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Quantitative Morphometric and Morphotectonic Analysis of Pahuj Catchment Basin, Central India

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ABSTRACT

In the present work, the morphometric and morphotectonic analysis of the Pahuj basin catchment of the Bundelkhand region of Central India was carried by using remote sensing and GIS techniques. The drainage map, Digital Elevation Model (DEM), density, contour, aspect, and other thematic maps were extracted from ASTER-DEM (30m resolution) data by using geographical information system (GIS) tool. Five order streams have been validated in the study area and an inverse relationship between the stream order and stream number has been established. The high mean bifurcation ratio (Rb=5.12) indicates that the drainage pattern is controlled by geological structures in the impermeable granitic terrain. The stream frequency (2.69) is indicative of the increment of stream population for drainage density. Contrary to this the drainage density (2.08) is suggestive of low to moderate infiltration rate and is showing the thin vegetal cover on the impermeable rocky terrain. The elongation ratio (0.61) and form factor (0.29) infer that the catchment basin is elongated and shows low peak flows. The value of ruggedness and Melton ruggedness number implies that the basin is moderately rugged and debris watershed and is less susceptible to soil erosion.

The drainage pattern of basin catchment flowing in diverse lithological and structural terrain (Archean and Palaeoproterozoic age) is exhibiting less influence of active tectonics. The NW-SE, E-W and NNE-SSW trending lineaments resembling the orientation of lower-order streams are suggestive of structural control. The NE-SW trending high order streams flowing in an elongated Pahuj basin catchment and coinciding with the orientation of major NE-SW lineaments are indicative of major tectonic control.

INTRODUCTION

Morphometry is explained as measurement and mathematical evaluation of the earth's surface and shape, size, and dimensions of landforms (Clarke, 1966; Agarwal, 1998; Obi Reddy et al., 2002). It is defined as the hydrological response of a river basin interrelated with size, shape, slope, drainage density, and length of the streams (Gregory and Walling, 1973). It reveals that the geological and geomorphological processes undergone in geological time have an influence on the drainage basin and are significant in understanding the landform processes, the physical and erosional property of soil (Horton, 1945; and Strahler, 1952, 1964). The development of fluvial landforms and drainage patterns shows the inherent control of lithology and tectonics (Horton, 1932; Ritter, 1986; Pati et al., 2008 Shukla et al., 2012). The quantitative physiographic methods for evolution and behavior of surface drainage networks have been widely used for the last several years by using conventional methods of Remote Sensing and GIS Techniques (Pareta and Pareta, 2011; Bhatt et al., 2020). The implications of linear, areal, relief and tectonic aspects of a drainage basin can be understood by carrying detail morphometric analysis (Nautiyal, 1994; Nag and Chakraborty, 2003; Pareta and Pareta, 2011; Pareta and Pareta, 2012; Maghesh et al., 2012; Bhatt et al., 2017; Bhatt et al., 2020).

Tectonic movements are playing important roles in controlling drainage patterns and the evolution of landforms (Ouchi, 1985; Radhakrishna, 1992; Sinha Roy 2001) and the river responds to vertical movements by aggradations or degradation (Marple and Talwani, 1993, Holbook and Schumm, 1999). Only a few studies pertaining to peripheral bulge tectonics caused by continued northward push of the Indian plate have been carried out by few workers on marginal plains of Ganga and Yamuna (Agarwal et al., 2002, Shukla et al., 2012, Ghosh et al., 2017and Gosh et al., 2019). Recently the morphotectonic studies confined to Cratonic Rivers have been done by few workers (Bhatt et al., 2014; Prakash et al., 2016, Prakash et al., 2017; Bhatt et al., 2017) by using advance techniques of remote sensing and GIS.

In the present work, the morphometric studies are carried out to understand the landform processes, the physical and erosional property of soil of the basin. These studies will provide information about hydrogeological characteristics of landform and control of geological features on the drainage of the basin. It will also be beneficial in the planning of watershed management, rainwater harvesting, conservations of soil and water resources, and an assessment of groundwater potential.

The orientation of lineaments can be interpreted for the evolution of drainage and watershed analysis. The morphotectonic studies based on remote sensing and GIS and field setting on cratonic rivers (major tributaries of Yamuna) flowing from Vindhyan and Bundelkhand terrain have not been studied in detail. There is a need to pursue research and field study on cratonward peripheral bulge tectonic features (small-scale deformation features; gentle folds, extensional normal faults, uplifted tilted blocks, fault scarps, and incised river channels) exposed in the cratonic part of the foreland basin of Ganga and Yamuna and marginal contacts of all cratonic rivers of Bundelkhand. Additionally, these studies should be supported by analysing morphotectonic parameters viz. sinuosity, direct bifurcation ratio, elongation ratio, asymmetrical factor, and transverse topography asymmetry, stream length gradient index (SL), longitudinal profile, etc in all cratonic rivers of Bundelkhand by using advance techniques of remote sensing and GIS. These studies would be helpful in understanding the tectonics and seismic hazards.

