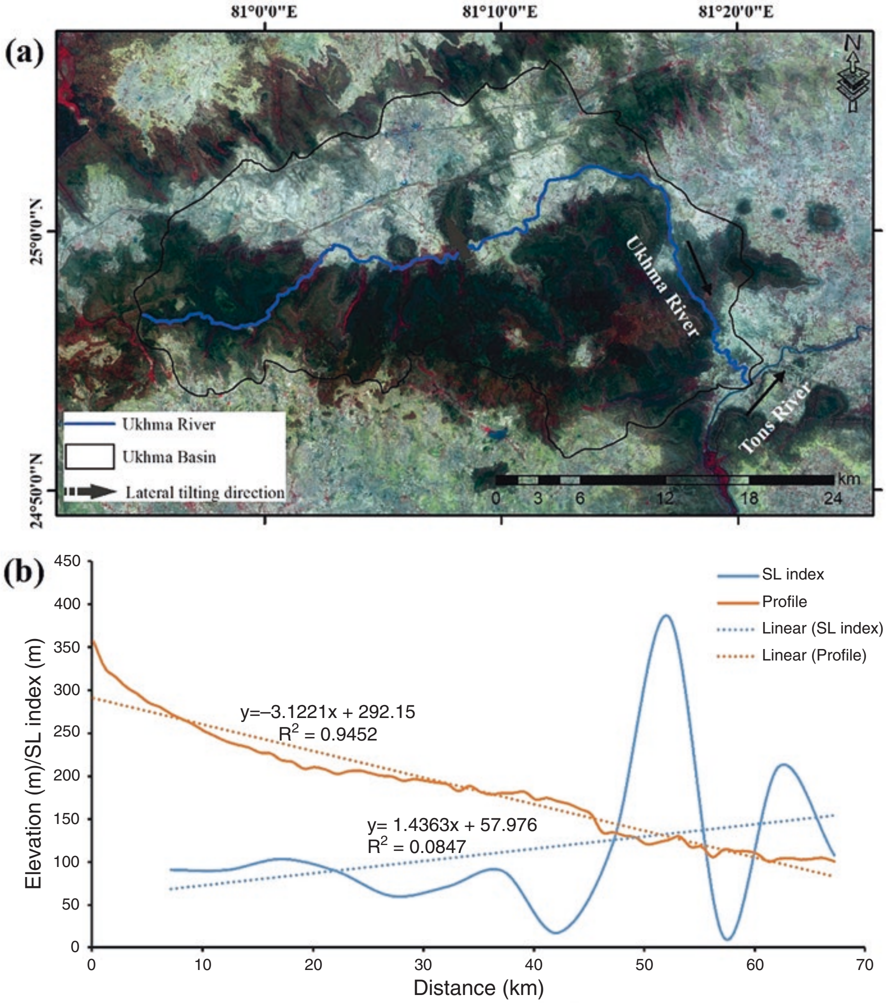

Fig. 9 (**a**) The AF value of the Ukhma river is 52.65, which is greater than 50, suggesting that the basin has been tilted in the northward direction (left side of the river) (**b**) longitudinal profile of the Ukhma river

4.6 Longitudinal Profiles

Longitudinal profiles of the river significance from the interaction between base-level change, fluvial incision, lithology, and tectonics (Brocard et al., 2003; Larue, 2008a, b). The variation in lithology of the region influences longitudinal profile development as well (Duvall et al., 2004; Stock & Montgomery, 1999; Ritter et al., 2002). The Ukhma river has a variable of curves and gradients in its longitudinal profile (Fig. 9b). These deviations from the longitudinal profile may indicate either a harmonious stream in which the upstream retreat alters the base level of the upstream basin (Bishop et al., 2005) or, in some instances, a dynamic equilibrium between tectonic movements and fluvial processes (Snow & Slingerland, 1990). These knick points connect the lithological variation and outcomes of regional tectonics in the longitudinal profile of the Ukhma river.

4.7 Asymmetry Factor (AF)

According to Cox et al. (2001) and Pinter (2005), AF is a crucial parameter for determining the directions of potential differential tectonism and tilting. A basin's lateral tilt concerning the river is indicated by this factor (Cox et al., 2001; Cuong & Zuchiewicz, 2001). The asymmetry factor is calculated as AF = 100 (Ar/At), where Ar is the area of the mainstream's right side and At is the drainage basin's total area. If AF exceeds 50, the river has tilted to the left of the basin in relation to the river (Molin et al., 2004), and if AF is greater than 50, the river has sunk to the right of the drainage basin (Molin et al., 2004). In the current review, the AF of the Ukhma Stream is 52.65 (Fig. 9a).

