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ORIGINAL ARTICLE

Geomorphic Analysis of Baghain River, Yamuna Basin, and its Implication for Drainage Characteristic and Tectonics using Remote Sensing and GIS Techniques

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ABSTRACT

The present study aims to access the geomorphic analysis of the Baghain river basin and its implication on landscape evolution. Baghain river originates from the Panna hill, and flows through marginal and central Ganga plain. It empties itself in to Yamuna river near Chilla village, Banda district, Uttar Pradesh. The river basin comprises of three major geological units associated with this basin: Bundelkhand gneissic complex, Vindhyan Supergroup (hard rock terrain known as Panna hill) and Alluvial deposit (marginal Ganga plain and central Ganga plain). The current work focuses on study of morphometric parameters and geomorphic indices of Baghain river basin using digital elevation model (DEM) and topographic maps (1:50,000 scale). This basin exhibits four types of drainage patterns: dendritic, parallel, trellis and rectangular. Bifurcations ratio (4.82) of river basin suggest that the most part of the basin is not influenced by any geological structures. The elongation ratio (0.50) suggests that the basin is moderately elongated. The drainage density (0.62) and stream frequency (0.22) also suggest that the basin has moderate to high permeable and easily erodible alluvium terrain.

The escarpment height is low in the proximal part (Panna Hill) and high in the middle and distal parts of the basin (marginal Ganga plain and central Ganga plain, respectively. Asymmetric factor (52) shows a leftward tilt of the basin. The region lies under marginal Ganga plain, and Bundelkhand plateau. The sharp bend present is probably due to the lithological variation. It reflects moderate gradient in the upper part (Panna hill), steep gradient in the lower part (Panna hill), and low gradient in the marginal to central Ganga plain.

INTRODUCTION

Indo-Gangetic plain is one of the most densely inhabited region because of fertile soil, aquifer-rich terrain, smooth landscape and suitable climate (Singh et al. 2011a, 2013, 2015; Singh and Gautam, 2018). The Indo-Gangetic basin developed 15 million years ago in response to the uplift of the Himalaya with lithospheric loading and depression of the Indian continental plate. Further, fluvial processes filled the Ganga plain, with enormous sediment deposition derived from the Himalaya in the north and Peninsular craton in the south (Singh and Bajpai, 1989; Singh, 2004; Singh and Tandan, 2007; Singh, 2018).

On the basis of the tectonic setting the Ganga plain is classified into three broad categories as piedmont plain, central alluvial plain and marginal alluvial plain (Singh, 1992; Singh et al. 1996). The marginal alluvial plain is highly variable, showing lineaments, indicating sudden movement along these faults (Singh, 1996).

The present day basin is an asymmetric trough, hosting vast sediment thicknesses (Singh, 1996; Srivastava et al. 2015) and the basin remains the world's largest area of modern alluvial sedimentation (Sinha et al. 2014). The neotectonic activities of the Ganga plain have been identified by many workers (Singh and Rastogi, 1973; Singh and Bajpai, 1989; Mohindra et al. 1992; Mohindra and Parkash, 1994; Singh and Ghosh, 1994; Srivastava et al. 1994; Misra et al. 1994; Kumar et al. 1996; Singh, 1996, 1999, 2001; Singh et al. 1996; Parkash et al. 2000; Agarwal et al. 2002; Singh et al. 2009; Awasthi and Singh. 2011a). Ganga plain is the consequence of the climate changes, tectonic activity and base-level changes during the late Quaternary (Singh, 1996, 2001, 2005; Srivastava et al. 2003).

The aquifer of the Ganga plain are one of the world's most important trans-boundary water resources, and the most heavily exploited aquifer in the world (Bonsor et al. 2017). Recently it is facing the challenges for drinking water, irrigation issues, deepening of water level and excessive discharges in many regions of Ganga basin. Ganga basin are prone river borne natural hazards also. Therefore, a proper understanding of river from its profile is needed.

The drainage analysis represents a valuable method of detecting tectonic activity and morphological change (Ouchi, 1985). The morphometric parameters of the basin can express significantly information about the hydro-geomorphic response to lithology, climate, and tectonic activity (Das, 2021). The evolutionary history of the drainage basin can be most intimately understood through the critical implication of various morphometric measures (Sharma and Sarma, 2013). Landscape changes and drainage evolution can be understood by evaluating geomorphic features and geographic indices, such as longitudinal profile (Lg); asymmetry factor (AF) and basin elongation ratio (Re) (Bull and Mc Fadden, 1977; Hack, 1957; Singh and Awasthi 2011a,b; Gautam et al. 2020). Asymmetric factors related to basin side slopes are associated with major waterways (Hare and Gardner, 1985; Cox, 1994; Cuong and Zuchiewicz, 2001; Keller and Pinter, 2002; Dehbozorgi et al. 2010; Perez-Pena et al. 2010; Singh et al. and Srivastava, 2011; Raj, 2012). The preferential orientation of the channel, channel diversions, twisted meanders, cliffs, asymmetric terraces and faults (Singh, 2001; Agarwal et al. 2002; Singh et al. 2022) explain recent tectonic in Gangetic plain. The Yamuna a snow-fed river and main right bank tributary of the Ganga River, originates from Bandarpunch Glacier, Uttarakhand. During its course from Uttarkashi to Allahabad it covers a distance of 1380 km and shows diverse patterns, i.e., steep draining, braided and meandering. During the summer season, the river Yamuna reduces to a small stream in many parts owing to sharp fall in water discharge due to excessive evaporation network of irrigation canals (Verma, 2011). The main tributaries of the Yamuna are Hindon, Chambar, Sindh, Betwa, Ken and Baghain (Singh, 2018). The Baghain river is the right tributary of the Yamuna river. It flows through Panna, Satna in Madhya Pradesh and Bandar in Chitraku district of Uttar Pradesh. The Bundelkhand district, Uttar Pradesh is considered a drought-prone region with much below-normal rainfall. Severe droughts are more prevalent in this region, according to a scientific report by the International Water Resources Management Institute (IWMI). Therefore, it is extremely important to monitor each natural water resource to meet the daily water needs of the area.

STUDY AREA

The study area (Baghain basin) is about 1691 km^2 covering parts of Panna, Satna districts of Madhya Pradesh and Banda, Chitrakoot districts of Uttar Pradesh. It extends from 80°5'15.378"E. to 81°8'9.206"E longitude and 24°36'24.011"N to 25°36'29.681"N latitude (Fig. 1). Physiographically district is characterised by Ganga, Yamuna plain and Vindhyan plateau. Geologically the upper area comprises Precambrian Bundelkhand granites unconformably overlain by Vindhyan, Quaternary alluvium and the lower area lies in the Central Ganga plain and Marginal Ganga plain. It consists of loose and unconsolidated fluvial sediments. The maximum and minimum height of the basin is 510 m and 89 m respectively (Fig. 4a). Geomorphologically, the watershed Plateau region the high land region of the study area have steep slopes while slopes become gentle towards the central Ganga plain.

Geological Setting

The Indian Peninsula is generally considered as a tectonically stable region. In some parts of this ancient landscape, however, the influences of tectonic can be observed (Kale, 2014). The Archean group is mainly represented by Bundelkhand granite and it is unconformably overlain by a Quaternary group of sediments represented by unconsolidated alluvium. About 64% of the total geographical area is covered with unconsolidated sediments rest 36% is occupied by the hard rocks of the Vindhyan system. Outcrops of the Vindhyan Supergroup cover vast areas in the Son valley and central India (Fig. 2b). The Lower Vindhyan group (Semi group) consists of carbonates, siliciclastics and volcaniclastics, whereas, the upper Vindhyan Group is dominated (Table 2) by siliciclastic with minor carbonates. Available age dating suggests that the lower Vindhyan sediments are 1800–1600 Ma and thickness 3000-4000 m. The ravined landscape of Yamuna and its tributaries is located mostly in the marginal ganga plain (MGP) on the peripheral bulge of the Ganga foreland and comprises 1.23 million hectares of badlands in India. A peripheral bulge is a basement high, parallel to the foreland basin that is located close to the craton and is caused by a lithospheric flexure that occurred in response to thrust sheet loading in the Himalaya (DeCelles and Giles, 1996; Singh, 1996; Ghosh et al. 2018).