STUDEY AREA

Pahuj a tributary of the Sind river drains through granitic terrain and low lying alluvium country of Bundelkhand craton in Central India. It covers 234 sq km area and flows through historic city of Jhansi in SW to NE direction. Its catchment extending in 28.33 km in length lies between latitude 25°18'30" to 25°27'27" N and longitude

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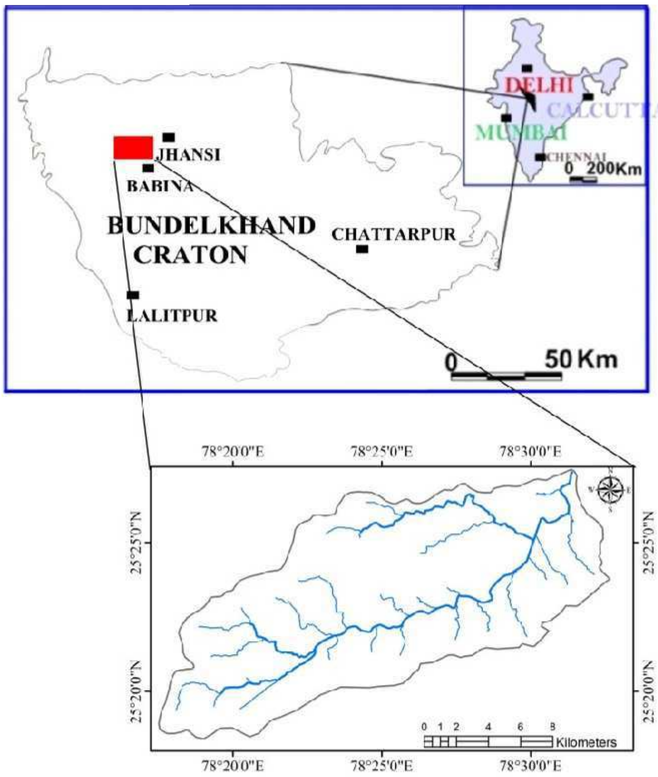

Fig.1. Location map of the Pahuj catchment basin.

78°17'33" to 78°131'22" E in Central India (Fig. 1). This semi-arid region faces acute surface and sub-surface water scarcity due to low recharge.

GEOMORPHOLOGICAL AND GEOLOGICAL SETTING

The investigated area is characterised by rugged and undulating topography with moderately elevated granitic hills and quartz reefs. The erosional and depositional landforms, granitic and quartz reefs (200-300m), and undulating pediplain and alluvial plains are the important geomorphic features in the study area (Bhatt et al., 2014; Bhatt et al., 2017). The lower flanks of NE – SW trending quartz reefs are covered with thick vegetation and scrubs. The granitic and gneissic terrains are characterised by hard and massive lithology and at places are covered by scrub. The isolated granitic and gneissic boulders are scattered in several places. The fractured, weathered, and sheared hard rock terrain and low lying alluvial plains are considered good potential zones for groundwater.

The geology of the Bundelkhand craton of central India is represented by Bundelkhand tonalite-tronjhemite-gneissic (TTG) Complex, greenstone complex, and Bundelkhand granitic complex (Basu, 1986; Pati et al., 1997; Fig. 2a and 2b). The tonalite-tronjhemite-granodiorite (TTG) gneisses (3.5-3.2 Ga) and streaky and mafic gneisses (3.1-3.2Ga) constitute important rock units of Bundelkhand TTG gneissic complex (Bhatt and Gupta, 2009; Bhatt et al., 2011; Bhatt and Gupta, 2014; Bhatt, 2014; Singh and Slabunov, 2015a; Bhatt and Singh, 2019). The metabasics, sheared felsic volcanics and banded iron formation (BIF), exposed in the central part of craton belong to greenstone belt of Neoarchean age (Singh and Slabunov, 2015a). Bundelkhand granitic complex mainly consists of various types of granitoids, quartz reefs and doleritic dykes (2.6-2.0Ga; Bhatt and Gupta, 2009; Bhatt et al. 2011; Bhatt and Gupta, 2014; Bhatt, 2014; Bhatt and Hussain, 2008; Bhatt and Khalid, 2012; Singh and Slabunov 2015a; Bhatt et al., 2017). The mylonitic granite gneisses and other rocks are also found important rock units of Bundelkhand TTG gneissic complex.

METHODOLOGY

The toposheets (G44M07 and G44M11) of the Survey of India (2010 and 2011) at the scale of 1:50000 were used as a base map to extract stream network and drainage map of the area. These toposheets were scanned, georeferenced, and mosaicked in the Arc GIS platform. All morphometric parameters were then quantified using USGS based Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) with 30 m resolution (Fig. 3). The ASTER-DEM (30m resolution) data were processed by the Arc GIS tool to delineate the drainage map, digital elevation model (DEM), watershed delineation map, density, contour, aspect and other thematic maps (Figs. 4, 5, and 6). The linear, areal, and slope parameters of Pahuj basin catchment were computed (Table 1, 2, and 3). The one-dimensional stream properties viz. stream order, stream number, stream length, mean stream length; stream length ratio, bifurcation ratio, etc are put into linear aspects of the basin (Table 1 and 2). The areal aspects involve two-dimensional stream properties such as basin length, basin perimeter, and basin area. The three-dimensional relief morphometric parameters (total relief, relative relief, relief ratio, gradient ratio, etc) are also calculated. These values are calculated using standard methods and equations mentioned in Table 3. The linear parameters were estimated by using the methods proposed by Horton (1945) and Strahler (1964). The areal aspects were quantified by using methods of Schumm (1956), Strahler (1956, 1964), Miller (1953), and Horton (1932), and the relief parameters were determined by applying the techniques of Horton