5 Discussion

The linear parameters provide information about the very high fraction of first-order stream, high infiltration rate, mature stage, and gentle slope. The areal parameters provide information about the value of circularity ratio (0.373), length of overland flow (1.337), drainage density (2.675), low water storage capacity, and concentration of peak discharge in the distal part of this basin (Table 1). The relief parameter gives information about the low value of relief ratio (0.007), relief (0.312), high infiltration rate, low surface runoff, and spreading of water within the basin (Table 1). The estimations of the bifurcation ratio for the Ukhma basin represent the basin's dismembered mountainous nature having mature geography.

The area with homogeneous lithologies and horizontal or gently dipping strata resembles the dendritic pattern. The basin's behavior during heavy rainfall, which may result in significant runoff and floods, is predicted using the morphometric parameters (Garde, 2006; (2010) (Perucca and Angilieri). According to Table 2, the Ukhma Basin's average Rb is 4.75, indicating a hilly area with moderate litho-unit permeability and high surface runoff. The drainage system's storage capacity limit can be determined and evaluated using the Rho coefficient. According to Horton (1945), it is utilized as a component of the drainage level of advance in a specific basin. Higher hydrologic storage during floods and decreased erosion during high discharge explain the higher Rho coefficient values found in the Dharkundi and Bedhak subbasins. The Karibarah subbasin's low drainage density is preferable to resistant lithology or extremely permeable subsoil beneath dense vegetation. In contrast, the Baridari subbasin's high drainage density is supported in locations with weak or impermeable materials and minimal vegetation cover. Lg ranges between 0.68 and 1.93 in the area under study. The Baridari and Chhatan subbasins are characterized by an early stage of basin development, whereas other subbasins, such as the Ukhma basin, are assumed to have reached a mature stage. The higher Ff values (>0.51) of the Gularha and Chhatan subbasins suggested a shorter period of high peak flow. In contrast, the lower Ff value of the Karibarah subbasin suggested a more extended period of insufficient peak flow. The Son-Narmada lineament is not the most common of the lineaments (Figs. 1b and 9). Through its overall morphology and knick points, where the river gradient changes rapidly, the longitudinal profile of the Ukhma river reveals the influence of regional tectonism (Fig. 9b).

The Ukhma river has an AF value of 52.65, which is higher than 50 and indicates that the basin has been tilted to the North (left side of the river) (Fig. 9a). By identifying abnormally high SL index values, the SL index was used to identify neotectonic activity (Merritts & Vincent, 1989; Keller & Pinter, 1996).

6 Conclusion

1. The bifurcation ratio suggests that some geologies and structures control the drainage pattern of the Ukhma basin.
2. The very high fraction of first-order streams indicates uniform lithology and gentle slope, explaining the significant portion of precipitation flow as surface runoff. The overland flow length shows the drainage basin's physiographical development and geomorphic maturity.
3. Morphometric parameters are used to predict the behavior of the basin during heavy rains that can generate significant runoff and create flooding.
4. The lineament study and longitudinal profile of the basin suggest that the regional tectonics somehow controls the drainage dynamics of the Ukhma Basin. The asymmetry factor of the Ukhma river indicates left-side channel shifting, i.e., in the northward direction.

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References

Auden, J. B. (1933). Vindhyan sedimentation in the son valley, Mirzapur District. *Memoirs of the Geological Survey of India, 62*, 141–250.