METHODOLOGY

The basin characteristics of the watershed was delineated using Survey of India (SOI) toposheet (1: 50,000 scale) and digital elevation model (DEM) image of Shuttle Radar Topography Mission (SRTM) having spatial resolution by ArcGIS version 10 (Table 1). Further

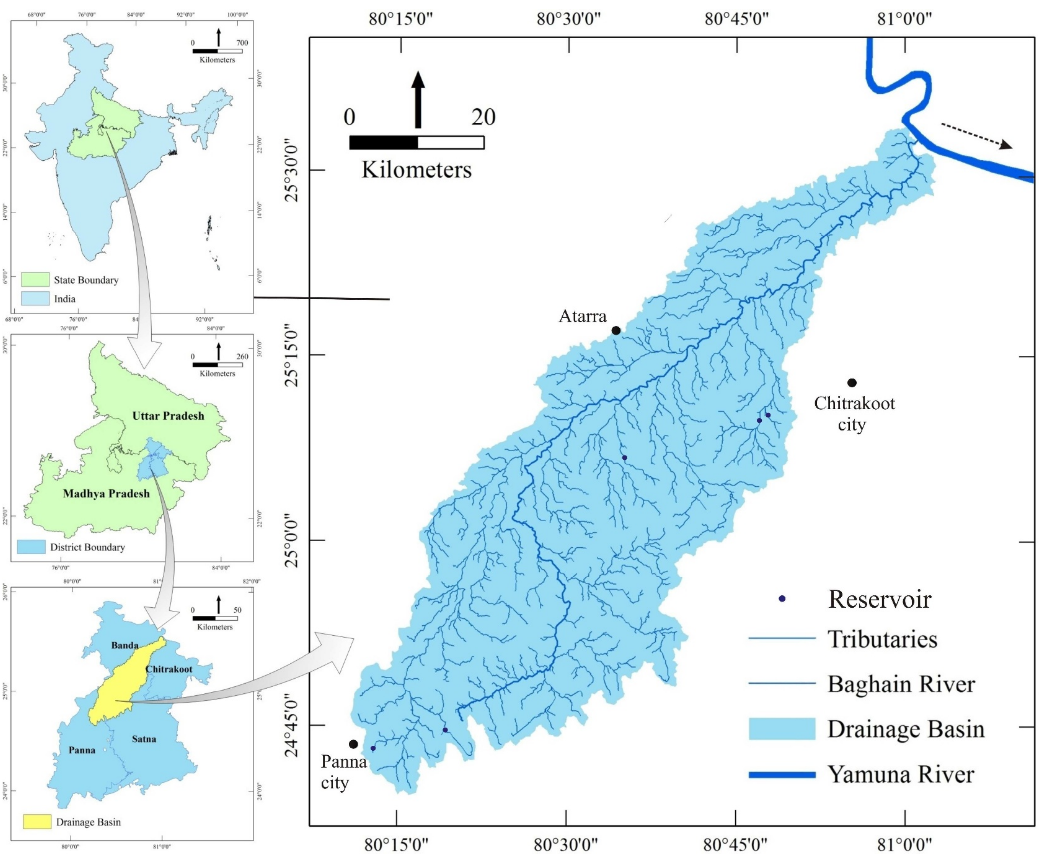


Fig. 1. Location map of study area.

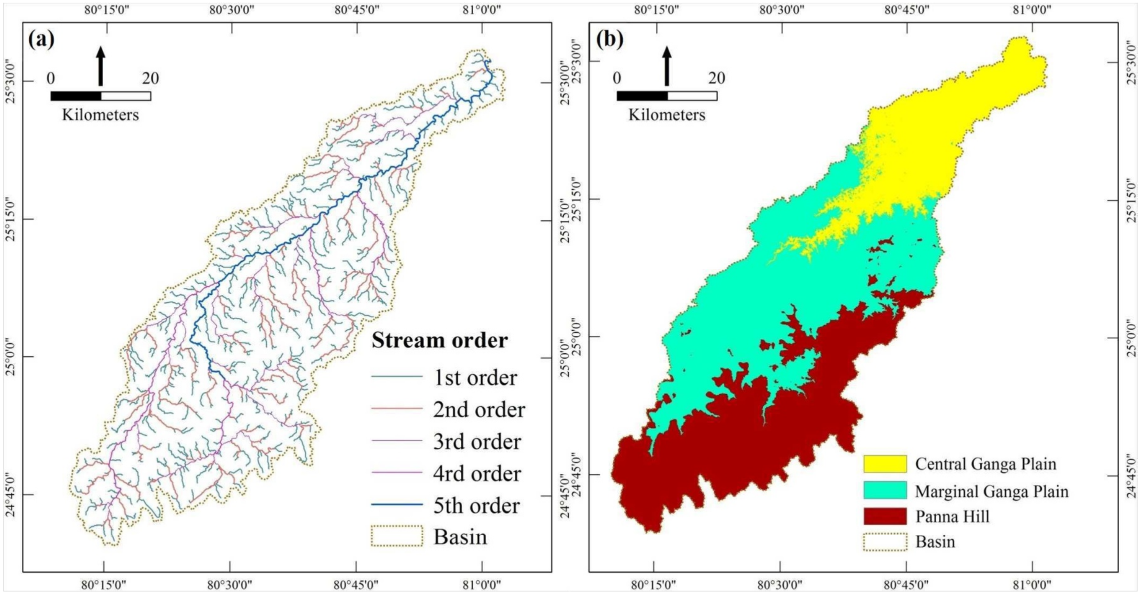


Fig. 2. (a) Drainage map of the basin and **(b)** Geological map of the study area.

process rectification, georeferencing, and the mosaic of the toposheets was done by UTM projections and WGS 1984 UTM Zone 43 datum. The GIS model gives the linear presentation of workflow which has been used to extract the drainage basin from the (SRTM), followed by fill DAM, flow direction, flow accumulation, basin raster and basin vector. (Fig. 3). The stream extraction using the stream ordering module followed by fill dam, flow direction, flow accumulation, stream order raster and stream order vector, further calculation of the morphometric parameters (Fig. 4). Strahler's scheme of stream ordering is simple and widely accepted for applications and it is extensively used for the morphometric analysis of river basin (Wakode et al. 2013; Stammler et al. 2013; Hayakawa and Oguchi, 2013). The drainage network was analyzed following the Horton (1945), and stream orders following Strahler (1964) method. Stream ordering is a method of assigning a numeric order to link in a stream network. This order is a method for identifying and classifying types of streams based on their numbers of tributaries. Some characteristics of streams can be inferred by simply knowing their order. The methodology adopted for computing and numerical formulas of morphometric parameters (Linear, Areal, Relief, and Geomorphic Indices) are given in Table 4.

RESULTS

Various morphometric parameters such as linear, aerial, relief have been computed and analysis of geomorphic indices of Baghain river basin are discussed in the following sections.