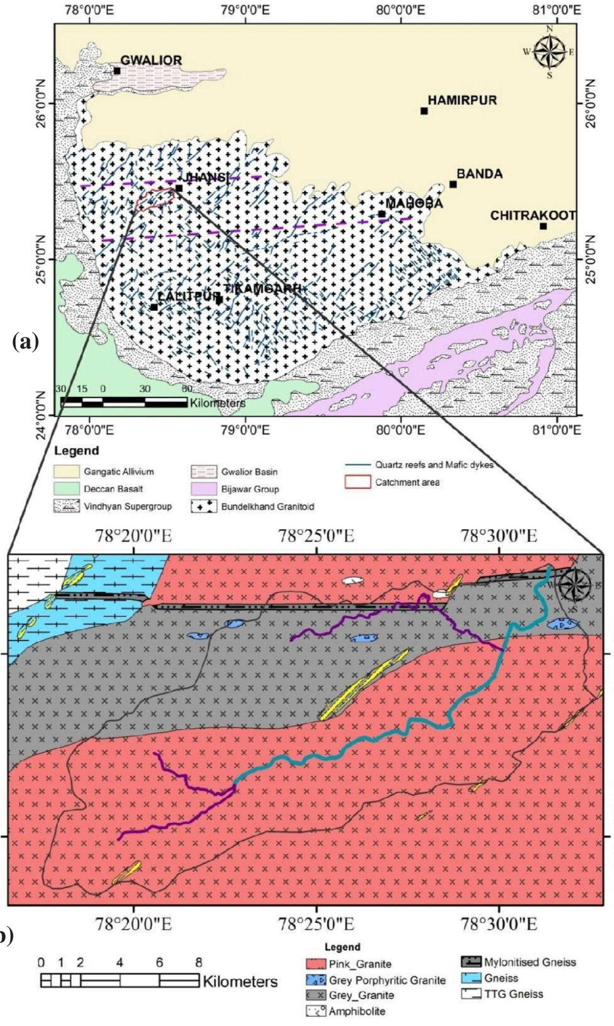

Fig.2. (a) Geological map of Bundelkhand craton (modified after Pati et al., 1997). **(b)** Geological map of Pahuj basin catchment showing important litho units (modified after Bhatt and Gupta, 2014).

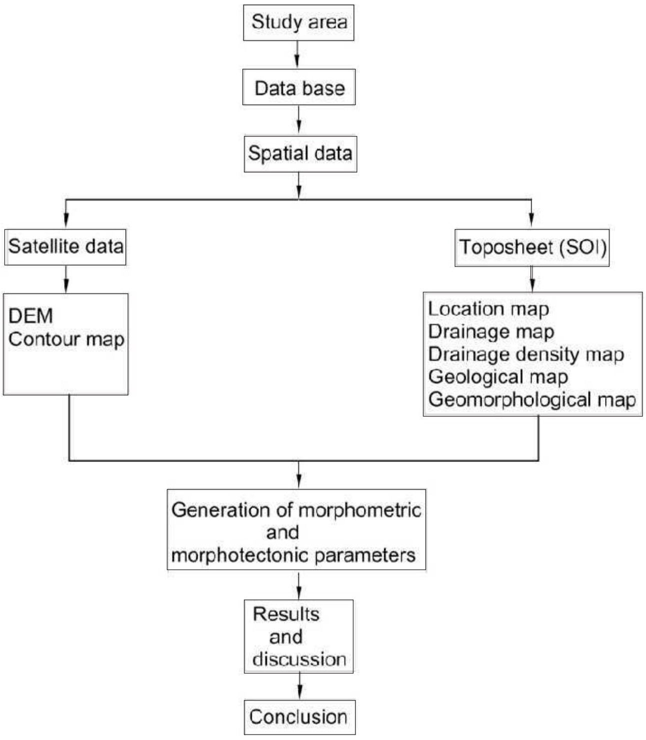

Fig.3. Methodology flow chart.

(1945), Broscoe (1959), Melton (1957), Schumm (1954), and Strahler (1952). The average slope analysis of the watershed area was done using the Wentworth method (1930).

RESULTS

The attempts were made to delineate the morphometric parameters of a Pahuj basin catchment watershed and to explore the structural and tectonic control on the drainage pattern. It also reveals the relationship between drainage morphometry and various landforms and provides a strategy for the planning of water management and water harvesting. About fifty-five parameters of linear, areal, and relief aspects were quantified by using Arc GIS software and USGS ASTER DEM data (30M resolution).

Table 1. Linear Parameters (Stream Length, and Stream Length Ratio) computed for Pahuj Basin Catchment

Su	Lu	Lu/Su	Lur	Lur-r	Lur*Lur-r	Luwm
I	264.77	0.54				
II	102.23	0.92	1.7	367	623.9	
III	70.86	2.62	2.84	173.09	491.57	2.27
IV	25.43	8.47	3.23	96.29	311.01	
V	23.10	23.10	2.72	48.53	132	
Total	486.39	35.65	10.49	684.91	1558.48	
Mean			2.62			

Su: Stream order, Nu: Number of streams, Rb: Bifurcation ratio, Nu-r: Number of the stream used in the ratio, Rbwm: Weighted mean bifurcation ratio

Table 2. Stream Order, Streams Number, and Bifurcation Ratio of Pahuj basin Catchment, Bundelkhand craton, Central India

Su	Nu	Rb	Nu-r	Rb*Nu-r	Rbwm
I	487				4.50
II	111	4.38	598	2619.24	
III	27	4.11	138	567.18	
IV	3	9	30	270.00	
V	1	3	4	12.00	
Total	629	20.49	770	3468.42	
Mean		5.12			

Su: Stream order, Nu: Number of streams, Rb: Bifurcation ratio, Nu-r: Number of the stream used in the ratio, Rbwm: Weighted mean bifurcation ratio

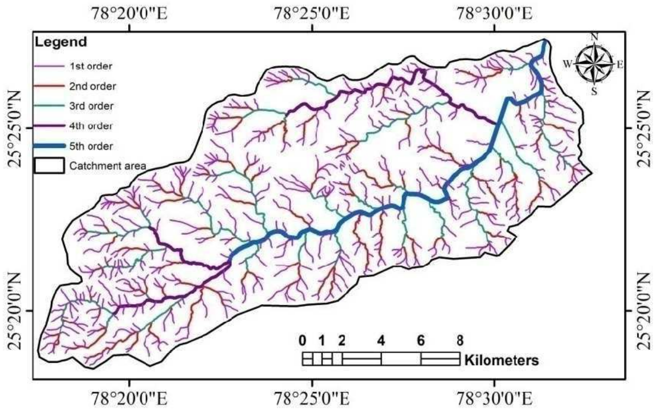

Fig.4. Drainage map showing Stream orders of Pahuj basin catchment based on Strahler's method.