Babar, M. D. (2001). Hydrogeomorphological studies by remote sensing application in Akoli watershed (Jintur) Parbhani dist., Maharashtra, India. *Spatial Information Tech Remote sensing and GIS-ICORG, 2*, 137–143.
Babar, M. D. (2002). Application of remote sensing in Hydrogeomorphological studies of Purna River basin in Parbhani District, Maharashtra, India. *Proceeding volume of the international symposium of ISPRS Commission VII on Resource and Environmental Monitoring, 34*, 519–523.
Babar, M. D. (2005). *Hydrogeomorphology, fundamental applications and techniques* (Vol. 1, p. 259). New India Publishing Agency.
Babar, M. D., & Kaplay, R. D. (1998). Geomorphometric analysis of Purna River basin Parbhani District (Maharashtra). *Indian Journal of Geomorphology, 3*, 29–39.
Bali, R., Agarwal, K., Nawaz, S. N., Rastogi, S., & Krishna, K. (2012). Drainage morphometry of Himalayan glacio-fluvial basin, India- hydrologic and neotectonic implications. *Environmental Earth Science, 66*, 1163–1174.
Banerjee, A. K., & Singh, H. J. M. (1981). Plaeogeography and sedimentation of Vindhyans in eastern Rajasthan. *Miscellaneous Publications of the Geological Survey of India, 50*, 89–94.
Bishop, P., Hoey, T. B., Jansen, J. D., & Artza, I. L. (2005). Knick point recession rate and catchment area: The case of uplifted rivers in eastern Scotland. *Earth Surface Processes Landform, 30*(6), 767–778.
Brocard, G. Y., van der Beek, P. A., Bourlès, D. L., Siame, L. L., & Mugnier, J. L. (2003). Long-term fluvial incision rates and postglacial river relaxation time in the French western Alps from 10Be dating of alluvial terraces with assessment of inheritance, soil development and wind ablation effects. *Earth and Planetary Sciences Letters, 209*, 197–214.
Burbank, D. W., & Anderson, R. S. (2000). *Tectonic geomorphology* (p. 274). Blackwell Science.
Chakraborty, C. (2006). Proterozoic intracontinental basin: The Vindhyan example. *Journal of Earth System Science, 115*(1), 3–22.
Chakraborty, P. P., Sarkar, S., & Bose, P. K. (1998). A viewpoint on intracratonic chenier evolution: Clue from a reappraisal of the Proterozoic Ganurgarh Shale, Central India. In B. S. Palliwal (Ed.), *The Indian Precambrians* (p. 61). Scientific Publishers.
Chakraborty, T., & Chaudhuri, A. K. (1990). Stratigraphy of the late Proterozoic Rewa Group and palaeogeography of the Vindhyan basin in Central India during Rewa sedimentation. *Journal of Geological Society of India, 36*, 383–402.
Clark, C. (1966). Morphometry from map, essay in geomorphology. *Amer Else Publishing Company New York.*, 235–274.
Corenblit, D., Tabacchi, E., Steiger, J., & Gurnell, A. M. (2007). Reciprocal interactions and adjustments between fluvial landforms and vegetation dynamics in river corridors: A review of complementary approaches. *Earth-Science Reviews, 84*(1–2), 56–86.
Cox, R. T., Van Arsdale, R. B., & Harris, J. B. (2001). Identification of possible quaternary deformation in the northeastern Mississippi embayment using quantitative geomorphic analysis of drainage-basin asymmetry. *Geological Society of America Bulletin, 113*(5), 615–624.
Cuong, N. Q., & Zuchiewicz, W. A. (2001). Morphotectonic properties of the Lo River fault near Tam Dao in North Vietnam. *Natural Hazards and Earth System Sciences, 1*, 15–22.
Duvall, A., Kirby, E., & Burbank, D. (2004). Tectonic and lithologic controls on bedrock channel profiles and processes in coastal California. *Journal of Geophysical Research, 109*, 1–18.
Garde, R. J. (2006). *River morphology*. New Age International.
Gregory, K. J., & Walling, D. E. (1973). *Drainage basin form and process a geomorphological approach*. Edward Arnold.
Hack, J. T. (1957). Studies of longitudinal stream profiles in Virginia and Maryland. *Unit States Geological Surface Professional Paper US Geological Survey, 294*(B), 45.
Horton, R. E. (1945). Erosional development of streams and their drainage basins hydrophysical approach to quantitative morphology. *Geological Society American Bulletin, 56*, 275–370.
Huggett, R., & Cheesman, J. (2002). *Topography and the environment*. Pearson Education.

Jadhav, S. I., & Babar, M. D. (2014). Linear and aerial aspect of Basin morphometry of Kundka sub-basin of Sindphana Basin (Beed), Maharashtra, India. *International Journal Geological Agriculture and Environmental Science, 2*, 2348–2354.

