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A GIS-based Approach in Drainage Morphometric Analysis of Sai River Basin, Uttar Pradesh, India

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ABSTRACT

This study focuses on hydrogeological processes and sub-surface geological activities. The basin area measured is 11,161 km^2 with NW-SE sloping trend. Sinuosity Index is 2.7 which show meandering nature. The drainage density, stream frequency and drainage intensity values were 0.62 km^{-1}, 0.23km^{-1} and 0.37 respectively which implies that low surface runoff, high permeable alluvium, high infiltration rate, easily erodible alluvium and low relief. Mean Bifurcation ratio of 5.11 indicates that the basin is structurally controlled. Stream length ratio shows mature stage of erosion and low runoff. The basin is found to be significantly elongated circularity ratio, elongation ratio, form factor, shape index and shape factor is 0.07, 0.33, 0.09, 4.28 and 11.61 respectively. Drainage texture of 0.15 (km^{-1}) suggest the smooth topography and high drainage density. Relief ratio is 0.23, low surface run-off, low erosion, and gentle slope. The constant of channel maintenance, length of overland flow, ruggedness number is 1.60, 0.80, 0.05 respectively, conclude the gentle slope, low surface runoff, high infiltration rate, least erodible and high permeability. The Rho coefficient of 0.11 shows the low capacity of water. The basin relief is 84 and relief ratio is 0.23 m indicating low run-off and low erosion. Hypsometric curve and integral show that the river is having intermediate stage of incision and erosion, Asymmetric factor, drainage basin shape, presence of high escarpment zones, fall displacement and uplifted barrier occur in the path of the channel identified in the transverse profile, longitudinal profiles due to intra-basinal sub-surface tectonic activity.

INTRODUCTION

The Gangetic plain developed with the steady filling of a deep front basin (near feet) of the Siwalik mountains during the Quaternary time with the intervention of major rivers (Valdiya, 2016). The Ganga plain is a recent and active foreland basin (Dickinson, 1974), where large amounts of sediments are transported, deposited and disturbed by rivers. On a regional scale, the Ganga plain has different geomorphic surfaces such as upland terrace surfaces, marginal plain upland surfaces, mega fan surfaces, terrace surfaces on the river valley, piedmont fan surfaces and active plain flood surfaces. (Singh, 1996 and Singh, 2018). Such regional geomorphic surfaces show numerous micro-geomorphic surfaces such as abandoned streams, rivers, lakes, point bars, etc (Kumar et al. 1995; Singh et al. 1999; Singh et al. 2009, 2013; Kumar, 2015). Tectonic activity plays a major role in evolving drainage patterns and influencing the actions of the river (Holbrook and Schumm, 1999; Sinha Roy, 2001; Valdiya and Narayana, 2007). Recently, remote sensing techniques are used in the identification of various geomorphic features of the Ganga plain. Snow-fed rivers like Ganga, Yamuna, Ghaghara, etc., ground-fed rivers like Chhoti Gandak, Gomati, Kalyani etc., whereas rain-fed rivers like Jharahi, Daha, etc. (Singh and Singh, 2005; Singh et al. 2010a; Singh et al. 2015). The impact of climate changes and related hazards on these rivers (especially for flooding) has been analysed by Singh (2007) and Singh et al. (2010). Kumar 2018). Many previous workers studied the regional scale mapping (based on various parameters) of Indo-Gangangetic Quaternary sediments and major regional geomorphic parts have been recognized (Singh, 1992, 1996, 1999). In addition, the recent studies also reflect the major geomorphic surfaces of the Ganga basin (Singh, 1992, 1996, 1994) with the help of specific parameters. The present study is an effort to demarcate regional and local geomorphology, drainage pattern, and drainage types. The river network quantification was provided by (Horton 1932 and 1945). Morphometric analysis signifies relatively simple methods to designate the processes of basins and comparing features of basins (Horton 1945; Strahler 1952). Morphometric analysis is one of the most important tools and techniques for assessing and evaluating the response of the drainage basin to climate change, drainage and flash flood risk (Mesa, 2006; Angillieri, 2008; Perucca and Angilieri, 2010; Singh and Awasthi, 2011a, b; Javed et al. 2009, 2011; Kumar et al. 2015; Rai et al. 2017; Kumar et al. 2018), and hydrologic processes (Eze and Efiong, 2010). Morphometric assessment is a significant method for hydrological system behaviour assessment and understanding. It gives a quantitative morphometric analysis of the river basin geometry specification to know the original path or rock hardness inconsistencies, structural controls of the drainage basin's recent geological and geomorphic diastrophism (Strahler, 1964). The area's quantitative morphological study, altitude, size, slope, land feature and drainage basin attributes of the area concerned (Singh, 1972). Measurement and mathematical evaluation of Earth's surface form and landform sizes provide the basis of map assessment for geomorphological examination (Bates and Jackson, 1980). The river morphometric analysis helps to evaluate the evolution of the landscape irrespective of space and time (Easthernbrook, 1993). The morphometric assessment is carried out effectively by measuring the channel network's linear, aerial, relief gradient and contributing to the basin's floor slope (Nautiyal, 1994). The interplay of tectonics and drainage basin morphologies is widely used as an identification tool in tectonic geomorphology (Bull and Mc Fadden, 1977; Burbank and Anderson, 2001).

STUDY AREA

The basin is part of the Gangetic plain and flowing between Ganga - Gomati interfluves region. Geographically it lies between 25°40'00"N to 27°50'00"N latitude and 79°50'00"E to 83°20'00"E longitude having an area about 11161 km^2 (Fig.1). It originates from Bijgawan village of Hardoi district at an elevation of 162 m and after travelling a 755 km distance finally debouches into Gomati river as a sixth order stream near Rajepur village of Jaunpur district. It is ground-fed river, exhibits meandering behaviour with sinuosity index (SI) of 2.7. The maximum height of the basin is 162 m in the proximal and

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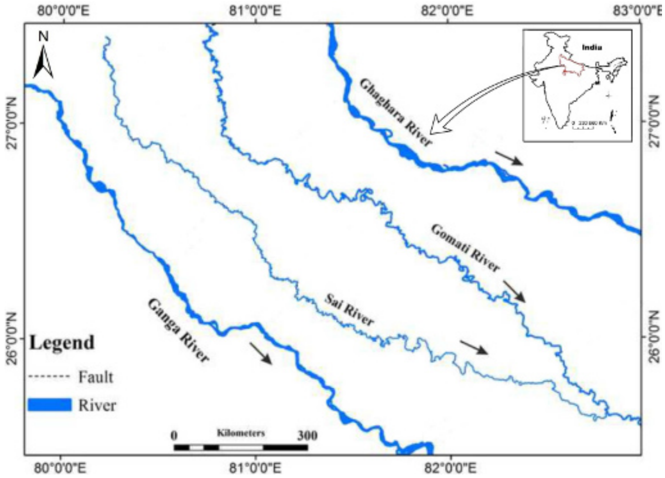

Fig.1. Location map of Study area

minimum height is 78 m in the distal part (Fig.2) and has the gentle slope towards NW – SE direction.