Drainage Pattern

The Baghain basin exhibits four types of drainage patterns as dendritic, parallel, trellis and rectangular. The dendritic pattern is most common in the basin and corresponds to the bifurcate pattern of tree roots (Fig. 5a.) The parallel patterns are developed in the high slope region of Panna hill towards marginal Ganga plain. It is characterised by a parallel-like pattern following the slope of the surface (Fig. 5b). Trellis patterns are developed in hard land areas of the basin, in which

Table 1. Specification of the satellite data sets used

Satellite/ Toposheet	Sensor	Range	Spatial Resolution	Data source
Topographical map	Topo-sheet	63D/01, 63D/02, 63D/05, 63D/06, 63D/09.63C/08, 63C/11, 63C/12, 63C/015, 63C/016. 63G/02, 63G/03	50,000 scale	Survey of India (SOI)
SRTM	DEM		90 meter	*

http://srtm.csi.cgiar.org/srtmdata

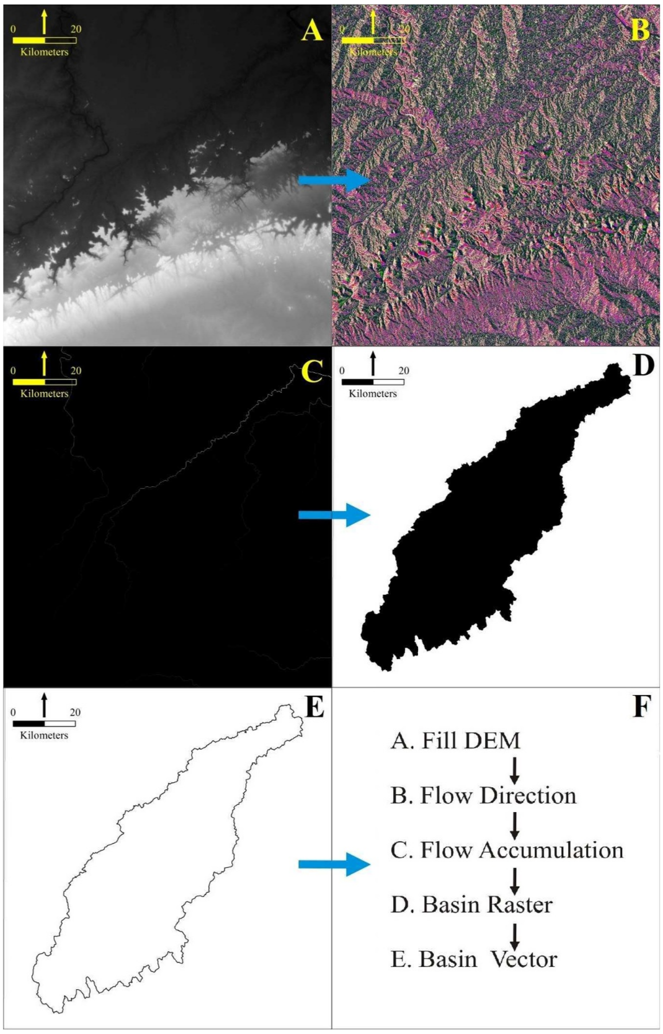


Fig. 3. Flowchart of the methodology (formation of the basin).

Table 2. Geology of the study area

Age	Supper group	Group	Lithology	Thickness	Reference
10 ka	Alluvial deposit	Newer alluvium	Sand, silt, clay	40 to 200 m	(Srivastava et al. 2003)
128-74 Ka		Older alluvium	Gravels, kankar	80 m	
1000–900 Ma	Upper Vindhyan	Bhander Group	Kaimur Sandstone	1300-1500 m	Valdiya 1969)
1000–1070 Ma		Rewa Group	Tirohan lime stone	100-300 m	Malone et al. 2008)
1110 Ma		Kaimur Group	Shale, Sandstone	400 m	Sarangi et al. 2004
		Unconformity			
1800–1600 Ma	Lower Vindhyan	Semri Group	Carbonates, dolomite, volcaniclastics	3000-4000 m	Misra and Kumar 2005)
		Unconformity			
3310–3560 Ma	Bundelkhand Genesis Complex		Bundelkhand granite gneiss		Valdiya (2016)

Table 3. Stream characteristic of the river

Stream order (U)	Stream Number (N_u)	Stream Length (L_u)	Log (N_u)	Log (L_u)	Stream Length Ratio (R_l)	Bifurcation ratio (R_b)
I	519	946	2.72	2.98	0.51	4.55
II	114	484	2.06	2.68	0.43	4.07
III	28	206	1.45	2.31	0.65	4.67
IV	6	134	0.78	2.13	0.93	6.00
V	1	125	0.00	2.10	0.00	
5	668	1895	7.00	12.20	0.50	4.82

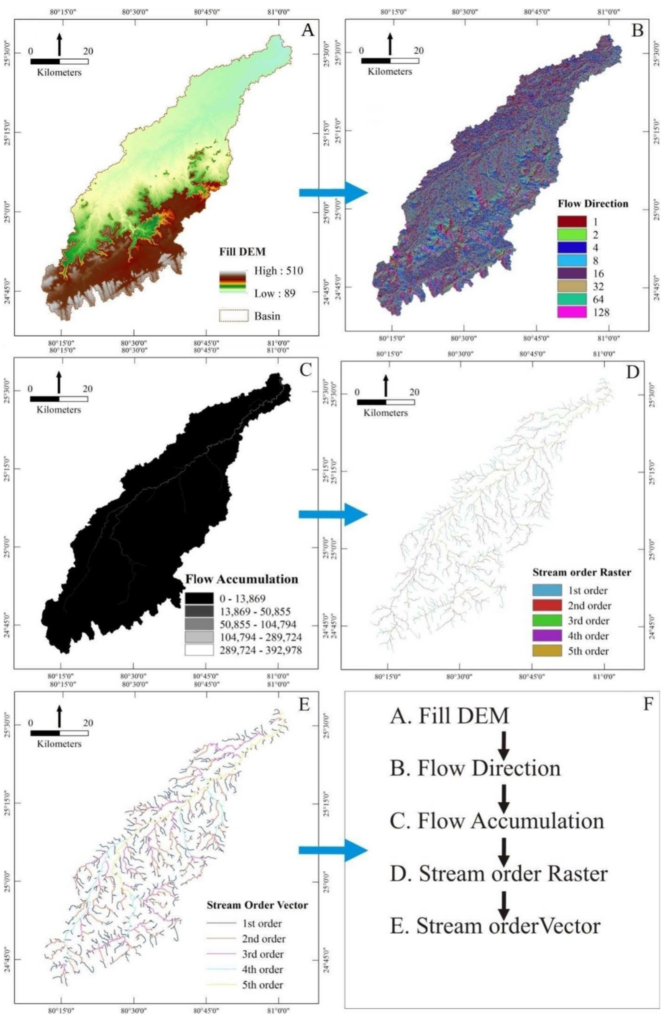


Fig. 4. Flowchart of the methodology (formation of the stream orders).

flow is parallel to each other and secondary tributaries join them at right angles (Fig. 5c). The rectangular drainage pattern is found in the high-land regions. It develops on a rocky terrain of the Vindhyan mountain range. The tributary streams make sharp bends and enter the mainstream at high angles (Fig. 5d).

Linear Aspects of the Basin

The Baghain river basin is a 5th order river basin with lower-order stream dominance (Fig. 2a). The total stream number declines slowly as the stream order increases the stream number and the total stream number (Fig. 6a). The total stream number of all orders is 668. The river basin exhibits 519, 114, 28, 06, and 01 of Ist, IInd, IIIrd, IVth and Vth order, respectively. The total stream length of all orders is 1895 km and the total (L_u) of I, II, III, IV and V order streams (Fig. 6b) is 946, 484, 206, 134, and 125 km, respectively. Stream length ratio is 0.50 for this basin. The values of the mean bifurcation ratio are 4.82. it is shown in Table 3.

Areal Aspects of the Basin

The drainage density is characterised by stream length per unit area in a region (Fig.7). It is 0.62 for this basin. Stream frequency (F_s) is 0.22 sq. km for this basin (Fig. 6c). The elongation ratio of basin is 0.50 (Table 3).

