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INTEGRATED MORPHOMETRIC AND CORRELATION-BASED ASSESSMENT OF THE KANDAR RIVER BASIN USING GEOSPATIAL TECHNIQUES: A SMALL TRIBUTARY OF RIVER AJAY, WEST BENGAL.

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***Abstract*:** In Geomorphology, the term 'Morphometry' refers to the quantitative measurement and analysis of forms of the Earth's surface. It is a key branch of Geography that measures the shape, dimensions and geometry of landforms. Morphometric techniques are very useful in understanding the geomorphological, geological and hydrological features of a drainage basin. Important information about the flood potential of a drainage basin can be obtained using these quantitative morphometric techniques. By applying mathematical, statistical and geospatial methods, it provides a scientific basis for interpreting landform processes and supports environmental management, hazard assessment and resource planning. To determine the geomorphic structure and hydrological behaviour of the Kandar Watershed or River basin as a tributary of the Ajay River in the eastern Indian side, this study will focus on the linear, areal, and relief of the drainage basin. The basin spans through Birbhum, Purba Bardhaman and Murshidabad districts and is typified by low gradient alluvial plains, which often suffer seasonal flooding and waterlogging. A GIS environment processes the DEM data and topographic maps with the help of spatial hydrological methods of drainage extraction and basin delineation. To explore the correlation between variables and their joint effects on basin behaviour, a group of morphometric parameters describing flow hierarchy, shape of the drainage basin, drainage texture, drainage relief features, as well as surface dissection, was computed. Statistical correlation was used to analyse this. The results indicate a highly extended geometry of the drainage basin with low structural complexity, with mild slopes, which implies moderate concentration of runoff and high susceptibility to the extended stagnation of surface water in case of heavy monsoon rain. The study suggests that digital geomorphometry is a valuable decision-support tool for identifying susceptibility to floods, watershed prioritisation, and sustainable management of river basins in alluvial subtropical landscapes.

KEYWORDS
Drainage basin Morphometry Analysis, SRTM DEM, Geo-spatial Technology, Flood Susceptibility.

1. INTRODUCTION

Rivers play a major role not only as shapers of the terrestrial landscape but also in shaping human life on the Earth (Morisawa; Wohl). Watersheds or drainage basins are mainly the region of fluvial processes where the three functions of running water: erosion, transportation and deposition bring about several geomorphological characteristics of the catchment (Sen). The hydrological behaviour of that catchment region influences the features of the basin, which are commonly categorised into three primary aspects: linear, areal, and relief (Chorley). This quantitative measure of the catchment area is understood as a basin morphometric analysis (Strahler). (Horton) is the pioneer of this quantitative chemical analysis of catchment area morphology. The term '*morphometry'* itself denotes the 'measurement of forms,' which came from the Greek words *morpho*, meaning 'form' and *metry*, meaning 'measurement'.

Morphometry is the science of measuring the shape or geometry of natural things such as plants, animals, and relief features (Strahler). Horton's laws were subsequently modified and developed by other notable geomorphologists such as Schumm (1956), Strahler (1957, 1964), Morisawa (1957, 1958), Shreve (1967) and Chorley (1969). This technique provides quantitative data relating to a large number of basin descriptors that aid in the understanding of drainage basin dynamics, terrain characterisation, structural control, and basin geometry (Horton; Strahler; Yadav et al.; Jain). Basin physiographic properties have been considered as a significant component of surface processes (Sen). It also helps to investigate hydrological behaviour like measures of groundwater potential, groundwater and drainage basin management and environmental estimates (Magesh et al.). When this morphometric quantification is associated with geospatial technologies, it is termed digital geomorphometry (Jain). The term 'Geomorphometry' refers to the science that measures the variability of landforms and is often classified into two main types: general geomorphometry, which conveys the overall assessment of land surface form, and specific geomorphometry, which implies the characteristics of individual landforms (Pandey and Das; Das et al.). Geospatial technology is a very effective analytics system used to create, store, manipulate, process and display the geospatial data, which can also model the real world for better decision making (Yadav et al.). Digital Elevation Models (DEMs) have often been used for the computation of morphometric characteristics of drainage basins through the extraction of topographic parameters and drainage networks, and their use explains various advantages over conventional topographical maps (Das et al.). Basin morphometry examines the hydrologic response of a catchment region and is utilised in several hydrological and geomorphological evaluations, including such flooding simulations and sediment transport (Wilford et al.; Diakakis).

The Kandar River flows across the alluvial plains in the Ajay River catchment. It is a fourth-order left bank tributary of the Ajay River. The Kandar River meets with the Bhagirathi–Hugli and Ajay rivers near the Katwa Town (88°80'E, 23°39'N, about 14 m above sea level), around 216 km upstream from Kolkata, in Purba Bardhaman district.