Geology

The Ganga plain is approximately 1000 km long in north-south direction and the width ranges from 450 km to 200 km (W-E) and covers an area of about 250,000 km^2 (Singh 1996, 2004). The Ganga plain is an asymmetrical sedimentary chain, with a few tens of meters thick towards peninsular craton and up to five kilometers thick past Himalayan source (Singh 2004). The flexing lithosphere below the Ganga plain indicates many inhomogeneities in the form of ridges and basement faults (Sastri 1971; Rao 1973). The following are: Monghyr-Saharsa ridge, East Ganga plain shelf, Gandak depression, Faizabad ridge, West Ganga plain shelf, Kasganj-Tanakpur spur, Delhi-Hardwar ridge, Ram Ganga depression. Such peaks and faults in the basement influenced the thickness of the alluvial fill (Bajpai, 1989; Singh, 1996) and also affected the surface of the river channel.

Climate

The present area is sub-tropical humid with 794 mm of annual rainfall. In general, rainfall intensity is declines from east to west. The highest temperature recorded is during the month of June, reaching

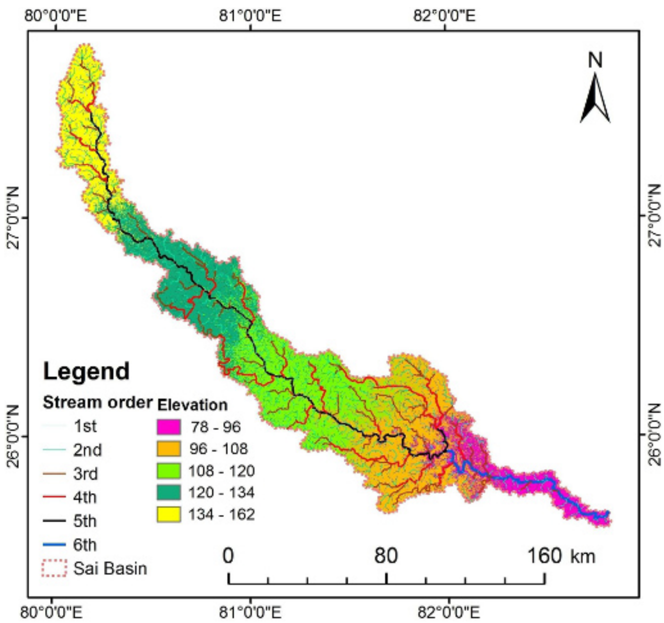

Fig.2. Digital Elevation Model of the Basin

Table 1. Specification of the data sets used

Sr. No.	Data type	Range	Data source
1	Toposheets	63A01-63A08 63B01-63B16 63F02-63F16 63G05-63G14 63J0463 K01-63K14	Survey of India (SOI)
2	SRTM DEM	3ARC (90 m)	http://srtm.csi.cgiar.org/srtmdata

up to 45 °C. The mean average temperature varies between 20 °C and 32 °C. Winds are mostly mild and only slightly heavier during the summer and monsoon seasons. They are often west and northwest between October and April and from May it shifts east and southeast during the southwest monsoon season.

METHODOLOGY

The Morphometric Analysis was carried out using Shuttle Radar Topography Mission (SRTM) Digital elevation model (DEM) 90 meter along with the Survey of India (SOI) toposheets of 1:50,000 scale on GIS 10 software. (Table 1). Further process rectification, geo-referencing and mosaic of the SOI toposheets by UTM projections and WGS 1984 UTM Zone 43 datum. Followed by drainage extraction, accumulation module, and calculation of the morphometric parameters using the stream ordering module is given in (Table 15). The height of the escarpment is generally the height of the vertical cliff along the banks of the river channel used by topographical maps along the right and left sides of the river and plotted separately against their corresponding downstream length. SRTM DEM (90 m spatial resolution) was used to extract longitudinal profiles drawn by measuring downstream of the river. Analysis of the drainage network according to Horton's laws (Horton, 1945) and stream orders were defined (Strahler, 1964). The linear, areal, and relief aspects of the basin were calculated using standard methods (Kale and Gupta, 2001; Reddy et al. 2004; Sreedevi et al. 2005; Garde, 2006; Singh and Awasthi, 2011b).

RESULT AND DISCUSSION

It is a sixth order river basin (Fig.3) and occupied an area of about 11161 km^2 , basin perimeter is 1393 km and basin length is 360 km. The river is trending NW and SE direction. Total numbers of 1st, 2nd, 3rd, 4th, 5th and 6th order streams are 2040, 457, 89, 18, 2 and 1 and Total length of 1st, 2nd, 3rd, 4th, 5th and 6th order streams are 3408, 1709, 782, 564, 371 and 128 km respectively. The total numbers of streams are 2607 with total length of 6962 km (Table 15). The drainage pattern of the basin is dendritic type.

Linear Aspects

Stream order (U)**:** The stream order of the basin is shown in (Fig.3). The streams numbers in each order is highlighted in (Table 2). The main significance of stream order is that it shows the rate of discharge in a basin.

Stream number (Nu): (Strahler, 1964) has classified the stream ordering system and the number of streams in each section (Nu) of the order (U). The total number of streams reduces gradually as the order of the stream increases. The Nu of the 1st, 2nd, 3rd, 4th, 5th and 6th order constitute 2040, 457, 89, 18, 2 and 1 km respectively (Table 2) and The geometric relationship between log value of stream number to stream order of the basin is shown in (Fig. 4).