Relief Aspects of the Basin

Relief aspect is included concerning topographic parameters (e.g. aspect, relief, mean slope, relief ratio, relative relief, ruggedness number and hypsometric integrals. The Aspect map probably applies to know a slope's direction. According to the aspect analyses, the area comes under flat 1.37%, sides facing the north 8.24 %, sides facing the northeast 13.28%, sides facing the east 11.71 %, sides facing the southeast 11.58 %, sides facing the south 11.32 %, sides facing the southwest 11.06 %, sides facing the west 11.68 %, sides facing the northwest 13.61 % and sides facing the north 6.15% (Fig. 8a). Here the highest point of the basin is 510 m amsl and the lowest point 89 m

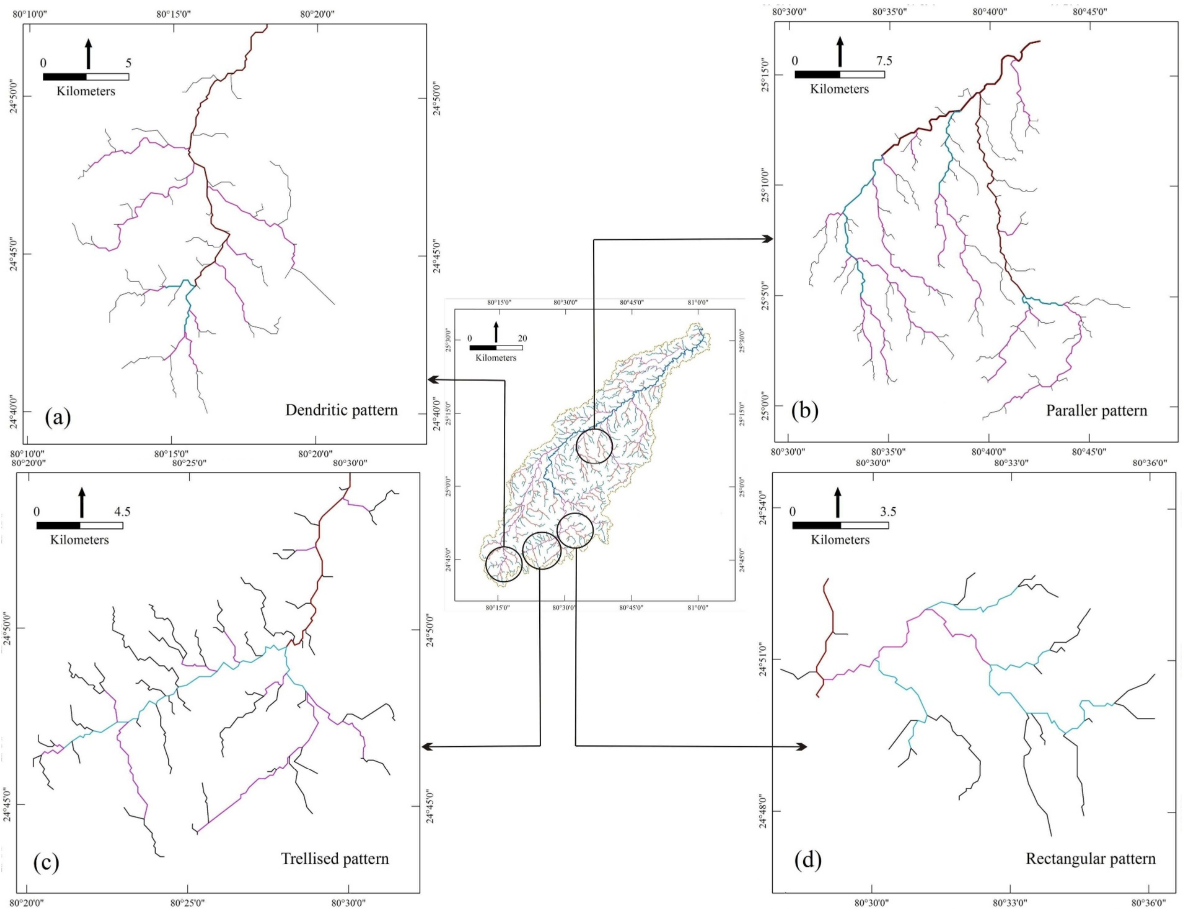


Fig. 5. Map showing various drainage pattern as **(a)** Dendritic pattern **(b)** Parallel pattern **(c)** Trellised pattern and **(d)** Rectangular pattern.

amsl. The basin relief of the basin is 421 m. Mean slope of the basin is 300 m. Relief Ratio (R_r) is 3.40 for this basin. Relative Relief (R_{rp}) is 95 m for Baghain basin (Fig. 8c). Ruggedness number of the basin is 0.42**.** Hypsometric integrals (H_i) of the basin is calculated and is HI < 0.4 (Table 4).

Analysis of Geomorphic Indices

Based on the integrated application of satellite imagery, geographic digital data and field validation, extraction of reliable information about the geomorphologic evolution of the basin was carried out. An attemptis made to evaluate the effect of geomorphic activity and its impact on the geomorphic rejuvenation of the area. The geomorphic features along the Baghain watershed valley indicate the geologic complexity setting.

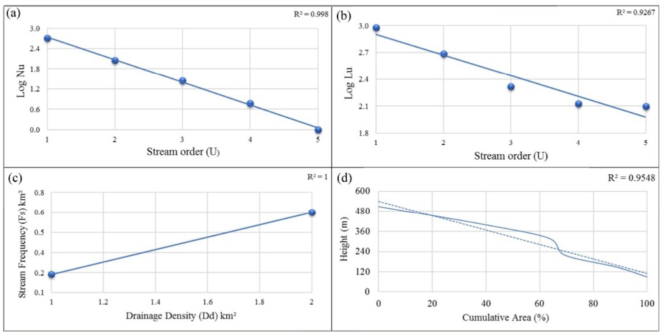


Fig. 6. (a) Regression of logarithm of the stream number versus stream order. **(b)** Regression of logarithm of the stream lengths versus stream order. **(c)** Relation between drainage density and stream frequency and **(d)** Cumulative hypsometric integrals showing the concave upward (Strahler, 1992).

Sinuosity Index (S_i)

The Baghain river is 189 km long and therefore river segments were divided into 30 sections. Each section has a length of 6.30 km long. The sinuosity of the river ranges 1.12 to 1.89 and the average sinuosity is 1.44. The study area has been characteristic by three Sinuosity zones based on (Miller, 1964) in (Table 4); namely as SIZ-I (low sinuosity zone), SIZ-II (high sinuosity zone) and SIZ-III (meandering zone) (Fig. 9a).

Escarpment Analysis (E_a)

Geomorphic indices are the most effective tools for the study of the tectonics of the region (Keller, 1986). Analysis of escarpment deals with riverbank heights 'r', and it refers to the geomorphic activity of any area. For the escarpment, analysis plotted the river bank height 'r' in a downward direction. It gives a considerable variation from one point to another point. 'E_a' of both river banks with various ups and downs. These inevitable ups and downs produce a cyclic wave-like characteristic of escarpments on both sides of the river (Kumar, 2015, 2018; Gautam et al. 2020). Escarpment height is the height of the vertical cliff along the margin of the river channel and river valley (Singh et al. 2009). The river starts with 20 m and 4 m height of left and right bank, respectively and after traveling 189 km distance, it finally confluence into Yamuna river and ends with 9 m and 3 m height for left and right river bank respectively. The minimum and maximum river bank height 'r' of left bank is 2 to 20 m and for right bank is 2 to 19 m. The average height 'r' of the left and the right bank is 8.8 and 9.7 m, respectively. Along the river, the five prominent zones include zone I (Panna hill), zone II (marginal Ganga plain), zone III, IV, V (central Ganga plain) have been divided according to variation in escarpment and height of channel showing several escarpments that occur in the course of the river indicative of the intra-

Table 4. Morphometric parameters of drainage network and their mathematical expressions