Kaila, K. L. (1986). Tectonic framework of Narmada–Son lineament: A continental rift system in central India from deep seismic soundings. In M. Brazangi & L. Brown (Eds.), *Reflection seismology: A global perspective* (Geodynamic series). AGU. 13 pp.

Kaila, K. L., Murthy, P. R. K., & Mall, D. M. (1989). The evolution of the Vindhyan basin vis-à-vis the Narmada–Son lineament, Central India, from deep seismic soundings. *Tectonophysics, 162*, 277–289.

Kanhaiya, S., Singh, B. P., Singh, S., Mittal, P., & Srivastava, V. K. (2019a). Morphometric analysis, bed-load sediments, and weathering intensity in the Khurar River Basin, Central India. *Geological Journal, 54*, 466–481.

Kanhaiya, S., Singh, S., Singh, C. K., Srivastava, V. K., & Patra, A. (2019b). *Geomorphic evolution of the Dongar River Basin, Son Valley, Central India*. Geology, Ecology, and Landscapes. https://doi.org/10.1080/24749508.2018.1558019

Kanhaiya, S., Singh, S., Singh, C. K., & Srivastava, V. K. (2019c). Pothole: A unique geomorphological feature from the bedrocks of Ghaggar River, Son valley, India. *Geology, Ecology, and Landscapes, 3*(4), 258–268.

Kaplay, R. D., Babar, M. D., Panaskar, D. B., & Rakhe, A. M. (2004). Geomorphometric characteristics of 30th September 1993 Killari Earthquake Area, Maharashtra (India). *Journal of Geophysics, 25*, 55–61.

Keller, E. A., & Pinter, N. (1996). *Active tectonics* (Vol. 1338). Prentice Hall.

Kumar, A., Jayappa, K., & Deepika, B. (2011). Prioritization of sub-basins based on geomorphology and morphometric analysis using remote sensing and geographic information system (GIS) techniques. *Geocarto International, 26*, 569–592.

Larue, J. P. (2008a). Effects of tectonics and lithology on long profiles of 16 rivers of the southern central Massif border between the Aude and the Orb (France). *Geomorphology, 93*, 343–367.

Larue, J. P. (2008b). Tectonic influence on the quaternary drainage evolution on the northwestern margin of the French Central Massif: The Cruese valley example. *Geomorphology, 93*, 398–420.

Leopold, L. B. (1969). *Fluvial processes in geomorphology*. Eurasia Publishing House.

Magesh, N. S., Jitheshlal, K. V., Chandrasekar, N., & Jini, K. V. (2012). GIS based morphometric evaluation of Chimmini and Mupily watersheds, parts of Western Ghats, Thrissur District, Kerala, India. *Earth Science Information, 5*, 111–121.

Melton, M. A. (1965). The geomorphic and paleoclimatic significance of alluvial deposits in southern Arizona. *Journal of Geology, 73*, 1–38.

Merritts, D., & Vincent, K. R. (1989). Geomorphic response of coastal streams to low, intermediate, and high rates of uplift, Medocino triple junction region, northern California. *Geological Society of America Bulletin, 101*(11), 1373–1388.

Miller, V. C. (1953). *A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee* (Vol. 3). Columbia University.

Miller, J. P. (1958). *High mountaineous streams effect of geology on channel characteristics and bed material, Mem*. New Maxi Bur Mines Mineral Resource.

Molin, P., Pazzaglia, F. J., & Dramis, F. (2004). Geomorphic expression of the active tectonics in a rapidly deforming forearc, sila Massif, Calabria, Southern Italy. *American Journal of Science, 304*, 559–589.

Mustafa, A. S. (2016). Drainage Basin morphometric analysis of Galagu Valley. *Journal Applied and Industrial Science, 4*, 2320–4609.

Naqvi, S. M., & Rogers, J. J. W. (1987). *Precambrian geology of India*. Clarendon Press/Oxford University Press. 233p.

Nur, A. (1982). The origin of tensile fracture lineaments. *Journal of Structural Geology, 4*(1), 31–40.

Pinter, N. (2005). Applications of tectonic geomorphology for deciphering active deformation in the Pannonian Basin, Hungary. In L. Fodor & K. Brezsnya'Nszky (Eds.), *Proceedings of the* *workshop on "applications of GPS in plate tectonics in research on fossil energy resources and in earthquake hazard assessment", occasional papers of the geological institute of Hungary* (Vol. 204, pp. 25–51).