Stream Length (Lu): The lengths of the stream were evaluated on

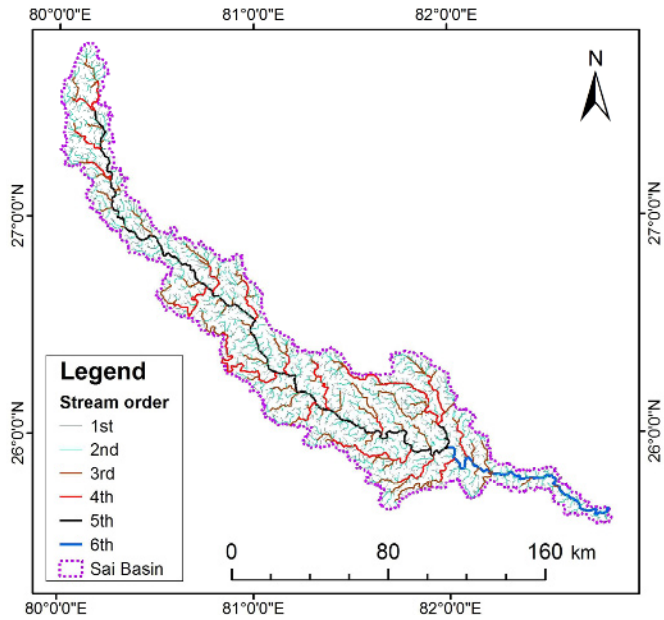

Fig.3. Drainage map of the basin

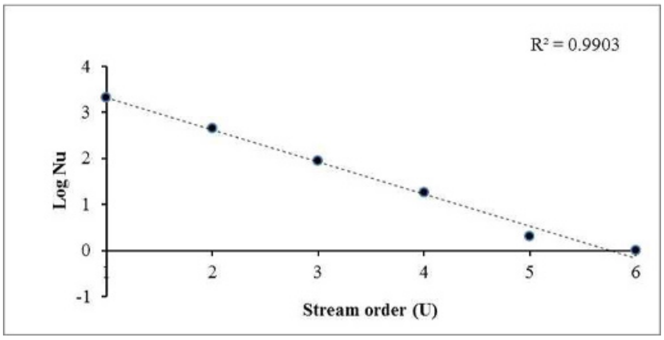

Fig.4. Relationship between Stream number and Stream order.

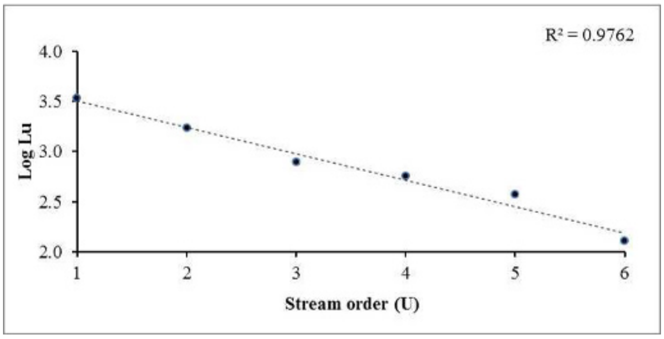

Fig.5. Relationship between Stream length and Stream order.

topographical maps (Horton, 1932) the length in each order raises exponentially with the increasing stream order.

Total length of first order streams is 6962 km. The length of the 1st, 2nd, 3rd, 4th, 5th and the 6th order constitute 3408, 1709, 782, 564, 371 and 128 km respectively (Table 2). The geometric Relationship between log value of Stream length to Stream order shown in Fig.5.

Mean Stream Length Ratio (Lsm): The mean stream length 59.84 which shows a decreasing pattern from highest to the least stream order. (Table 1).

Cumulative Stream Length (Csl): The cumulative length of the stream segment of continuous orders tends to be a number series starting with the average length of the first orders and increasing according to a constant length ratio. The Csl of the basin calculated is 656.87 (Table 2).

Main Stream Length: The main stream length of the basin is the length of the 6th order, that is, the principal stream which has a total length of 128 km (Table 2).

Stream-length Ratio (Rl): The stream length ratio of the basin varies from 0.35 to 0.72. While the mean stream length ratio is 0.54 which shows mature stage of erosion and low runoff (Table 3)

Weighted Stream Length Ratio (Lurwm): Weighted mean of the stream length as 4.98, the stream length ratio is 0.54. (Table 4).

The formula used for this is:

Lurwm = Lur*Lur-r/Lur-r

where, Lurwm = weighted mean bifurcation; Lur = bifurcation ratio of a per stream order; Lur-r = The addition of the stream length of a stream order and that of the previous order

Bifurcation Ratio (Rb): Horton (1945) Reflect the degree of the consequences of drainage network. Nu is total number of stream order 'u' and Nu + 1 are the Number of segments of the higher order. In the Basin, the Rb is 5.11 which show the basin is lithologically and structurally controlled (Table 3)

Mean Bifurcation Ratio (Rbm): Mean bifurcation ratio is classified into three, the classification and the interpretation of the classification is shown in (Table 3). The mean bifurcation ratio of the basin was calculated to be 5.11 which indicate the basin has influence of geological structure.

Weighted Mean Bifurcation Ratio (Rbwm): Strahler (1952) achieved the Mean bifurcation ratio through multiplication of the bifurcation ratio by the total number of the streams associated with the proportion and for each consecutive order and taking the average

Table 2. Stream Characteristic of the River

Stream order (U)	Stream Number (Nu)	Stream length (Lu) (km)	Mean Stream length ratio (km) length (km)	Cumulative Mean Stream	% (Nu)	% (Lu)	Log Nu	Log Lu
1st Order	2040	3408	1.67	1.67	78.25	48.95	3.31	3.53
2nd Order	457	1709	3.74	5.41	17.53	24.55	2.66	3.23
3rd Order	89	782	8.79	14.2	3.41	11.23	1.95	2.89
4th Order	18	564	31.33	45.53	0.69	8.1	1.26	2.75
5th Order	2	371	185.5	231.03	0.08	5.33	0.3	2.57
6th Order	1	128	128	359.03	0.04	1.84	0	2.11
Total	2607	6962	59.84	656.87	100	100	9.48	17.09

Table 3. Stream length ratio and Bifurcation ratio

Stream length ratio (Rl)		Bifurcation ratio (Rb)	
2^{nd} ord/1^{st} ord	0.50	2^{nd} ord/1^{st} ord	4.46
3^{rd} ord/2^{nd} ord	0.46	3^{rd} ord/2^{nd} ord	5.13
4^{th} ord/3^{rd} ord	0.72	4^{th} ord/3^{rd} ord	4.94
5^{th}ord/4^{th} ord	0.66	5^{th}ord/4^{th} ord	9.00
6^{th} ord/5^{th} ord	0.35	6^{th} ord/5^{th} ord	2.00
Mean stream length Ratio	0.54	Mean Bifurcation Ratio	5.11

Table 4. Weighted Stream Length Ratio

Stream order (U)	Stream length (Lu)	Bifurcation ratio (Lur)	Lur-r	Lur*Lur-r	Lurwm (Lur*Lur-r/ Lur-r)
1	3408				
2	1709	4.46	5117	22842	
3	782	5.13	2491	12791	
4	564	4.94	1346	6655	
5	371	9.00	935	8415	
6	128	2.00	499	998	
Total	6962	25.54	10388	51701	Lurwm = 4.98

of the sum of the values. The calculated weighted mean bifurcation ratio 4.62 (Table 5). The formula applied for this is:

$$Rbwm = Rb*Nu\text{-}r/Nu\text{-}r$$

where Rbwm = bifurcation ratio of the weighted mean; Rb = bifurcation ratio of a per stream order; Nu-r = The addition of the stream number of a stream order and that of the previous order.

Areal Aspects

Drainage Density (Dd): The Dd is 0.62 km/km^2 for this basin (Table 15). It is extremely permeable and readily erodible alluvium. It is primarily affected by the bed material's resistance to erosion and infiltration capacity (Singh et al., 2015) (Fig.6).