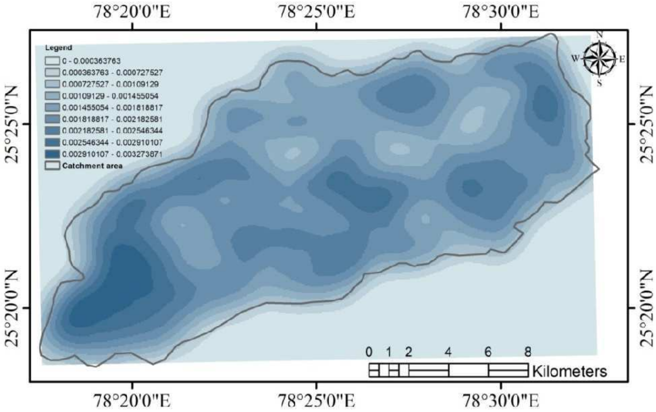

Fig.5. Drainage density map of Pahuj catchment basin.

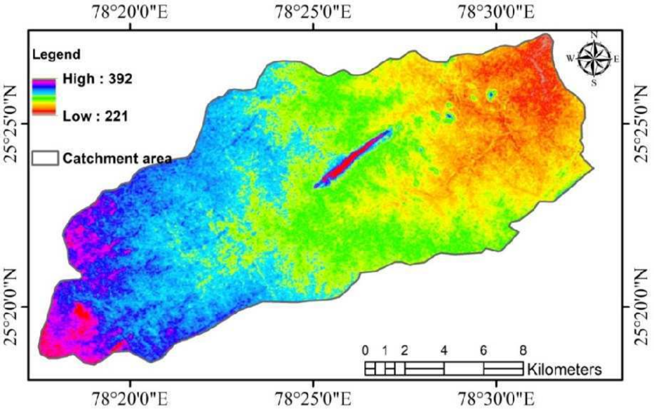

Fig.6. Digital elevation model (DEM) of the Pahuj catchment basin.

Drainage Pattern

Strahler's method has been used to order the stream segment of the catchment. Five orders of streams classification are depicted in Fig.4. I to III orders stream are named as lower order and IV to V orders stream are ranked as higher-order streams respectively. Dendritic to sub-dendritic drainage pattern is dominantly noticed in the Pahuj basin catchment. However, the trellis drainage pattern formed by the network of tributaries of lower-order streams with high order streams is also observed. The dendritic pattern resembles with the homogenous granites. The first order stream represented by rills and gullies is showing variable trends in NW-SE and NE-SW directions (Fig. 7a). The second and third-order streams are trending in NNE-SSW and