Parameters	Formula/Description	References
Linear Aspects		
Stream order	U = Hierarchical rank	Strahler (1957)
Stream Number	$N_u = N_1+N_2++....$ Nu where Nu = Total Number of streams	Strahler (1964)
Stream length	L_u = L1+L2++.... L_u where Lu = Total length of stream (Kms)	Horton (1945)
Stream length ratio	$R_l = L_u/L_{u-1}$ where Lu = Total stream length of the order 'u'. Lu-1 = The total stream length of its next lower order)	Horton (1945)
Bifurcation ratio	$R_b = N_u/N_{u+1}$ where Nu = Total Number of stream segments of order, Nu+1 = Number of segments of the higher order	Horton (1945)
Areal Aspects		
Drainage density (km^{-2})	$D_d = \Sigma L_u/A$ where Lu = Total length of streams, A = Basin area.	Horton (1932, 1945)
Stream frequency	$F_s = \Sigma N_u/A$ where Nu = Total Number of streams, A = Basin area	Horton (1932, 1945)
Elongation ratio	$R_e = 2/L_b\ (A/\pi)^{0.5}$) where A = Basin area, (km/km)², Lb = Basin length, π = 3.14	Bull and Mc Fadden (1977)
Relief Aspects		
Maximum elevation	H = Max. elevation of the Basin (m)	GIS analysis/DEM
Minimum elevation	h = Min. elevation of the Basin (m)	GIS analysis/DEM
Mean slope of the basin	Sbm	GIS analysis/DEM
Basin relief	R = H–h where, R = Vertical distance, H = Max. elevation, h = min. elevation	Hadley and Schumm (1961)
Relief ratio (km-1)	Rr = R/Lb where, R = Basin relief, Lb = Basin length	Schumm (1956)
Relative Relief	Rrp = R*100/P where R = Basin relief, P = Perimeter of the basin	Melton (1957)
Ruggedness number	Rn = Dd*(R/1000) where R = Basin relief, Dd= Drainage Density	Strahler (1956)
Hypsometric Integrals	$Hi = S_{bm}$-h/H-h where S_{bm} = Mean elevation, H = Max. elevation, h = Min. elevation	Strahler (1952)
Geomorphic Indices		
Sinuosity Index	$S_i = C_l/V_l$ where C_l = Channel length (K_{ms}), V_l= Valley length (K_{ms})	Miller (1964) (1968)
Escarpment analysis	Es	Toposheet (SOI)
Longitudinal profile	L_g = Relation b/w height and distance	GIS analysis/DEM
Transverse profile	T_p= Relation b/w height and distance	GIS analysis/DEM
Asymmetry factor	A_f =100(Ar/A_t) where A_r = Right side area of drainage downstream, A_t= Total basin area	Hare and Gardner (1985)

basinal tectonic activity of the Ganga plain (Thakur, 2007). Zone I is located approximately 35 km downstream distance, while the zones II (35 to 108 km) and zones III (108 to 147 km) zones IV (147 to 162 km) zones V (162 to 189 km) downstream distance, respectively (Fig. 9b).

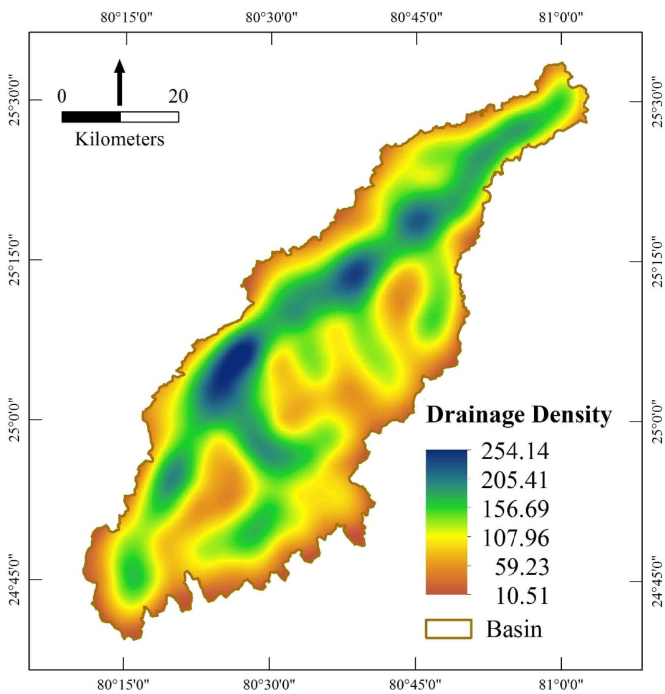


Fig. 7. Map showing the Drainage density

Longitudinal Profile (L_p)

The longitudinal profile is divided into three zones, namely Panna hills as high land, marginal Ganga plain (from high to low slope) and Central Ganga plain (lowest slope) (Fig. 10a). Moderate gradient (~ 2.95m/km) are present at an elevation ranges between 400-310 m (upper part of Panna hill), steep gradient (~ 31.75m/km) are found between 310-170m (lower part of Panna hill), while the low gradient (~ 0.79m/km) are present between an elevation 170-89 m (marginal to central Ganga plain) (Fig. 10b).

Transverse Profile (T_p)

Transverse profile of basin prepared using DEM approximately perpendicular to Baghain watershed trending in NE-SW direction. This profile starts with 510 m height at the head and after reaching the maximum, the profile further shows the decline and ends its journey at 89 m height at the mouth. Five profiles have been drawn as BTP-1, BTP-2, BTP-3, BTP-4, and BTP-5. The BTP-1 includes 25.91 km length along a where (a) denotes the starting point and (a´) denotes endpoint of the profile, BTP-2 includes 39.19 km length along (b) where (b) denotes the starting point and (b´) denotes endpoint of the profile, BTP-3 includes 35.02 km length along with (c) where (c) denotes the starting point and (c') denotes endpoint of the profile, BTP-4 includes 22.41 km length along with (d) where (d) represents the starting point and (d') denotes endpoint of the profile, BTP-5 includes 9.33 km length along with (e) where (e) denotes the starting point and (e') denotes endpoint of the profile across the main channel (Fig. 11a). In each profile shows irregularity, undulation, and tilting toward the right bank. In the middle course, the valley increases in width, and in the lower course the valley again is narrow. The upper course tilts toward the left valley side of the section BTP-1 BTP-2 and BTP-3 while the lower coarse tilts toward the section BTP-4 and