Stream Frequency (Fs): The calculated Fs is 0.23 km^{-2} for the basin (Table 15) which shows strongly permeable alluvium, low relief and very poor stream frequency Fig.6.

Drainage Texture (T): It is calculated by multiplying drainage density with stream frequency. Drainage texture of drainage basin depends on climate, rainfall, soil, vegetation, lithology, infiltration rate, relief of area (Horton 1945; Smith 1950). The drainage texture

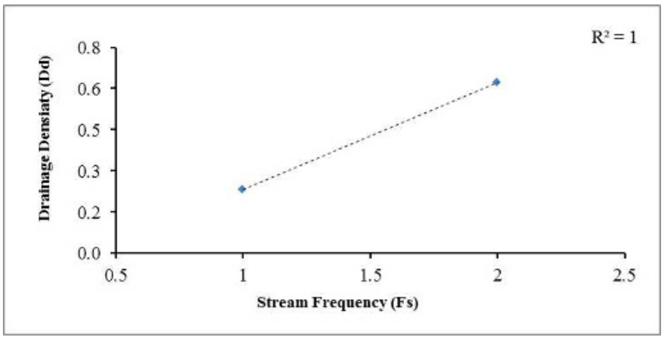

Fig.6. Relation between Drainage density and stream frequency

for this basin is 0.15 km^{-1} tends toward the coarse drainage texture. Which shows greater permeability and potential for groundwater recharge (Table 15)

Texture ratio (Rt): The basin Rt is 1.87 (Table 15). It depend son the lithology, relief and infiltration capacity of the basin.

Elongation Ratio (Re): The Re value is 0.33. Which indicates the elongated basin shape (Table 15).

Circularity Ratio (Rc): The Rc value of basin is 0.07 (Table 15) it indicate the elongated shape, mature topography and support dendritic pattern of drainage network.

Form Factor (Ff): Form factor ratio is derived by dividing the area of the basin by the square of the basin length, that is, A/Lb^2 which is $11161/360^2$. The Ff of the basin is 0.09 which shows that the basin is elongated (Table 15).

Length of overland flows (Lg): The length of the overland flow (Lg) is about half the reciprocal density of drainage basin (Horton, 1945). The Lg for the basin is 0.80 which explains longer path for the concentration of flow (Table 15).

RHO coefficient (RHO): The RHO value is 0.11 for this river basin, indicates low storage capacity of water (Table 15).

Table 5. Bifurcation ratio classification based on Horton (1945)

Sr. No.	Range	Interpretation
1	<3	Flat region
2	3-5	Geological structures do not distort the drainage pattern
3	>5	Lithologically and structurally control

Table 6. Weighted mean Bifurcation ratio (Rbwm)

Stream order (U)	Stream number (Nu)	Bifurcation ratio (Lur)	Nu-r	Rb*Nu-r	Rbwm (Rb*Nu-r/ Nu-r)
1	2040				
2	457	4.46	2497	11146	
3	89	5.13	546	2804	
4	18	4.94	107	529	

Table 7. Drainage texture (T) of the Basin classified as Smith (1950).

Sr. No.	Range	Interpretation
1	<4	Coarse texture
2	4-10	Intermediate texture
3	10-15	Fine texture
4	>15	Ultra-fine texture

Table 8. Elongation ratio classification based on Schumm (1956)

Sr. No.	Range	Interpretation
1	>0.9	Circular
2	0.8-0.9	Oval
3	0.7-0.8	Less elongated
4	0.5-0.7	Elongated
5	<0.5	More elongated

Table 9. Significant of form factor classification based on Horton (1945)

Range	Inferences	Interpretation
0	Highly elongated	Low peak flow
0 - 0.6	Slightly elongated	Flatted peak flow
0.6 - 0.78	Perfectly circular	Moderate to high peak flow
0.78 – 1.0	Circular	High peak flow

Constant of Stream Maintenance (C): The C of the basin is 1.60 which indicates the gentle slope, low surface run-off, high infiltration rate, least erodible and high permeability (Table 15).

Drainage Intensity (Di): The drainage intensity is the ratio of the stream frequency to the drainage density. (Faniran, 1968). Di = Fs/ Dd. The study has low drainage intensity of 0.37. The low value of drainage intensity implies that drainage density and stream frequency have little effect.

Shape Index (Sw): The Sw of the basin is 4.28 (Table 15).

Shape factor (Sf): The Sf value calculated for the basin is 11.61 indicating elongated drainage basin (Table 15)

Relief Aspects

Mean slope of the Basin (Sbm): The mean slope of the basin is 116.3 (Table 15).

Basin Relief (R): Basin relief is the difference in height between the maximum and lowest points of the basin, which determines the shape and transport of sediments suggested by Hadley and Schumm (1961). The basin R is 84 m, which shows low transportation and spread of water through the basin and low runoff. (Table 10, 15)

Table 10. Absolute relief class of basin

Elevation (m)	Absolute Relief	Area (km^2)	Area (%)
162	High	1189	11
134	Moderate High	1130	10
120	Moderate	2366	21
108	Moderate low	2779	25
96	Low	2605	23
78	Very low	1092	10
	Total	11161	100

Relief Ratio (Rr): It is the ratio between basin relief and basin length (Schumm, 1963) and it's proportional to the surface runoff and the intensity of the erosion. The Rr is 0.23 for this basin which explains low surface discharge and low erosion (Table 15).

Ruggedness number (Rn): It is defined as the part of relief of the basin and drainage density (Strahler, 1956). The Rn of the basin is 0.05 (Table 15) the low ruggedness value of the basin revel that the area is less sensitive to erosion of soil and gentle slope (Strahler, 1968) A high value of occurs when the slope is steep.

Melton ruggedness number (MRn): It is a slope index that gives a specific depiction of relief roughness in the watercourse (Melton, 1965). The MRn number for the basin is 0.74 (Table 15)

Geometric Aspects

Basin Area (A): It is the area of drainage basin boundary (Schumm 1956). The area of the basin is 11161 km^2.

Basin length (Lb): According to Schumm (1956) the basin length as the largest dimension of the basin parallel to the main drainage line. The basin length is measured as 360 km.

Mean Basin Width (Wb): The mean basin width is calculated (Horton 1932). Where, A is area of the basin and Lb is basin length. The mean basin width of the basin is 31km.

Basin Perimeter (P): It refers to the basin size and shape. The calculated perimeter of the basin is 1393 km.

Relative Perimeter (Pr): The relative perimeter is determined by dividing the area by the perimeter of the basin which is 11161/360. The relative perimeter of the study area is 8.01.

Lemniscate's (K): The K value is 2.90 for the basin (Table 15). This shows that the watershed comprises the highest region in its initial areas with a large amount of higher-order streams.