Pophare, A. M., Lamsoge, B. R., Katpatal, Y. B., & Nawale, V. P. (2014). Impact of over-exploitation on groundwater quality: A case study from WR-2 watershed, India. *Journal of Earth System Science, 123*(7), 1541–1566.

Prakash, K., Singh, S., & Shukla, U. K. (2016a). Morphometric changes of the Varuna River basin, Varanasi district, Uttar Pradesh. *Journal of Geomatics, 10*, 48–54.

Prakash, K., Mohanty, T., Singh, S., Chaubey, K., & Prakash, P. (2016b). Drainage morphometry of the Dhasan River basin, Bundelkhand Craton, Central India using remote sensing and GIS techniques. *Journal of Geomatics, 10*, 21–132.

Prakash, K., Singh, S., Mohanty, T., Chaubey, K., & Singh, C. K. (2017). *Morphometric assessment of Gomati River basin, middle Ganga plain*. Spatial Information Research. https://doi.org/10.1007/s41324-017-0110-x

Prakash, K., Rawat, D., Singh, S., Chaubey, K., Kanhaiya, S., & Mohanty, T. (2019). *Morphometric analysis using SRTM and GIS in synergy with depiction: A case study of the Karmanasa River basin, North central India*. Applied Water Science. https://doi.org/10.1007/s13201-018-0887-3

Rai, P. K. (2017). A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. *Applied Water Science, 7*, 217–232.

Rai, P. K., Mishra, S., Ahmad, A., & Mohan, K. (2014). A GIS-based approach in drainage morphometric analysis of Kanhar River Basin India. *Applied Water Science*. https://doi.org/10.1007/s13201-014-0238-y

Reddy, G. P. O., Maji, A. K., & Gajbhiye, K. S. (2004). Drainage morphometry and its influence on landform characteristics in a basaltic terrain, Central India – A remote sensing and GIS approach. *Journal of Applied Earth Observation and Geoinformatics, 6*, 1–16.

Ritter, D. F., Kochel, R. C., & Miller, J. R. (2002). Process geomorphology wavel and press. In I. L. Long Grove, E. A. Keller, & N. Pinter (Eds.), *Active tectonics: Earthquakes uplift and landscape* (2nd ed., p. 362). Prentice Hall.

Rogers, J. J. (1986). The Dharwar craton and the assembly of peninsular India. *The Journal of Geology, 94*(2), 129–143.

Roy, A., & Bandyopadhyay, B. K. (1990). Cleavage development in Mahakoshal group of rocks of Sleemanabad-Sihora area, Jabalpur District, Madhya Pradesh. *Indian Miner, 44*(2–3), 111–128.

Rudraiah, M., Govindaiah, S., & Vittala, S. S. (2008). Morphometryusing remote sensing and GIS techniques in the sub-basins of Kagna River Basin, Gulbarga district, Karnataka, India. *Journal of Indian Society of Remote Sensing, 36*, 351–360.

Schumm, S. A. (1986). Alluvial river response to active tectonics. *Active Tectonics*, 80–94.

Schumm, S. A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Geological Society of American Bulletin, 67*, 597–646.

Shukla, T., Verma, A., Adnan, A., Pandey, M., & Shukla, U. K. (2014). Scarp sandstone: An example of estuarine sedimentation within the Mesoproterozoic Kaimur Group of the Vindhyan Basin, (Mirzapur, U.P.) India. *Journal of Paleontological Society of India, 59*, 45–58.

Singh, P., Thakur, J., & Singh, U. C. (2013). Morphometric analysis of Morar River basin, Madhya Pradesh, India, using remote sensing and GIS techniques. *Environmental Earth Science, 68*, 1967–1977.

Singh, S., & Kanhaiya, S. (2015). Morphometry of the Barakar River Basin, India. *International Journal of Current Research, 7*(7), 17948–17955.

Singh, S., Kanhaiya, S., Singh, A., & Chaubey, K. (2018a). Drainage network characteristics of the Ghaggar River Basin (GRB), Son Valley, India. *Geology, Ecology, and Landscapes*. https://doi.org/10.1080/24749508.2018.1525670

Singh, S., Kumar, S., Mittal, P., Kanhaiya, S., Prakash, P., & Kumar, R. (2018b). Drainage Basin parameters of Bagh River, a sub-basin of Narmada River, Central India: Analysis and Implications. *Journal of Applied Geochemistry, 20*(1), 91–102.