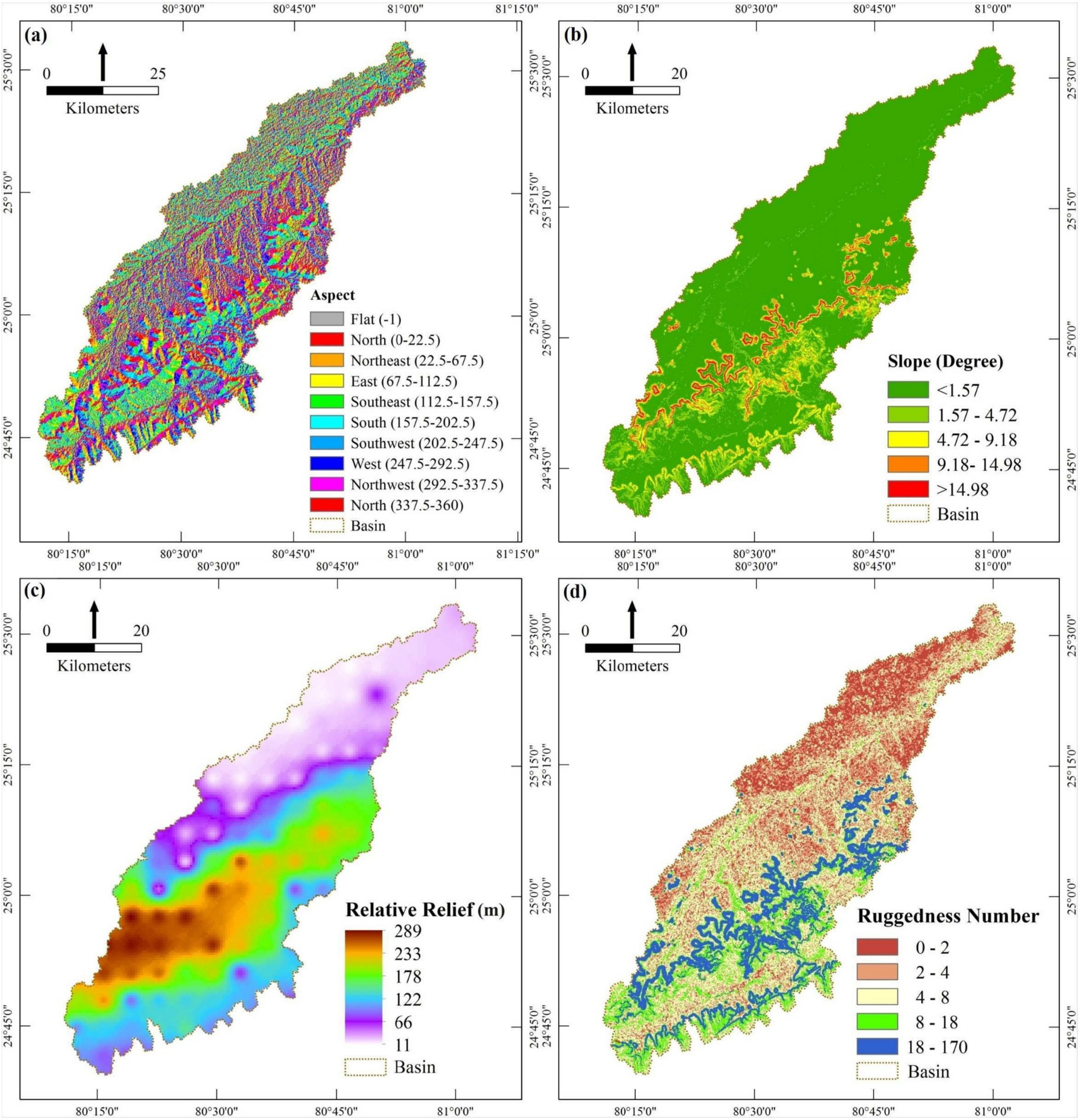


Fig. 8. (a) Map showing Aspect map of the basin. **(b)** Map showing slope of the basin. **(c)** Map showing relative relief of the basin and **(d)** Map showing ruggedness number of the basin.

BTP-5. The profile BTP-1 and BTP-2 with northwest slopes and upliftment part are considered the Panna hill while subsidence of that marginal Ganga plain. The third transverse profile (BTP-3) shows a has three-zone uplifted part of Panna hill having an altitude of more than 340 m. On the northwest side, the topography initially indicates a steep slope followed by a very gentle slope of marginal Ganga plain and central Ganga plain. The fourth and fifth transverse profile (BTP-4 and BTP-5) has southeast slopes with an altitude range of 80-120 m. and shows incision due to the soft lithology of the part of the Central Ganga plain (Fig. 11b). These variations in the lithology are due to slope variation in the upper, middle, and lower reach of the river path. This tilting of the profile shows the subsurface geological activity.

Asymmetry Factor (A_f)

The asymmetry factor (AF) is a method that evaluate the existence of tectonic tilting at the drainage basin and it can be applied relatively large area (Hare and Gardner, 1985). AF significantly greater or smaller than 50 shows the influence of active tectonics/ lithologic control (El Hamdouni et al. 2008; Kale, 2008). AF for this basin is 52 that shows the it Tilt toward left side of basin (Fig. 12a). Since the region is come under marginal Ganga plain and bundelkhand plateau region. The sharp bend present in the (Fig. 12b) probably due to the lithological variations (Table 4).

DISCUSSION

Baghain river basin comprises of three major geological sections namely: Bundelkhand genesis complex, Vindhyan Supergroup (Panna hill) and alluvial deposit (marginal Ganga plain and central Ganga plain) (Table 2). It characterised by dendritic, parallel, trellis and rectangular drainage patterns (Fig. 5a). Dendritic drainage pattern frequently occurred in Ganga plain region while parallel pattern is common is marginal Ganga plain. Schumm et al. (2000) suggested that parallel drainage systems are associated with extended landforms with moderate to steep gradient (Fig. 5b). This region has high gradient (~ 31.75m/km) (Fig. 10b). The trellis drainage patterns occur at the high land area at (300 m amsl) and formed the network of tributaries and consequent to Baghain basin (Fig. 5c). The trellis drainage patterns are associated with hard rock terrain (Pandey, 2013) which follow the regional slope and are well adjusted to the different geological structures. A rectangular pattern is associated joints and faults at right angles, in which streams lack regional continuity (Zhang, 2013). Rectangular pattern in the basin present

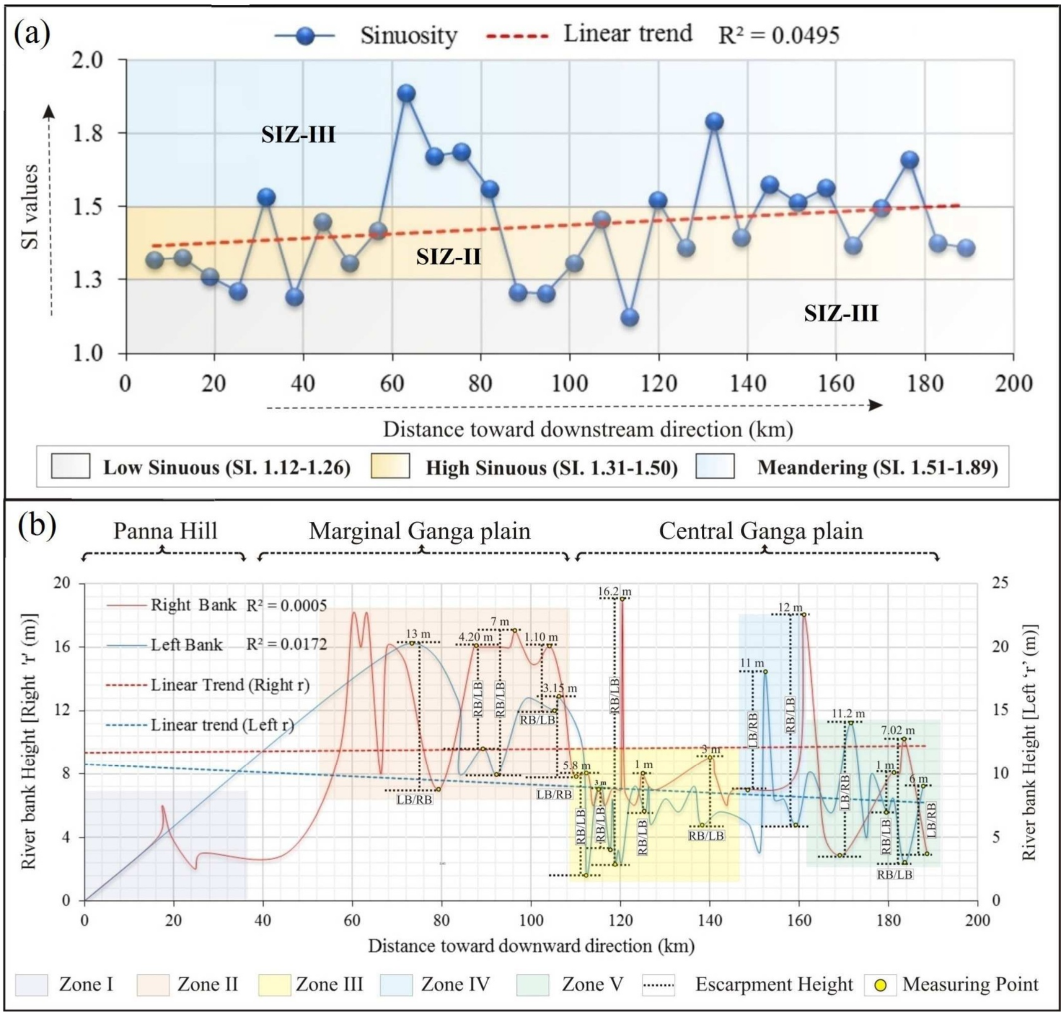


Fig. 9. **(a)** Graph showing Sinuosity indexes showing spatial distribution based on (Miller, 1964) and **(b)** Downstream variation of escarpment heights recorded on left and right banks of the Baghain River. Linear fit lines indicate the increasing downstream trend of escarpment heights. The downstream wave-like variability in the riverbank, zone I (Panna Hill), zone II (Marginal Ganga plain), zone III-VI-V (Central Ganga plain) shows the several escarpments occur in the course of the river indicative of the intra-basinal tectonic activity of the Ganga Plain (Thakur, 2007).