Morphotectonic Aspects

Sinuosity Index (Si): The sinuosity index has been determined for all these sections for monitoring the channel sinuosity parameters of the basin and measured using the procedure (Miller, 1964). Sl = Cl/ Vl. Where, Cl = Channel length, Vl = Valley length. River having a range from 1.4 to 2.3. The average sinuosity of 2.7 is called meandering in nature (Fig.7). In Ganga plain, most groundwater-fed rivers cut through lateral erosion and exhibit meandering behaviour. (Singh and Awasthi, 2011a).

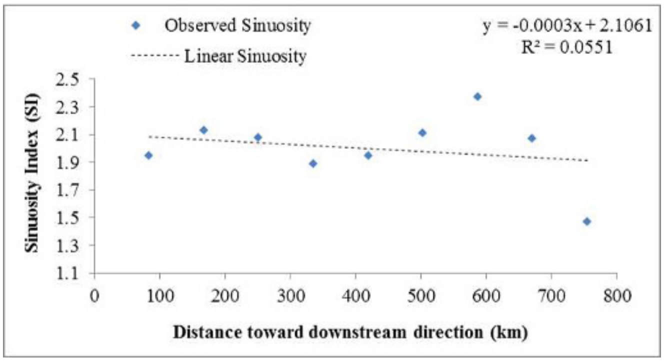

Fig.7. Sinuosity Index (Si) classification based on (Miller 1964)

Hypsometric Curve and Integrals (Hi): The hypsometric curve of a basin presents the distribution of area and altitudes of the basin. Strahler (1952) has classified three types of landforms on the basis of shapes of the hypsometric curve, each denoting the three typical stages of basin dissection, namely (i) young stage, (ii) mature stage and (iii) old stage. Convex shaped curves are associated with young stage, which indicate that the region is slightly eroded and undissected, mature stage corresponds to S-shaped curves being concave upwards at higher elevations and convex downwards at lower elevations characterized by moderately eroded regions and old stage of basin is related to concave shaped curves indicate highly eroded and deeply dissected landscapes. Hypsometric curves are related to geomorphic and tectonic evolution of drainage basins in terms of their forms and processes (Strahler, 1964). The HI results show three types of basin. Basin with HI > 0.5 with deep incision and slight erosion; (2) basin with 0.4 < HI < 0.5 indicates an approximate balance and intermediate process of incision and erosion from recent active tectonic activity; (3) low-relief and extreme erosion HI < 0.4 basins (Strahler, 1952; Keller and Pinter, 1996). Here, the hypsometric curve is used to illustrate the relationship between basin elevation and basin area. It is important to show the conditions of the basin, both hypsometric integral and hypsometric curve. HI is calculated by following formula Hi=Sb-h/H/h, where, Hi of the basin is 0.46 (Table 11). Shows a convex curve in proximal part and concave curve in distal part. The relief of the basin decreases

Table 11. Hypsometric integral (Strahler, 1952; Keller and Pinter, 1996)

Class	Range	Stages of the basin
1	0-0.3	Dissected drainage basins.
2	0.3-0.45	Deeply incised streams.
3	0.45-0.60	Smooth upland surface

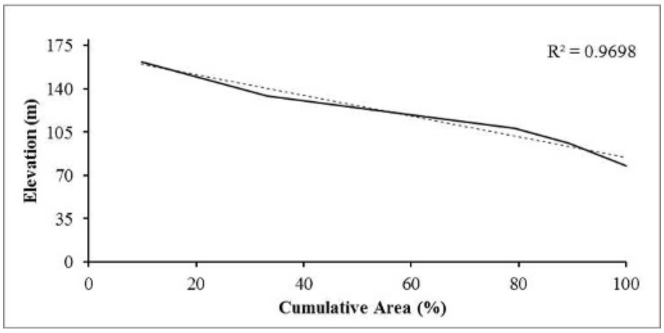

Fig.8. Hypsometric integral of the basin

with higher elevation while area increases with low elevation (Fig.8) which indicates the mature stage of the stream (Strahler, 1952) and equilibrium and an intermediate stage of incision and erosion from recent active tectonics (Strahler, 1952; Keller and Pinter, 1996)

Asymmetry Factor (Af): The Asymmetry index determining the tectonic tilting of the basin drainage with respect to the main water course (Cox 1994). This index also distinguish the directions of neo tectonic activity and is responsible to uplift and subsidence of distinct blocks versus broad tilting (Pinter 2005). The asymmetric factor (AF) is deflned as AF =100*(Ar/At), Where Ar is Area of the right facing downstream of the trunk stream, and At is the Total area of the drainage basin. The value of AF-index with > 50 indicates tilting towards the left bank and value <50 indicate towards the right bank side of the basin significant tilting of the drainage basin due to either active tectonics or lithologic control (Cox. 1994). (Fig. 9) Asymmetry factor of the basin is 52.40 resulting basins are tilted toward left side by the higher level of neo-tectonic actions (Table 12).

Table 12. Asymmetry factor (Keller and Pinter, 1996)

Class	Range	Inferences
1	AF = 50	Stable setting Environment
2	50 < AF > 50	Suggest Tilt

The general downstream changes of escarpment heights on both the margins of river suggest that incision in the poximal segment of the river is low, becomes maximum in the medial segment with two high escarpment zones II and III and a moderate incision in the distal segment. The escarpment height of the river for both the margins of the river strongly indicate the incision toward downstream (Fig.11). This increasing trend toward downstream indicates that the incision

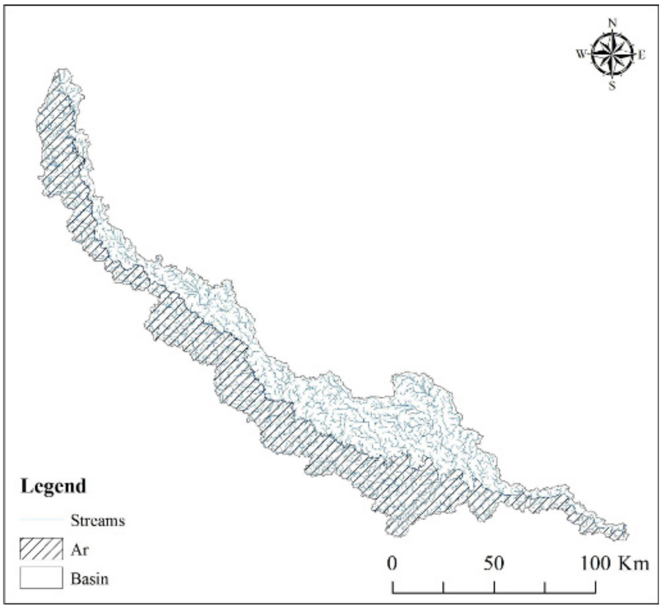

Fig.9. Asymmetry factor (Af) of the basin based on (Molin at al. 2004)