The river passes through the districts of Birbhum, Bardhaman, and Murshidabad (Figure 1). This river extends about 531 square kilometres within the Ajay River basin. The Kandar River is 256 km long, and its watershed has a circumference of around 205 km.

The slope of the watershed is 5.08 °, and the river starts at an elevation of 36.3 meters. The climate of this region is hot and humid. Summer lasts from May to June, and the monsoon season from July to September brings nearly 85% of the yearly rainfall. Winter is short and lasts from late November to mid-February (Bandyopadhyay et al.).

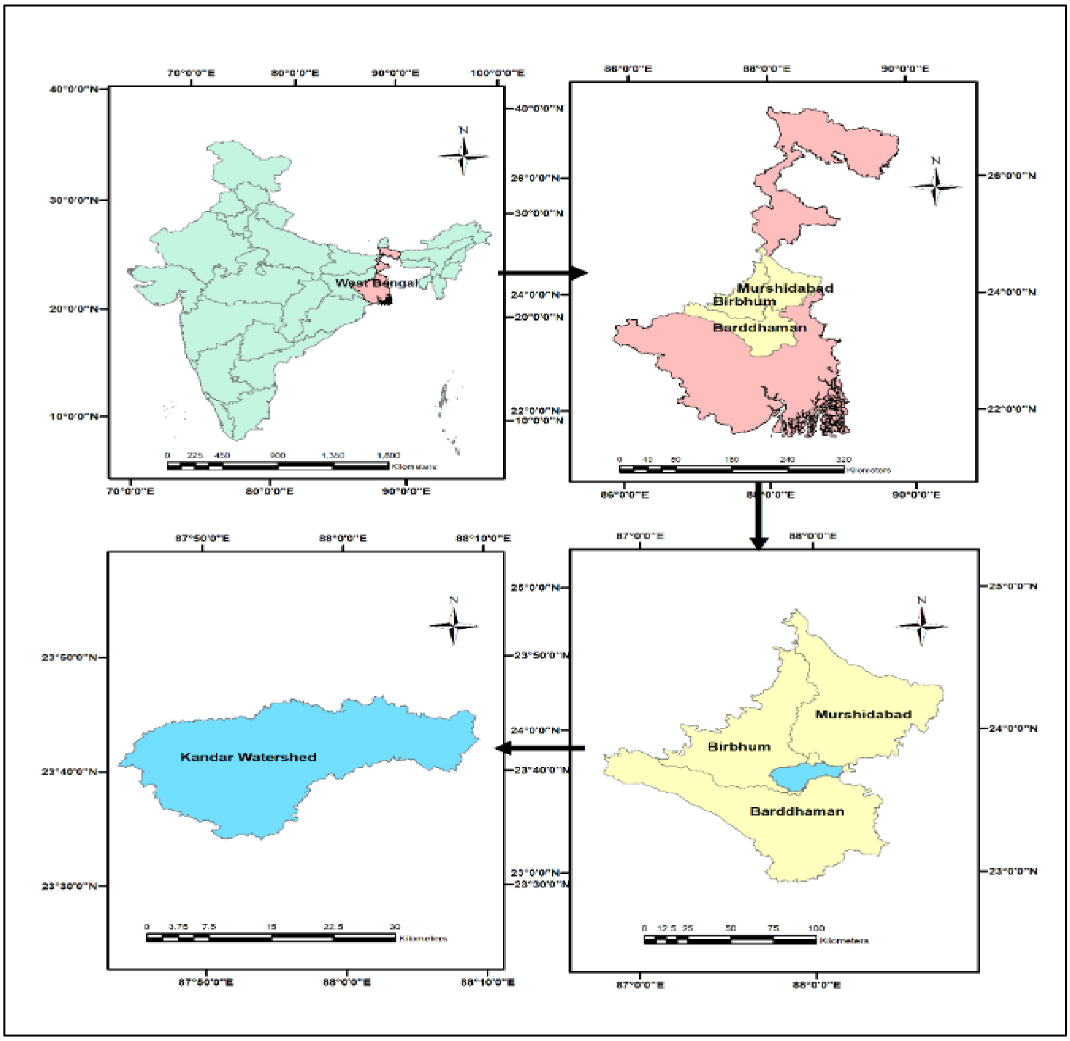

figure 1: location map of the kandar river basin

One significant feature of this flood-prone river is the absence of any major dam in its course (Bandyopadhyay et al.). The geological characteristics are mainly newer alluvium (different combinations of sand, silt and clay) because of frequent inundation (Roy and Sahu). The Ajay River is one of the major flood-prone rivers and the lower segment of its watershed often faces floods due to heavy sediment deposition. The basin has a gentle slope, and the soils are fine-loamy in texture with brown, grey, and dark grey colours. Orthic Luvisols constitute the majority of the basin, while Ferric Luvisols make up the balance (FAO Soil classification map, 2005).