Table 3. Morphometric Parameters computed for Pahuj basin catchment

S No	Morphometric Parameter	Formula	Result	Reference
A	**Drainage Network**			
01	Stream Order (Su)	Hierarchical Rank	1 to 5	Strahler, 1964, Horton 1945
02	1^{st} Order Stream (Suf)	Suf = N1	487	Strahler, 1952
03	Stream Number (Nu)	Nu = N1+N2+…Nn	629	Horton, 1945
04	Stream Length (Lu) Kms	Lu = L1+L2 …… Ln	486.39	Horton, 1945
05	Stream Length Ratio (Lur)	Lu+1/Lu	1.70-3.23	Horton, 1945
06	Mean Stream Length Ratio (Lurm)	See Table 1	2.62	Horton, 1945
07	Weighted Mean Stream Length Ratio (Luwm)	See Table 1	2.27	Horton, 1945
08	Bifurcation Ratio (Rb)	Nu/Nu+1	3-9	Schumm, 1956
09	Mean Bifurcation Ratio (Rbm)	See Table 2	5.12	Schumm, 1956
10	Weighted Mean Bifurcation Ratio (Rbwm)	See Table 2	4.50	Schumm, 1956
11	Main Channel Length (Cl) Kms	GIS Software	29.75	Horton, 1945
12	Rho Coefficient (ρ)	ρ = Lur / Rb	0.51	Horton, 1945
B	**Basin Geometry**			
01	Basin Length (Lb) Kms	GIS Software Analysis	28.33	Schumn, 1956
02	Mean Basin Width (Wb)	Wb = A / Lb	8.26	Horton, 1932
03	Basin Area (A) Sq Km	GIS Software Analysis	234	Strahler, 1964
04	Basin Perimeter (P) Kms	GIS Software Analysis	73.89	Schumm, 1956
05	Relative Perimeter (Pr)	Pr = A / P	3.17	Schumm, 1956
06	Length Area Relation (Lar)	$Lar = 1.4 * A^{0.6}$	36.95	Hack, 1957
07	Lemniscate's (k)	$k = Lb^2 / A$	3.43	Chorley, 1957
08	Form Factor Ratio (Rf)	$Ff = A / Lb^2$	0.29	Horton, 1932
09	Shape Factor Ratio (Rs)	$Sf = Lb^2 / A$	3.43	Horton, 1956
10	Elongation Ratio (Re)	$R_e=2 \sqrt{(A/ \pi)}/L_b$	0.61	Schumm, 1956
11	Texture Ratio (Rt)	Rt = N1 / P	6.59	Horton, 1945
12	Circularity Ratio (Rc)	$Rc = 12.57 * (A / P^2)$	0.54	Miller, 1953
13	Circularity Ration (Rcn)	Rcn = A / P	3.17	Miller, 1953
14	Drainage Texture (Dt)	Dt = Nu / P	8.51	Horton, 1945
15	Compactness Coefficient (Cc)	Cc = 0.2841 * P /A 0.5	1.37	Melton, 1957
16	Fitness Ratio (Rf)	Rf = Cl / P	0.40	Melton, 1957
17	Wandering Ratio (Rw)	Rw = Cl / Lb	1.05	Smart and Surkan, 1967
C	**Drainage Texture Analysis**			
01	Stream Frequency (Fs)	Fs = Nu / A	2.69	Horton, 1945
02	Drainage Density (Dd) Km / Kms^2	Dd = Lu / A	2.08	Strahler, 1952
03	Constant of Channel Maintenance (Kms^2 / Km)	C = 1 / Dd	0.48	Schumm, 1956
04	Drainage Intensity (Di)	Di = Fs / Dd	1.29	Faniran, 1968
05	Infiltration Number (If)	If = Fs * Dd	5.60	Faniran, 1968
06	Drainage Pattern (Dp)	Dn-SubDn	-	
07	Length of Overland Flow (Lg) Kms	Lg = A / 2 * Lu	0.24	Faniran, 1968
D	**Relief Characteristics**			
01	Height of Basin Mouth (z) m	GIS Analysis / DEM	230.00	-
02	Maximum Height of the Basin (Z) m	GIS Analysis / DEM	378.00	-
03	Total Basin Relief (H) m	H = Z - z	148.00	Strahler, 1952
04	Relief Ratio (Rhl)	Rhl = H / Lb	0.005	Schumm, 1956
05	Absolute Relief (Ra) m	GIS Software Analysis	378.00	-
06	Relative Relief Ratio (Rhp)	Rhp = H * 100 / P	0.20	Melton, 1957
07	Dissection Index (Dis)	Dis = H / Ra	0.39	Singh and Dubey, 1994
08	Gradient Ratio (Rg)	Rg = (Z - z) / Lb	0.005	Sreedevi, 2004
09	Watershed Slope (Sw)	Sw = H / Lb	0.005	-
10	Ruggedness Number (Rn)	Rn = Dd * (H /1000)	0.31	Patton and Baker, 1976
11	Melton Ruggedness Number (MRn)	$MRn = H / A^{0.5}$	0.01	Melton, 1965
12	Contour Interval (Cin) m	GIS Software	20.00	
13	Slope Analysis (Sa)	GIS Analysis / DEM	1°-20°	Rich, 1916

NNW-SSE to NW-SE directions respectively (Figs. 7a and 7b). The higher IVth and Vth order streams have variable trend in WNW-ESE to NE-SW directions respectively (Fig. 7b).

Linear Aspects

About 487 and 111 streams have been identified in first and second-order respectively. The third- order has 27 streams while the fourth and fifth-order has 3 and 1 stream respectively. The catchment size and hierarchy are controlled by stream order. An inverse relationship between stream order and stream number is shown in figure 8. The mean stream length increases with increasing order. The stream length ratio varies from 1.70 to 3.23 in the first-order stream. It is indicative of the presence of moderately resistant rocks, low slope, and topography in the basin catchment. The bifurcation ratio (Rb) varies from 3.00 to 9.00 in all stream order. Its highest value (Rb= 9.0) is recorded in IV order streams while the lower values are calculated in lower order streams.

Areal and Relief Parameters

The total area of the catchment basin is 234 square kilometers and the perimeter is 73.89 km. It shows an elongated shape of the catchment. The stream frequency was estimated at 2.69. It indicates

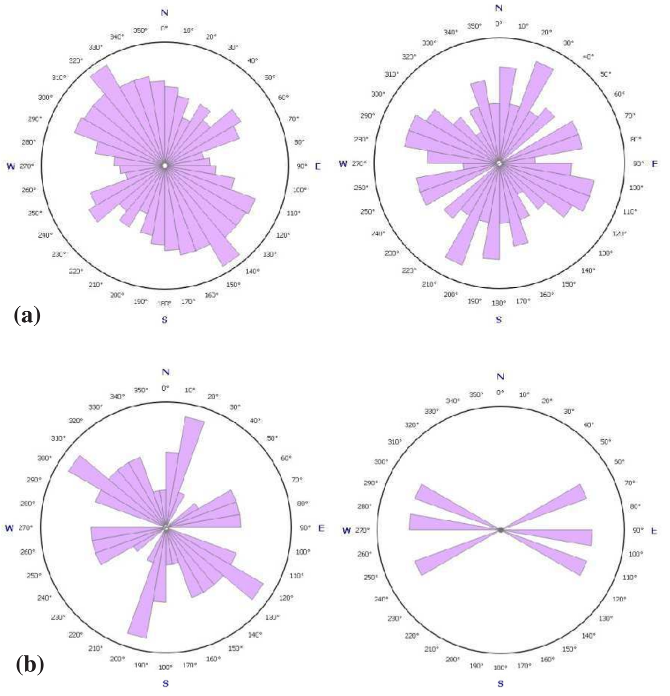

Fig.7. Rose diagram showing orientation of **(a)** First and second-order streams. **(b)** Third and fourth-order streams.

that the stream population is increasing for drainage density. The value of drainage density (2.08) is suggestive of medium infiltration ratio and moderate permeability. The stream frequency (2.69) is characterised by low vegetation and low infiltration rate. The value of the elongation ratio can be classified into three categories (Schumm 1956); circular (>0.9), oval (0.9-0.8) and elongated (<0.7). The elongation ratio (0.61), form factor (0.29), and circulatory ratio (0.54) calculated for the Pahuj catchment basin implies that the basin is elongated and prone to headward erosion.