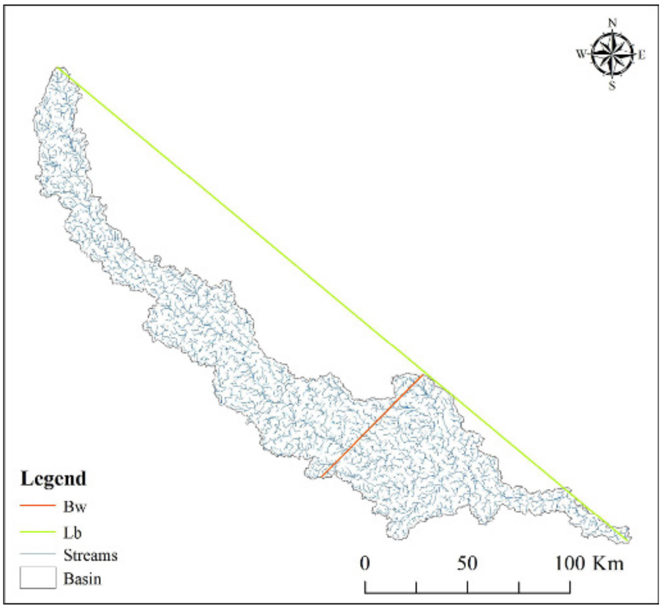

Fig.10. Segments selected for computation of Drainage basin shape (Bs)

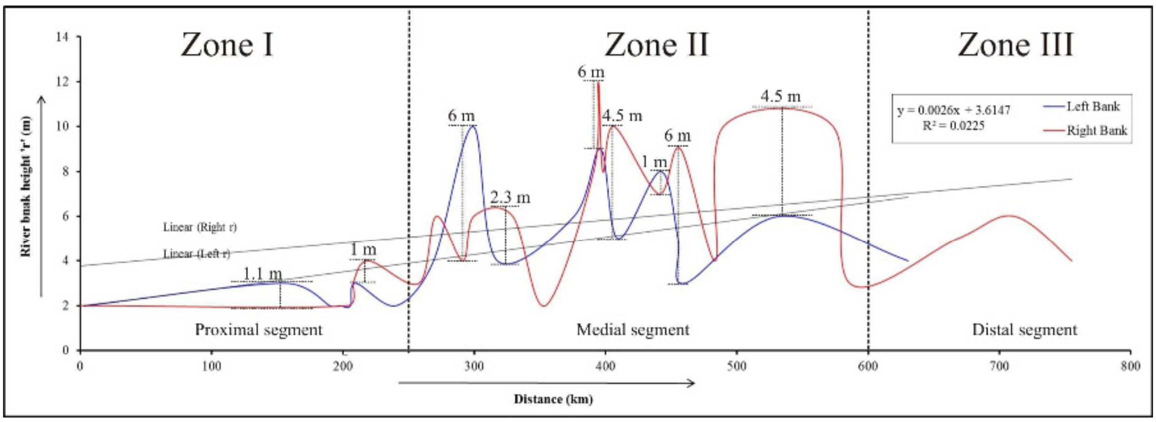

Fig.11. Downstream variation of escarpment heights recorded on left and right banks of the River. Linear fit lines indicate the downstream increasing trend of escarpment heights. The downstream wave-like variability in the river bank, Zone I (proximal segment), Zone II (medial segment), Zone III (distal segment) shows the numbers of escarpment occur in the course of river (after Thakur 2007)

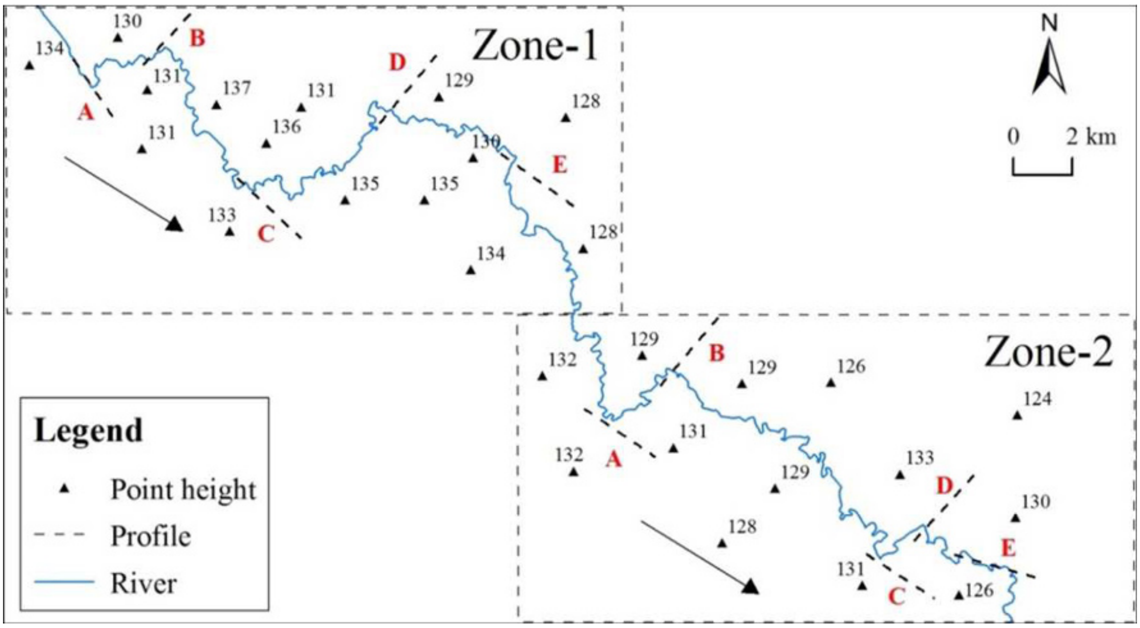

Fig.12. Transvers profile of the river at 90 degree turn point.