Although the literature on morphometric analysis of large river basins across the Ajay River system continues to accumulate, we have not been as interested in smaller tributaries at the sub-basin level, particularly in low-gradient alluvial environments where these local water spikes in the runoff and seasonal waterlogging are commonly observed. A majority of the available literature is mainly centred on either descriptive morphometry or basin-scale flood analysis and lacks the rigorous exploration of the statistical interactions between linear, areal, and relief parameters in an attempt to determine prevailing geomorphic controls. This paper fills in to quantitatively assess the morphometric parameters of the Kandar River watershed by applying geospatial methods to assess inter-parameter relationships as indicated by correlation analysis and to interpret the implications of the results to the behaviour of runoff, the strength of erosion and the vulnerability to floods. The originality is enhanced by the fact that digital morphometric computation was coupled with structured statistical modelling to determine geomorphic-hydrologic connections at a micro-watershed level in an unstudied tributary system. It might be added in the future that high-resolution DEM datasets, rainfall-runoff modelling, and sediment yield analysis and hydrodynamic simulation under conditions of climate variability could be used to enhance the predictive flood risk assessment and watershed management planning.

2. RESEARCH METHODOLOGY:

This paper is geospatial and quantitative in nature to analyse the morphometric features of the Kandar watershed. The elevation data from the topographic maps was imported into a GIS environment to delineate the basin and extract drainage. The standard morphometric parameters indicative of linear, areal, and relief aspects were evaluated with the mathematical formulations. Statistical techniques were also used to test interrelationships between variables and to interpret the basin's hydrological response. The general methodological approach is summarised in a flowchart below (Figure 2).