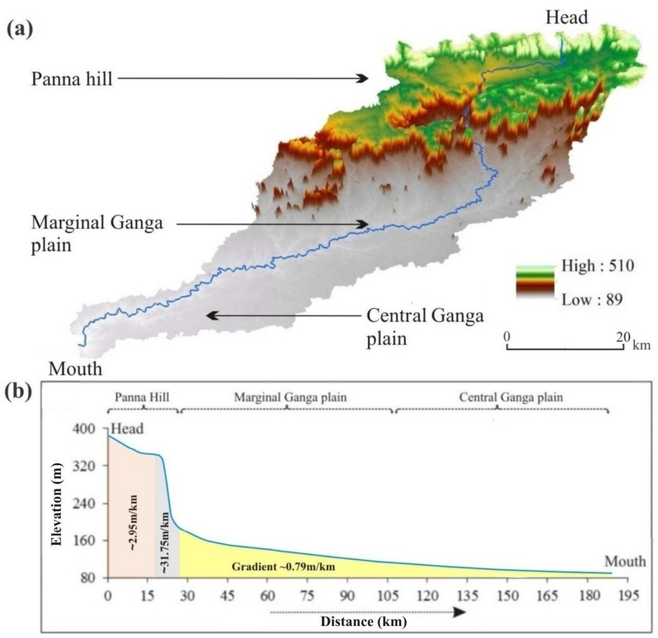
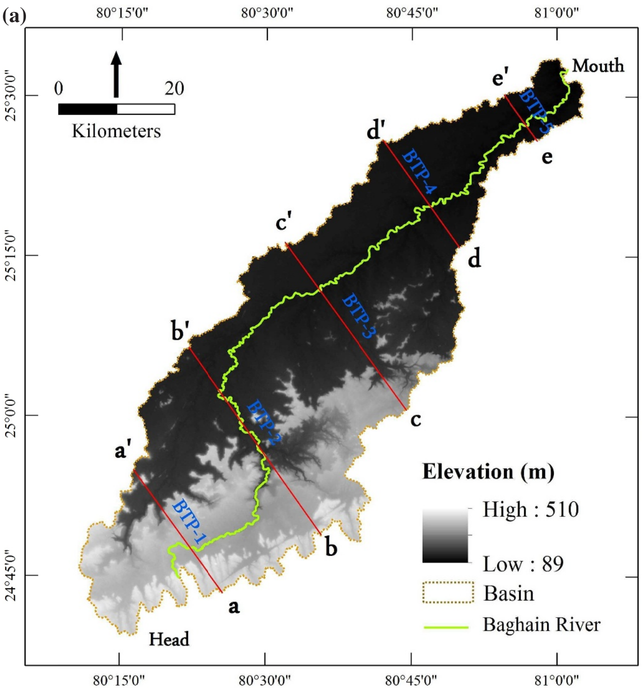


Fig. 10. **(a)** 3D model of the Baghain basin showing plateau and alluvial plain **(b)** Longitudinal profile of the basin.

at elevated area of rocky segments of Bundelkhand Craton (Pati, 2020) (Fig. 5d).

The basic characteristic of stream networks is the stream segment and assignment of stream orders is the first stage in geomorphic analysis. The stream order refers to the hierarchical rank of streams (Fig. 2a). The stream order increases when streams of the same order intersect. This method proposed by Strahler (1957). Therefore, the intersection of two first-order links will create a second-order link, the intersection of two second-order links will create a third-order link, and so on. The intersection of two links of different orders, however, will not result in an increase in order. For example, the intersection of a first-order and second-order link will not create a third-order link but will retain the order of the highest ordered link (Tarboton et al. 1991). Horton (1932) proposed the stream frequency factor as a ratio of the total stream number in a basin. It is used to determine the permeability of subsurface material, vegetation, and relief.

Elongation ratio values generally lie between 0.4 and 1.0 which is allied with an extensive variation in climate and geological properties. The values close to 1.0 represent the regions of very low relief, while the values in between 0.6 and 0.8 are followed with higher relief and steeper ground slope (Strahler, 1964). It is classified into circular (0.9–1.0), oval (0.8–0.9), less elongated (0.7–0.8), and more elongated (0–0.5). In this basin, it is exibits elongation in nature. Drainage density



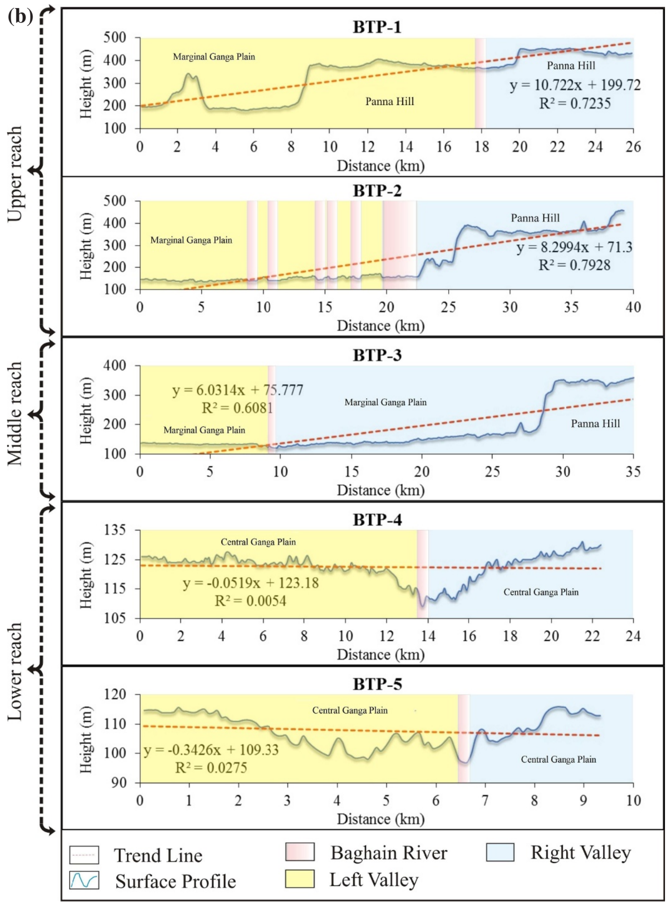


Fig. 11. (a) Index map of transverse profile of Baghain river basin. **(b)** Transverse profile of the Baghain river basin. Section within five profiles following BTP_1, to BTP_5. In which bluecolour shows the right bank, yellow colour shown left bank, pink colour showing the main channel. The surface profile showing irregularity and the linear trend of profile showing the tilting of the basin.

and Stream frequency reflects moderate to high permeable and erodible alluvium (Fig. 6c and 7). Low value indicates a highly permeable region (Horton, 1945; Strahler, 1952; Nag and Chakraborty, 2003), while high value indicates the impermeable subsurface material. It is primarily affected by the resistance of the bed material to erosion and the infiltration potential (Verstappen, 1983; Singh et al. 2015).

Aspect map suggest that the basin having east facing slope direction. Basin relief is a parameter that determines the drainage gradient and affects flood patterns and the volume of sediment that can be transported (Hadley and Schumm, 1961). It is also an important factor in geomorphic processes and landform characteristics of the basin (Sreedevi et al. 2004).