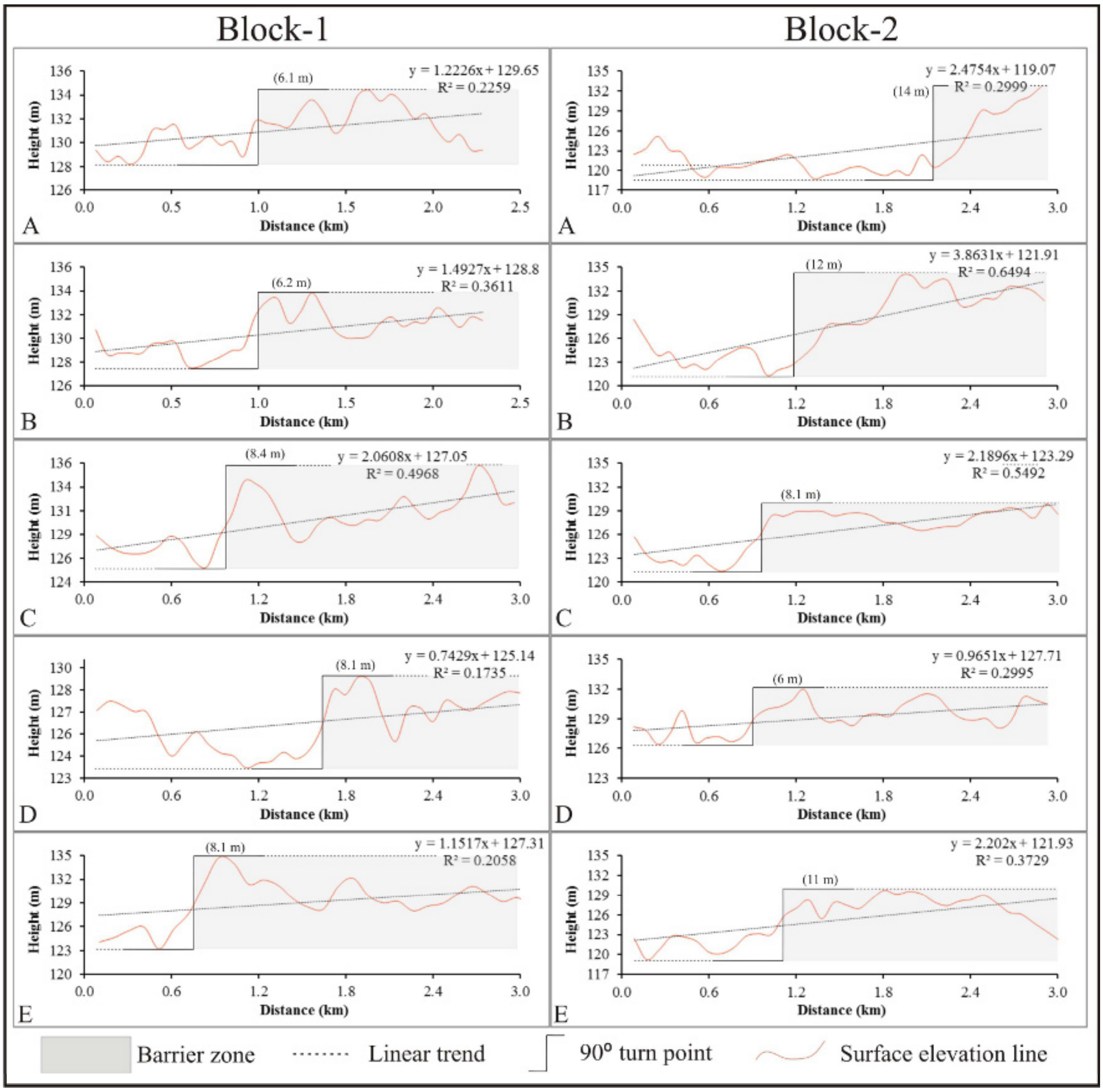

Fig.13. Transverse profile of the basin drawn from 90 SRTM DEM.) Zone 1 and Zone 2 within five profile in each zone taken where river turning 90 degree, when barrier occur (Shadow zone) in the path of the channel which show area is uplifted due to sub surface tectonic activity.

by the River has occurred under 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 an indicative of intra-basinal tectonic activity of the Ganga Plain (Thakur 2007).

Drainage basin shape (BS): The shape of a drainage basin is controlled by tectonic processes. Significantly elongated basins often characterize tectonically active regions, and sub-circular shapes when deformation markedly decreases (Bull and Mcfadden, 1977). The drainage basin shape is 3.27. High values indicate extended basin suggesting high tectonic processes and low value index indicates circular basin indicating less active tectonic processes Bull and McFadden (1977) (Table 13). The present values indicate the basin is tectonically active (Fig. 10).

Table 13. Drainage basin shape (Bull and McFadden, 1977)

Class	Range	Inferences
1	>2.3	Strong
2	1.5-2.3	Moderate
3	<1.5	Weak

Transverse profile (Tp): Transverse profile of the basin prepared using 90 SRTM DEM, which defines two zones namely as zone 1 and zone 2 with five profiles in each zone, these profile taken where river turns 90 degree because of barrier. This shows the area is uplifted due to sub-surface tectonic activity. The sinuosity of the river changes in zone 1, The calculated sinuosity index in sections A, B, C, D, E is 2.9, 1.8, 2.3, 2.6, 1.9 respectively, whereas in zone 2 sinuosity index of section A, B, C, D, E, is 1.8, 1.5, 2.2, 1.7, 2.1 respectively as shown in Figs.12 and 13.

Fault analysis (Fa): The river follow five transverse faults recognized i.e., Sitapur–Shahjahanpur fault (SSHFt), Sidhaur–Sandila fault (SSAFt), Lucknow fault (LUKFt), Faizabad–Lalganj fault (FALFt), Azamgarh–Allahabad fault (AZAFt) respectively (after Pati el al. 2015) (Fig.14). These faults occur in the longitudinal profile of the Sai river basin at different locations.

Longitudinal profile (Lp)**:** The river shows a perfectly graded profile, considerable amount of incision and alternating deposition along their profiles showing tectonic instability. The gradual decrease in slopes interrupted by distinct points showing sudden change in slopes. (Table 14). These displacement in some region of the profile is due to sub-surface tectonic activity (Fig.15).

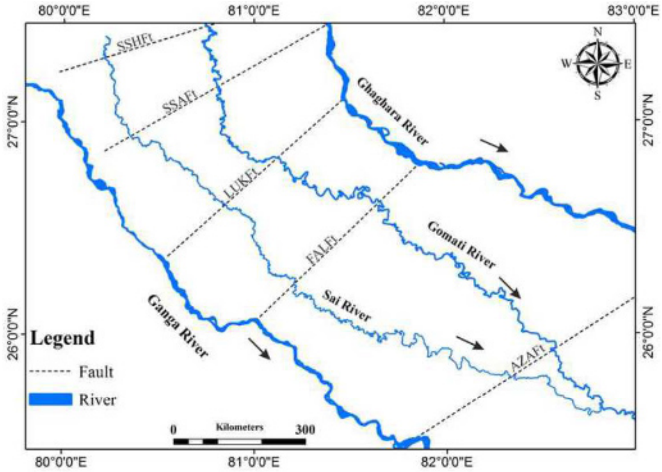

Fig.14. Major structural disturbances in the basin (after Pati el al. 2015)

Table 14. Stream longitudinal profile (Ls) (Hack (1973)

Class	Range	Inferences
1	Smooth	Equilibrium condition no tectonically influenced
2	Topographical undulation	Disequilibrium condition suggest that river tectonically influenced

CONCLUSIONS

The study has been described morphometric, morphotectonic parameters. The morphometric parameters concluded that the basin is meandering in nature, low surface runoff, high permeable alluvium, high infiltration rate, easily erodible alluvium, low relief, mature stage of erosion and the basin was found to be significantly elongated, smooth topography and high drainage density, low erosion, and gentle slope, low capacity of water storage, The Morphotectonic parameters such as Hypsometric curve and integral (Hi) show that the river has intermediate stage of incision and erosion, Presence of high escarpment zones, fall displacement and uplifted barrier occur in the path of the channel identified in the transverse profile and in longitudinal profiles due to intra-basinal sub-surface tectonic activity.