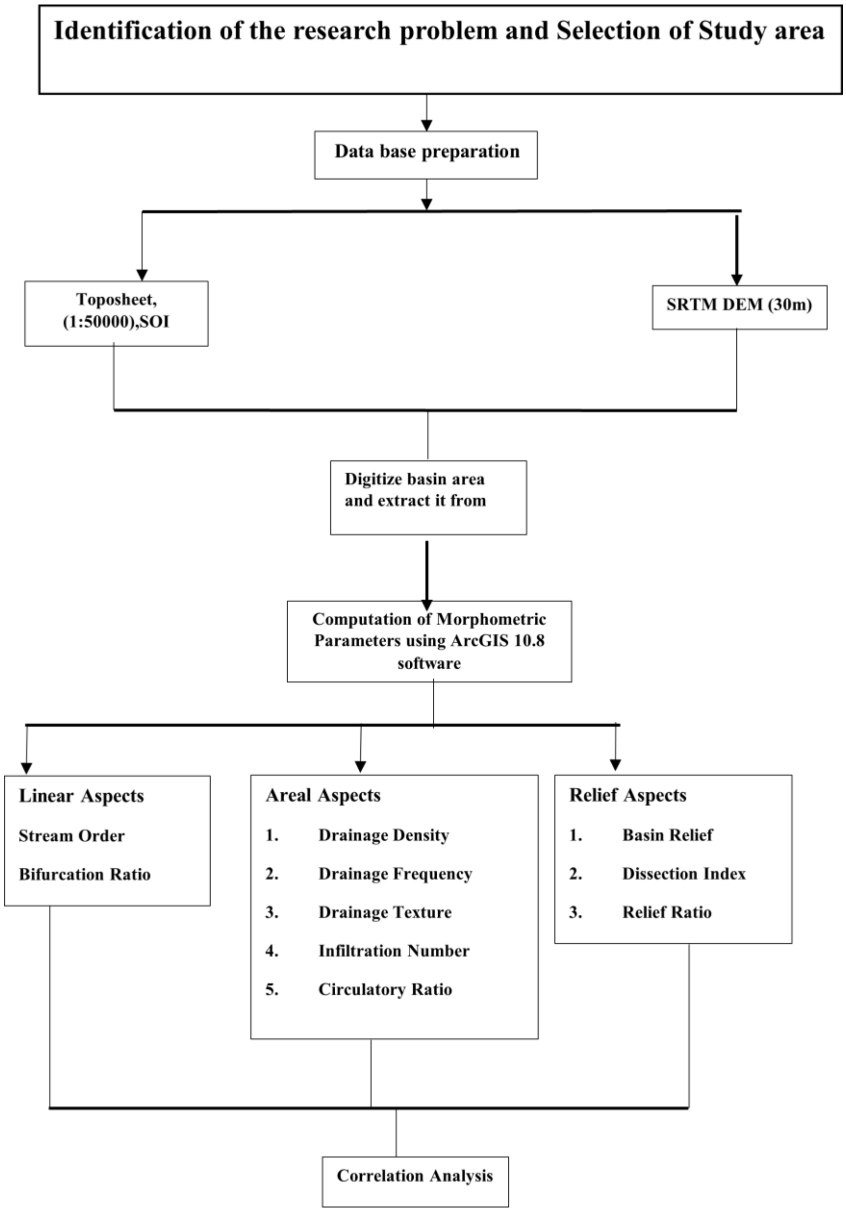

figure 2. flowchart of the methodology of this research study

2.1. MATERIALS:

i. For preparing the base map, topographical maps with the R.F. of 1:50,000 were collected from the SOI website. The sheets 79A/2, 73M/14, and 73M/13 were downloaded and georeferenced. A US Army 1:2500000 map from Google was also used to digitise the study area.

ii. The DEM data with a 30 m resolution were downloaded from the Earth Explorer. Here, the SRTM (Shuttle Radar Topography Mission) Digital Elevation Model has been used at 30 m resolution to obtain better results.
iii. For soil classification, the FAO soil map was used.
iv. A lithology map at a 1:50,000 scale was collected from the Geological Survey of India.

2.2. METHODS:

A. FOR MORPHOMETRIC CHARACTERISTICS:

In this study, topographical maps were used to locate the basin accurately and to draw its boundary. The stream network of the Kandar watershed was extracted and various morphometric characteristics were computed using SRTM DEM data in the GIS environment (ArcGIS 10.8). The Spatial Analyst extension and the Arc-Hydro tool in ArcMap 10.8 were applied to study the basic topography and drainage features of the Kandar watershed (Ghosh and Jana), like the drainage network, flow direction, flow accumulation, stream order, slope aspect and hill shade. The three sets of morphometric variables- linear, areal, and relief aspects—were calculated using tools available in ArcGIS 10.8.

B. CORRELATION ANALYSIS:

Using morphometric parameter values, a correlation analysis was conducted in SPSS 22.0 to assess how the parameters are related.

3. RESULTS AND DISCUSSION

3. A. MORPHOMETRIC CHARACTERISTICS:

A drainage basin's numerous morphometric features are divided into three categories: 1) linear aspects, 2) areal aspects, and 3) relief aspects (Chorley). For the Kandar basin, these have now been described.

1. LINEAR ASPECTS:

The lengthwise information about a stream network is provided by linear features, which include stream ordering, bifurcation ratio, and stream length (Table 1). It is critical to understand the stages of drainage basin geomorphic evolution, channel migration, flood behaviours, and so on (Das, P.). In this study, the following methods were chosen to identify the linear features of the Kandar watershed.

table 1: laws and methods used to find out the linear aspects of the basin

Aspect	Parameter	Formula / Laws	Reference
LINEAR	Stream Order	Hierarchical ranking of streams	(Arthur N. Strahler)
	Stream Number (Nu)	Number of stream segments in each order	(Horton)
	Bifurcation Ratio (Rb)	Rb= Nu/(Nu+1) Where Nu is the number of stream segments in a particular order and Nu + 1 = the number of streams in the next higher order	(Schumm)
	Mean Bifurcation Ratio (Rbm)	Rbm = Mean Rb of all orders	(Arthur N. Strahler)
	Orderwise Stream Length (Lu)	Length of all stream segments in a given order	(Horton)
	Mean Stream Length (Lsm)	Lsm=Lu/Nu Where, Lu = length of the entire stream in a given order and Nu = number of streams in that order	(Strahler)

1.1 STREAM ORDER:

The place of a stream in the hierarchy of tributaries is determined by its stream order (Leopold et al. 135). The concept of stream order was first propounded by Robert E. Horton in 1932, but it was attempted even before Horton by Gravelius (1914). In the Gravelius method, there was no idea of the magnitude of the stream network that was gathered; thus, it was not so acceptable. Later, this method has been slightly modified by Strahler (1964), Scheidegger (1965), Woldenberg (1966) and Shreve (1967). When the stream order increases, the discharge and flow velocity of the stream also increase (Costa, 1987).