Mean slope indicate the overall terrain condition of the basin (Dipak et al. 2015). The present of high Basin relief in area is a result of the topographic variation at different places (Fig.8b). The relief ratio is a dimensionless parameter measured between basin relief and basin length (Schumm, 1963). Relief ratio normally increases with decreasing drainage area and size of a drainage basin (Gottschalk, 1964). The high values of R_r are due to the presence of resistant rocks in the area. The relative relief was computed by the equation given by (Melton, 1957). It is a ratio between basin relief to the perimeter of the basin. The ruggedness number has been defined as the product of basin relief and drainage density (Strahler, 1956) and practically combines slope steepness with its length (Pareta and Pareta, 2011;

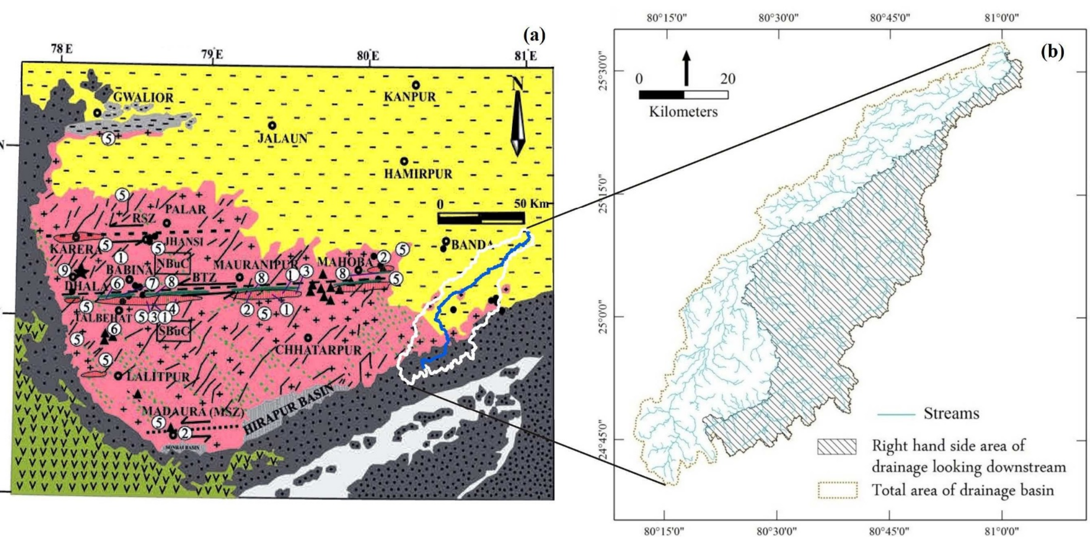


Fig. 12. (a) Enlarged geological map of Bundelkhand Craton (Pati, 2020). **(b)** Asymmetry factor map of the basin.

Patel et al. 2013). The (R_n) of the basin is considered medium soil erosion, permeability, runoff, infiltration rate (Fig. 8d). Hypsometric integral, a dimensionless parameter is Suggested by (Strahler, 1952) (Fig. 6d). the results of (H_i) imply three phases of the basin: (1) Basin of deeper incision reflecting HI > 0.5 and slight erosion from active tectonics; (2) Basin is having 0.4 < HI < 0.5 Reveal approximate equilibrium and an intermediate stage of incision and erosion from prominent active tectonic and (3) Basins having HI < 0.4 defined by low relief and severe erosion. Here, using the hypsometric curve, to established the relationship between the elevation of the basin and the basin area (Table 4).

The measured sinuosity index zones (SIZ) along with linear fit curve for channel following SIZ-I (SI-1.12 to 1.26) which indicates the low sinuosity. SIZ-II (SI-1.31-1.50) value shows the high sinuosity which leads to lateral erosion (Gautam, 2019). The occurrence of high sinuosity SIZ-II zone shows the suddenly high peak due to low discharge. Sinuosity increases, when the bank at the outer bend of a channel bend erodes greater than the bank at the inner bend. Alluvial meander theory relates this imbalance in lateral erosion to hydraulics (e.g**.,** Einstein, 1926; Ikeda et al. 1981; Edwards and Smith, 2002 and Singh and Awasthi, 2011ab). SIZ-III (SI-1.51.1.89) reveals the meandering in nature. Most meandering streams show a significant change of sinuosity through time and hence the plan forms reflectionally the geomorphic history but the valley slopes are influenced by geological control such as active tectonics, tributary contributions (Burnett and Schumm, 1983; Wyzga, 2006). Timar (2003) showed that in the interflow of rivers, significant sinuosity variations were found to correspond with discharge and sediment load changes.

The escarpment analysis strongly indicate the downstream increasing trend of the fluvial incision. The general downstream changes of escarpment heights on both the margins of the river suggest that Escarpment height is low in the proximal part (Panna Hill), and is the highest in the middle (marginal Ganga plain) and distal segment (central Ganga plain) of the river. Figure 9b displays the graph of the Baghain watershed showing an increase and decrease in the height of escarpments on both banks along its entire channel length. The downstream increase in the escarpment height is not uniform and shows distinct variations in its height values at various places. The escarpment heights of the river vary along its length in multiple segments. Escarpment height is higher on the right margin than the left margin of the river. It produces a wave-like feature of escarpment height on both river banks. The escarpment height of the river for both bank of the margins of river strongly indicates the incision toward downstream. The downstream increasing trend in the escarpment height indicates a high incision magnitude for the river. The river shows a high degree of incision in this zone and a difference in the magnitude of escarpment heights.

Downstream wave-like variation in average escarpment height reveals undulating topography with prominent upwarps and downwards attributed to the compressional tectonics of the Ganga plain (Singh et al. 2009). This increasing trend toward downstream indicates that the incision by the river has occurred under a geological process that has lowered the base level of the river near its downstream end. However, the presence of high escarpment zones in the river is indicative of the intra-basinal tectonic activity of the Ganga plain (Thakur, 2007). The peek zone in the basin profile shows sudden upliftment and a gradual decrease in slopes in their region due to morphological activity. This interruption may affect the surface geomorphic features such as uplifting and incision (Ramírez-Herrera, 1998). This watershed has a calculated value is 52 and shows that the basin is Tilting (Fig. 12 and Table 4). The river is turning suddenly in 90 degrees. This turn in the profile is due to a highland area of Bundelkhand gneisis; and low land area is part of Ganga basin.

CONCLUSIONS

The morphometric parameters and its implication for the drainage characteristics and tectonics are given below

1. Baghain river flows through the Bundelkhand region and is a sustainable source for the water budget of this region.
2. Baghain river basin comprises of three major geological units namely: Bundelkhand gneissic complex, Vindhyan supergroup (hard rock terrain name as Panna hill) and alluvial deposit (marginal Ganga plain and central Ganga plain).
3. The river is characterised by four types of drainage patterns namely as: dendritic, parallel, trellis and rectangular.
4. The bifurcations ratio is (4.82) suggest that most part of the basin does not influence by any major geological structures.
5. The elongation ratio (0.50) suggest that the basin is moderately elongated. Drainage density (0.62), and stream frequency (0.22), reflects moderate to high permeable and erodible alluvium.
6. The escarpment heights on both the margins of the river suggest that escarpment height is low in the proximal part (Panna Hill), high in the middle (marginal Ganga plain) and distal segment (central Ganga plain). The escarpment height of the river for both bank of the margins of river strongly indicates the incision toward downstream. The downstream increasing trend indicates a high incision magnitude for the river. This increasing trend toward downstream indicates that the incision by the river has occurred under a geological process that has lowered the base level of the river near its downstream end.
7. Asymmetric factor (52) shows its tilt toward left side of basin. Since the region comes under marginal Ganga plain and Bundelkhand plateau region. The sharp bend is due to the lithological variations.
8. Basin is having Moderate gradient in upper part of Panna hill, steep gradient in lower part of Panna hill and low gradient in marginal to central Ganga plain.

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