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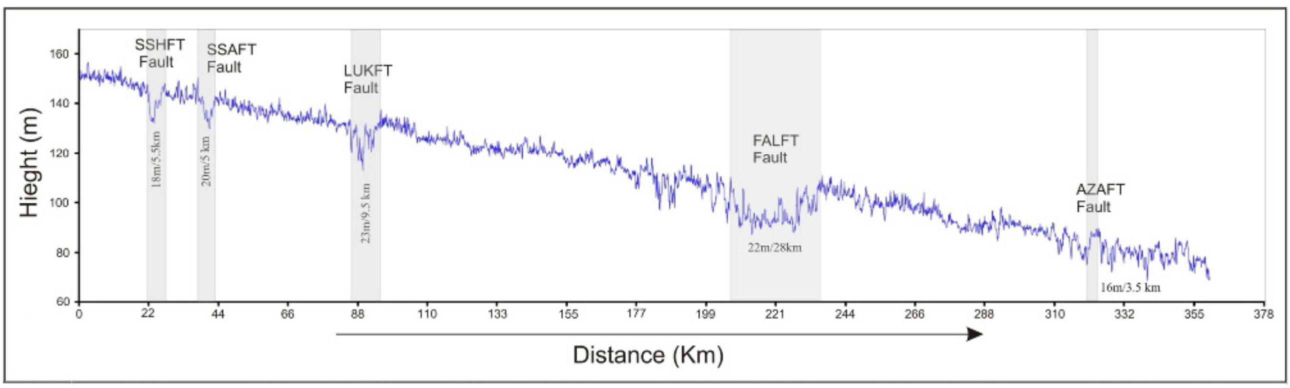

Fig.15. Longitudinal profile of the basin drawn from 90 SRTM DEM. The presence of fall displacement in some region of the profile associated with tectonic activity under sub-surface (after Pati 2015)

Table 15. Morphometric parameters of drainage network and their mathematical expressions

Sr. No.	Morphometric Parameters	Formulae	References	Result
	Linear Aspects			
1	Stream order (U)	Hierarchical rank	Strahler (1964)	6
2	Stream Number (Nu)	Nu =N1+N2++….Nu	Strahler (1964)	2607
3	Stream length (Lu) Kms	Lu = L1+L2++…..Lu	Horton (1945)	6962
4	Mean Stream length ratio (Lsm)	Lsm = Lu/Nu	Strahler (1964)	59.84
5	Cumulative Stream length (Csl)	Csl	Horton (1945)	656.87
6	Stream length ratio (Rl)	Rl = Lu/Lu-1	Horton (1945)	0.54
7	Weighted Stream Length Ratio (Lurwm)	Lurwm (Lur*Lur-r/Lur-r)	Strahler (1952)	4.98
8	Bifurcation ratio (Rb)	Rb = Nu/Nu+1	Horton (1945)	5.11
9	Mean Bifurcation ratio (Rbm)	Rbm	Strahler (1957)	5.11
10	Weighted Bifurcation ratio (Rbwm)	Rbwm (Rb*Nu-r/ Nu-r)	Strahler (1952)	4.62
	Areal Aspects			
11	Drainage density (Dd)	Dd = Lu/A	Horton (1932, 1945)	0.62
12	Stream frequency (Fs)	Fs = Nu /A	Horton (1932, 1945)	0.23
13	Drainage texture (T)	$T = Dd \times Fs$	Smith (1950)	0.15
14	Texture ratio (Rt)	Rt = N1/P	Horton (1945)	1.87
15	Elongation ratio (Re)	$Re = (2/Lb)\ (A/ð)^{0.5}$	Schumm (1956)	0.33
16	Circulatory ratio (Rc)	$Rc = 4\pi A/P^2$	Miller (1953)	0.07
17	Form factor (Ff)	$Ff = A/Lb^2$	Horton (1932)	0.09
18	Length of overland ûow (Lg)	Lg =1/2Dd	Horton (1945)	0.80
19	Rho coeûcient (RHO)	RHO = Rl/Rb	Horton (1945)	0.11
20	Drainage Intensity (Di)	Di = Fs/Dd	Faniran (1968)	0.37
21	Constant of channel maintenance (C)	C = 1/Dd	Schumm (1956)	1.60
22	Shape Index (Sw)	Sw = 1/Fs	Horton (1932)	4.28
23	Shape Factor (Sf)	$Sf = Lb^2/A$	Horton (1945)	11.61
	Relief Aspects			
24	Maximum elevation (m)	H (m)	GIS analysis/DEM	162
25	Minimum elevation (m)	h (m)	GIS analysis/DEM	78
26	Mean slope of the basin (Sbm)	Sbm	GIS Tool	116.3
27	Basin relief (R)	R = H – h	Hadley, Schumm (1961)	84
28	Relief ratio (Rr)	Rr = R / Lb	Schumm (1956)	0.23
29	Ruggedness number (Rn)	Rn = Dd * (R/1000)	Strahler (1956)	0.05
30	Melton Ruggedness Number (MRn)	MRn = R / A0.5	Melton (1965)	0.74
	Geometric Aspects			
31	Basin area (A)	A (Sq. m)	Schumm (1956)	11161
32	Basin length (Lb)	Lb (km)	Schumm (1956)	360
33	Mean Basin Width (Wb)	Wb = A/Lb	Horton (1932)	31
34	Maximum Basin Width (Wbm)	Wbm (km)	GIS Tool	71
35	Basin Perimeter (P)	P (km)	Schumm (1956)	1393
36	Relative Perimeter (Pr)	Pr = A/P	Schumm (1956)	8.01
37	Leminiscate ratio (K)	$K = Lb^2/4A$	Chorley (1957)	2.90
38	Channel Length (Cl)	Main channel length (kms)	Muller (1968)	755
39	Valley Length (Vl)	Valley length (kms)	Muller (1968)	281
40	Right bank half area (Ar)	Ar	GIS Tool	5848
	Morphotectonic Aspects			
41	Sinuosity Index (Si)	Si = CL/VL	Miller (1964, 1968)	2
42	Hypsometric Integrals (Hi)	Hi = Sbm-h/H-h	Strahler (1952)	0.46
43	Asymmetry factor (Af)	AF =100 (Ar/At)	Molin at al. (2004)	52.40
44	Drainage basin shape (Bs)	BS = Bl / Bw	Bull and Mcfadden (1977)	5.07
45	Escarpment analysis (Ea)	Ea	Toposheet	
46	Transverse profile (Tp)	Tp	GIS analysis/DEM	
47	Longitudinal profile (Lp)	Relation b/w height and distance downstream	Hack (1973)	
48	Fault analysis (Fa)	Fa	Pati et al. (2015)	

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