Singh, S., Prakash, K., & Shukla, U. K. (2020). Spatiotemporal migration of the River Ganga in middle Ganga Plane: Application of remote sensing and GIS technique. *Journal of the Indian Society of Remote Sensing.* https://doi.org/10.1007/s12524-020-01170-z

Singh, S., Singh, A. K., Kumar, P., & Jaiswal, M. K. (2021). Morphotectonic analysis of the Bihar River, Madhya Pradesh, India. In *Proceedings of the Indian national science academy*, 87, 163–174

Singh, S., Kanhaiya, S., Kumar, S., & Yadav, S. K. (2022). Spatial and temporal variation in NDVI and NDWI of the Ukhma River Basin, Central India. *Journal of Scientific Research, 66*(3), 62–65

Snow, R. S., & Slingerland, R. L. (1990). Stream profile adjustment to crustal warping: Nonlinear results from a simple model. *Geology, 98*, 699–708.

Solangi, G. S., Siyal, A. A., & Siyal, P. (2019a). Analysis of Indus Delta groundwater and surface water suitability for domestic and irrigation purposes. *Civil Engineering Journal, 5*(7), 1599–1608.

Solangi, G. S., Siyal, A. A., & Siyal, P. (2019b). Spatiotemporal dynamics of land surface temperature and its impact on the vegetation. *Civil Engineering Journal, 5*(8), 1753–1763.

Sreedevi, P. D., Owais, S., Khan, H., & Ahmed, S. (2009). Morphometric analysis of a watershed of South India using SRTM data and GIS. *Journal of Geological Society of India, 73*, 543–552.

Sreedevi, P. D., Subrahmanyam, K., & Shakeel, A. (2004). The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. *Environmental Geological, 47*, 412–420.

Srivastava, D. C., & Sahay, A. (2003). Brittle tectonics and pore-fluid conditions in the evolution of the great boundary fault around Chittaurgarh, northwestern India. *Journal of Structural Geology, 25*, 1713–1733.

Stock, J. D., & Montgomery, D. R. (1999). Geologic constraints on bedrock river incision using the stream power law. *Journal of Geophysical Research: Solid Earth, 104*, 4983–4993.

Strahler, A. N. (1957). Quantitative analysis of watershed geomorphology. *Eos, Transactions American Geophysical Union, 38*(6), 913–920.

Strahler, A. N. (1958). Dimensional analysis applied to fluvially eroded landforms. *Geological Society of American Bulletin, 69*, 279–300.

Strahler, A. N. (1964). Quantitative geomorphology of drainage basin and channel networks. Section 4ii in *Handbook applied hydrology 4–39 to 4–76*.

Tewari, H. C., Murthy, A. S. N., Kumar, P., & Sridhar, A. R. (2001). A tectonic model of the Narmada region. *Current Science, 80*, 873–878.

Thomas, J., Joseph, S., & Thrivikramaji, K. P. (2010). Morphometric aspects of a small tropical mountain river system, the southern Western Ghats, India. *International Journal of Digital Earth, 3*, 135–156.

Vandenberghe, J. (2002). The relation between climate and river processes, landforms and deposits during the quaternary. *Quaternary International, 91*(1), 17–23.

Verma, A., & Shukla, U. K. (2020). Heterolithic lower Rewa sandstone of the Neoproterozoic Rewa group, Vindhyan Basin, U. P., India: An example of tidal point bar. *Precambrian Research, 350*, 105932. https://doi.org/10.1016/j.precamres.2020.105932

Verma, P. K. (1996). Evolution and age of the great boundary fault of Rajasthan. *Geological Society of India Memoirs, 36*, 197–212.

Verma, R. K. (1991). *Geodynamics of the Indian Peninsula and the Indian plate margin*. Oxford and IBH. 357pp.

Vittala, S. S., Govindiah, S., & Honne, G. H. (2004). Morphometric analysis of sub-watersheds in the pavagada area of Tumkur district, South India, using remote sensing and GIS techniques. *Journal of Indian Society of Remote Sensing, 32*, 351–362.

Waikar, M. L. (2014). Morphometric analysis of a Drainage Basin using geographical information system: A case study. *International Journal of Multidisciplinary and Current Research, 2*, 180–184.