The highest point of the catchment basin is 378 m and the total basin relief is 148 m (Table 3). The low relief values are indicative of less resistant rocks in the catchment area. The relief ratio (0.005) of the Pahuj catchment basin indicates that the catchment is showing variation in gradient and is more susceptible to erosion in steeper slope. The ruggedness number is expressed as the product of basin relief and drainage density (Strahler, 1958). The low value of ruggedness and Melton ruggedness number computed for the study area infers that the moderately rugged terrain is less prone to erosion.

TECTONIC PARAMETERS

Orientation and Density of Lineaments

The lineaments are important components to delineate structural and morphological features and intensity of deformation on the earth's surface (Nur, 1982). The lineaments are classified based on an alignment of structural and morphological features, drainage pattern and textural contrast and tonal differences. The major trends of lineaments are coinciding with tectonic features of the area (Fig. 9a). The orientation of lineaments is represented by a rose diagram (Fig. 9b). The orientations of linear features were determined by using open Aster DEM Geomatica software. The density map was prepared from the linear data (Fig. 9c). Three main sets of lineaments showing three major deformation trends were noticed in the study area. The E-W, NE-SW, and NW-SE trends of lineaments are representing shear zones, quartz reefs, and dykes respectively (Fig 9a and 9b). The frequency of NE-SW trending lineaments is low and is corresponding to IV and V high order streams. The high frequency of lineaments represented by NW-SE and NNE-SSW trends are corresponding to the trends of I, II, and III low order streams (Figs 9a.9b and 9c). The catchment appears in an elongated shape and its trend is coinciding with the orientation of major NE-SW lineament (Fig. 9). It implies that the main course of higher-order streams is controlled by the major tectonic elements (NE-SW). The Pahuj river flowing in the Bundelkhand granitic terrain has less influence of tectonic activity.

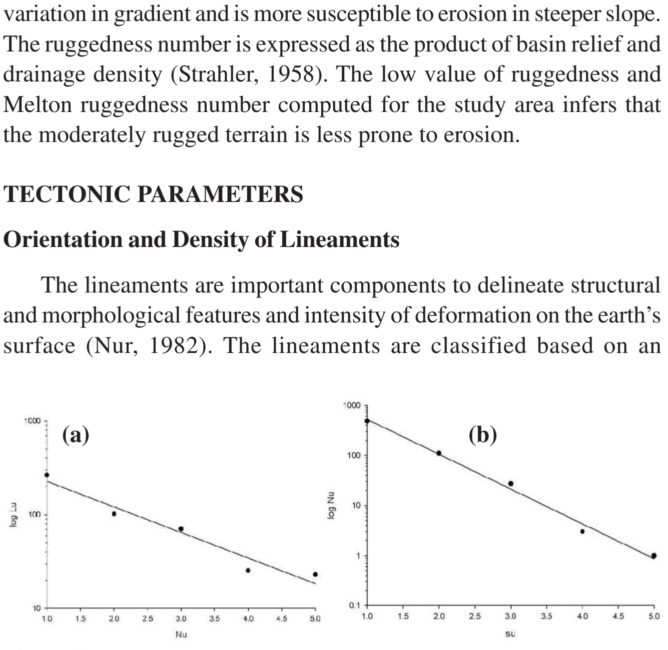

Fig.8. **(a)** The relationship between the logarithm of a stream length and Stream order. **(b)** The relationship between the logarithm of Stream number and Stream order.

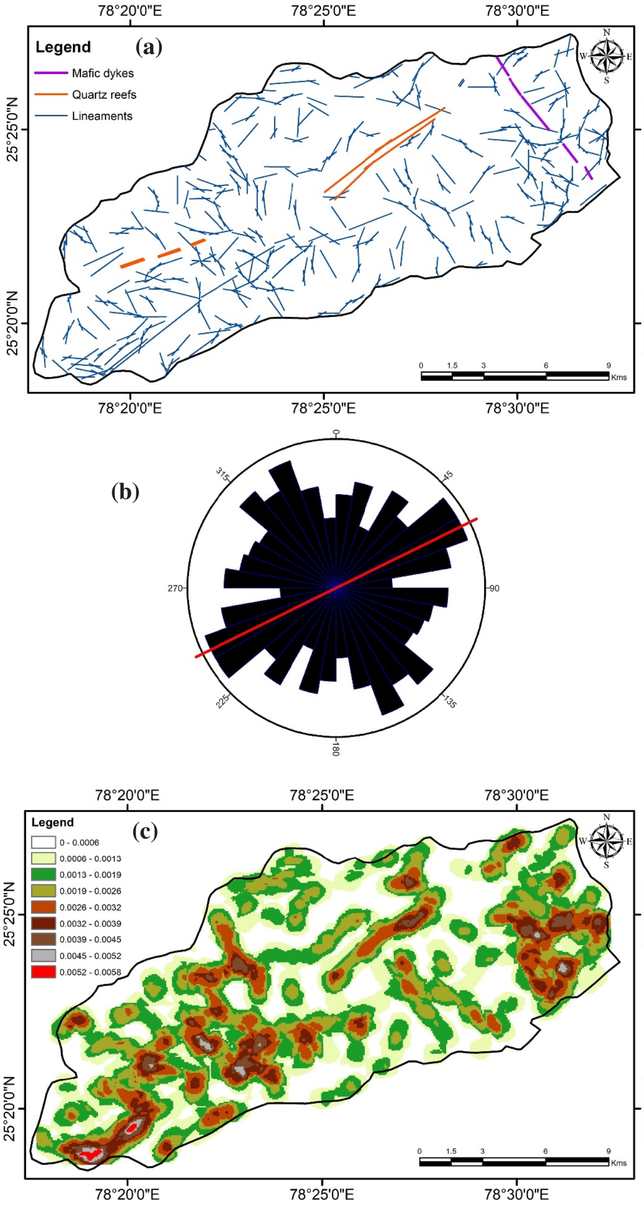

Fig.9. **(a)** Lineament map of the Pahuj catchment basin. **(b)** Rose diagram showing orientation of lineaments. **(c)** Lineament density variation map Pahuj catchment basin.

Asymmetric and Transverse Factors

The asymmetric factor facilitates the lateral tilting of a basin for the main watercourse (Cox, 1994; Mohan et al., 2007; Singh and Srivastava, 2011). The directions of possible differential tectonic activity are also included in this index. It is also sensitive to uplift and subsidence of discrete blocks versus broad tilting. Similarly, the Transverse topography asymmetry (T) is also a reconnaissance tool for the measurement of lateral tilting in the study area (Cox et al., 2001). It is also explained as T=Da/Dd (Table 4), where Da is the distance from the stream channel to the middle of the drainage basin and Dd is the distance from the basin margin to the middle of the basin (Fig. 10a).

If the value of Da=0 and then the ratio Da/Dd is also 0, signifying asymmetrical basin, representing that the stream segment is in the middle of the drainage basin and it will be non-tilted basin. The values of transverse topography asymmetry are recorded 0.29 for the C segment and low value 0.47 is calculated for B block (Table 4).

DISCUSSION

The geological and geomorphological processes are playing a remarkable role in the landform processes and physical and erosional property of soil (Horton, 1945; Strahler, 1952, 1964). The linear features are mainly influenced by topographic features. The stream length of each micro watershed was measured based on the Horton method. Usually, the maximum length of the stream is measured in the first-order stream while it decreases in the higher orders (Fig. 8). The changes in stream length ratio from one order to another order are indicating their late youth stage development. It is noticed that the lowest stream order has a maximum stream number. Contrary to this the stream number decreases as the order increases (Fig. 8). It follows Horton's law. Bifurcation ratio refers to the degree of integration between stream segments of different orders in the drainage basin and it shows the relationship between hydrological characters and geological structures of a basin (Singh et al., 2014). The bifurcation ratio for the Pahuj catchment basin ranges from 3 to 9 and its mean value is 5.12. This infers that the drainage of a stream network was inherently influenced by lithology and geological structures present in the basin. The low value of the Rho coefficient (0.51) is indicative of small hydrologic storage during the flood and is moderately prone to soil erosion. The areal parameters have significance in depicting the influence of geological structures, climatic conditions, and denudation on the drainage basin. Smith (1950) has given five drainage texture classification; very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8), and very fine (>8). The coarse texture density observed in the Pahuj catchment basin infers that the elongated shape of the catchment is showing moderately permeable soil cover with high runoff and sparse vegetal cover. The lower numeric values of elongation ratio and form factor of basin reveals that the basin is elongated in shape and has a steeper slope and low peak flow of longer duration. The value of the circulatory ratio varies from zero to one and is influenced by the length and frequency of stream, geological structures, land cover, climate, relief, and slope of the basin (Miller, 1953). Its value (0.54) computed for the study area implies that the elongated basin is dominated by youth and mature stages and is consisting of more homogenous geological terrain.

Table 4. Transverse topographic asymmetry (T) ofPahuj basin catchment

	T= Da/Dd
A	0.56
B	0.47
C	0.29
D	0.44
E	0.47
F	0.47

D_a = Distance between active channel and basin midline; D_d = Distance between basin divide to basin midline

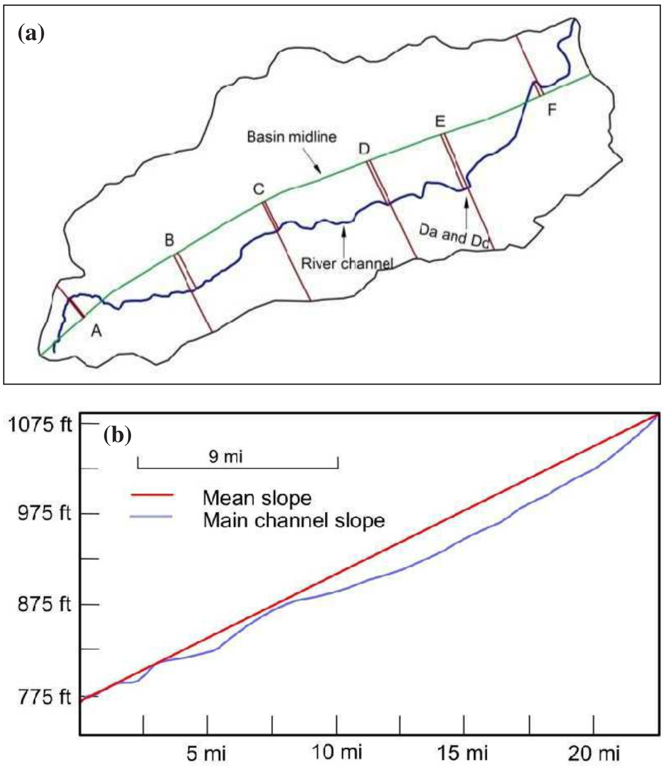

Fig.10. **(a)** Transverse topographic asymmetry (T) of Pahuj catchment basin. **(b)** shows the average and main slope of the channel of the Pahuj river.

Basin relief determines the stream gradient and influences the flood pattern and volume of the sediment that can be transported (Hadley and Schumn, 1961). The basin relief ratio expressed as the overall steepness of a basin and the erosional processes operating on basin slope (Schumn, 1956). It is an imperative factor for understanding the denudation process of a basin (Sreedevi et al., 2004). The gradient ratio refers to mark channel indication assisting the assessment of the runoff volume (Sreedevi et al., 2004). The higher value of relief ratio is indicative of the occurrence of a steep slope, high runoff and intensive erosional processes operating on the basin slope. The basin relief ratio of the Pahuj catchment basin reveals that the gradient is moderately elevated and the erosional processes are not much intensive on these slopes. The low value of ruggedness and Melton ruggedness number computed for the study area infers that the moderately rugged terrain is less prone to erosion.

Prakash et al. (2016) presented the spatial distribution lineaments and lineament density maps of Dhasan river a major tributary of Betwa. They inferred that the linear structural features represented by fractures (joints and faults), shear zones, quartz reefs, and basic dykes are showing NE-SW, E-W, and NW-SE major trends. The higher density of lineament is noticed in the upper part of the basin and most of the streams of Dhasan are following the NE-SW trend. The morphotectonic analysis of the Jamini river basin, Bundelkhand craton, central India was carried out by Prakash et al. (2017). Their studies were focussed on the extensional tectonic system demonstrated by NE-SW, NW-SE, NNE-SSW, ENE-WSW, E-W, and N-S trending lineaments. The E-W, NE-SW, and NW-SE trending lineaments are showing three major deformation trends in the study area. The low frequencies of NE-SW trending lineaments are corresponding with trends of IV and V high order streams. While the dominant NW-SE and NNE-SSW trending lineaments are showing high-frequency parallel to trends of I, II, and III low order streams (Figs. 9a, 9b and 9c).

The observations on transverse asymmetry reveal that the less tilting is noticed in the Pahuj catchment basin and it is not tectonically active. The river is originated from moderately elevated (~370M) granitic hillocks and quartz reefs of Bundelkhand craton (Fig. 10b) and is flowing in the low lying alluvium country. In the whole stretch of ~29 km in granitic terrain, the river has a gentle slope in the Precambrian granitic terrain (Fig.10b). The river does not show much elevation drop. It infers that the area is not affected by active tectonics. As stated the morphotectonic studies based on remote sensing and GIS depicting peripheral bulge tectonics in the marginal contacts of Cratonic Rivers in the Yamuna and Ganga foreland basins have yet not been attempted. However, the role of active tectonics was demonstrated by the migrated course of Ganga and elevated cliffs developed in late Quaternary near Ramnagar in Varanasi (Shukla et al., 2012). These raised terraces of cliffs showing deformed structures viz. reverse faults, folds, crack filled and soft-sediment structures were evidently proved that the Ganga river was migrated towards Varanasi before 400 ka and was followed by another tectonic event causing the upliftment of the Ramnagar cliff (Shukla et al., 2012). Agarwal et al. (2002) carried out the extensional tectonic activity in the cratonward parts (peripheral bulge) of the Ganga Plain foreland basin. They observed that the cratonward peripheral bulge small-scale deformation features, e.g., gentle folds (up-arching of the sediment layers), extensional normal faults and uplifted tilted blocks and incised river channels (20–60-m-high cliffs) exposed in the cratonward part of the foreland basin (Pleistocene–Holocene age) show evidence of active tectonics in the last few thousand years. Sinha et al. (2009) inferred that the stratigraphic and petrographic evidence is found significant tools to prove the occurrence of the red alluvium sand from Bundelkhand craton in the Himalayan foreland. They suggested that the red feldspathic sand and gravel (119 ka) derived from the cratonic river (Betwa) of Bundelkhand may have provided basin's axial drainage for a prolonged period. The present geological and morphometric studies support their views and pointed out that the K-rich granites occupying a larger area (Fig. 2) in Bundelkhand craton may be intensively eroded and transported by these cratonic rivers than the other rocks and therefore, these rivers are transporting the larger volumes of red alluvium sands at the margins of foreland basins. Ghosh et al. (2017) imply that the presence of oriented fractures in the first order ravine in marginal Ganga plains was genetically evolved in the extensional stress regime of the peripheral bulge. The late Quaternary sedimentary sequences that occurred in various horizons of marginal Gangetic plain were studied by Ghosh et al. (20019) by using optically stimulated luminescence dating (OSL). They inferred that these horizons were evolved due to the interaction of peripheral bulge tectonics in a climate of over past 100 kyr.

CONCLUSIONS

These studies infer that the advance techniques of remote sensing and GIS tools are considered conventional tools for the study of morphological and morphotectonic features in the basin. The morphometric analysis reveals the dominance of impermeable rocks with the high gradient in the catchment. The high and mean bifurcation ratio indicates that the watershed was inherently controlled by lithologically variable and tectonically less deformed granitic terrain. The areal data computed for the catchment of Pahuj watershed indicates the shape of a watershed is elongated and the basin is characterized by high runoff, low infiltration with moderate permeability and sparse vegetation. The high relief terrain may be of erosive nature and is moderately rugged. These studies would be useful in making planning for watershed management and water harvesting.

The NE-SW trending lineaments coinciding with the trends of quartz reefs are following the trends of high order (IV and V) streams. The TTG gneisses, gneisses and amphibolites of Archean to Neoarchean age and granitoids of Precambrian age were tectonically displaced by E-W and NE-SW brittle-ductile shear and oblique fault zones in the study area. These major shear and fault zones were acted as passages to divert the flow direction of drainage. The transverse topographic asymmetry and other asymmetric factors are indicative of less influence of tectonic activity on the drainage of the catchment. The NW-SE, E-W and NNE-SSW trends of extensional tectonic units are followed by low and high order streams.

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