In this study, stream hierarchies were classified using Strahler's stream order, which is also known as the Stream Segment Method. According to Strahler (1964), all small, unbranched fingertip streams are classified as 1st-order streams. When two 1st-order streams meet, they form a next higher order stream towards downstream. Similarly, when two 2nd-order streams join, a 3rd-order stream forms, and the pattern continues in this way along the river. The Kandar River basin is classified as a 4th-order basin with an area of 531 square kilometres by using Strahler's (1964) stream orders method. Among the Sub-Watersheds, SW-A and

SW-C are also 4th-order basins, covering 121 square kilometres. and 80 square kilometres, respectively. In contrast, SW-B, SW-D, and SW-E are 3rd-order basins with areas of 117, 128, and 86 square kilometres, respectively (Table 2).

table 2: linear aspects of morphometric parameters of kandar river and its sub-watershed

SL NO.	Name of the Basins	Area (sq. Km.)	Order	Total length (in km)	Bifurcation Ratio (BR)
1	Kandar River	531	IV	276	5.875
2	SW-A	121	IV	54	7.7
3	SW-B	117	III	58.5	13.167
4	SW-C	80	IV	50	4.6
5	SW-D	128	III	66.5	3.167
6	SW-E	86	III	47	3.667

1.2 STREAM NUMBER (Nu):

R. E. Horton (1945) introduced the idea of stream number, which refers to the total number of stream segments in each stream order. An inverse relationship is observed between stream number and stream order. A high stream number suggests greater water discharge and a quick peak flow during rainfall or storms, while a low stream number indicates a lower discharge rate. In this study, 119 stream segments were identified in the Kandar basin. The First-order streams have the highest number of streams, followed by 2nd-order, 3rd-order, and 4th-order streams, respectively, 58, 34, 13, and 14 streams.

1.3 BIFURCATION RATIO (BR):

It is a dimensionless value that represents the ratio between the number of streams in one order and the number of streams in the next higher order within a basin. It was customary to know the degree of assimilation among stream segments within the river basin. Natural drainage systems usually have a bifurcation ratio that ranges between 2 and 5 (Strahler). The higher value of BR indicates highly dissected terrain, mature topography with a higher degree of drainage integration, and higher discharge potential (Horton) with relatively minimal lag for triggering the flash flooding during heavy rains (Chorley).

From Table 2, it is clear that SW-B has the highest BR value. This indicates that the area has high surface runoff and discharge due to its hilly terrain and steep slopes. Therefore, SW-B is highly dissected and has a greater flood risk. In contrast, SW-D has the lowest BR value, suggesting a flatter terrain. In this study, the value of the average bifurcation ratio varies from 1.056 to 4.389.

1.4 STREAM LENGTH (Lu):

That a given order's total stream length is inversely proportional to its stream order, i.e. total stream length reduces as stream order rises and vice versa (Horton). From the table (Table 2), it's evident that utmost stream length is found within the First order stream, which constitutes 138 km of the entire stream length followed by second order (78 km), third order (31 km) and fourth order (29 km) meaning it follows the law of stream length as Horton's introduction (1945).

2. AREAL ASPECTS:

The areal extent of complete drainage is crucial for demonstrating its relative importance, from continental dimensions to extremely small areal extents (Sen) (Table 3). The maximum flood discharge per unit area decreases as the size of the basin increases.

table 3: laws and methods used to find out the areal aspects of the basin

Aspect	Parameter	Formula / Laws	Reference
AREAL	Basin Area (A)	Plane area within the perimeter along the drainage basin	-------
	Stream Frequency / Drainage Frequency (Fs)	Fs= Nu/A where, Nu = Total number of streams of all orders, A = Area of the basin	(Horton)
	Drainage Texture (Dt)	Dt= Nu/P where, Nu = Total number of stream segments of all orders, P = Basin perimeter	(Horton)
	Infiltration Number (In)	In=Df ×Dd where, Df = Drainage density, Df = Drainage frequency	(FANIRAN)

	Drainage Intensity (Din)	Din= Df/Dd where, Df = Drainage frequency, Dd = Drainage density	(FANIRAN)
	Length of Overland Flow (Lof)	Lof= Dd21, where, Dd = Drainage density	(Horton)
	Constant of channel Maintenance (CCM)	CCM= 1/Dd where, Dd = Drainage density	(Schumm)
	Circularity Ratio (Rc)	Rc=4×Π×A/P2 where, Π = 3.14, A = Area of the basin, P = Perimeter	(Miller)
	Elongation Ratio (Re)	Re = 1.128 A/Lb Where, A = Area of the basin, Lb = Basin length	(Schumm)
	Form factor (Rf)	Rf= A/Lb^2 Where, A = Area of the basin, Lb^2 = Square of the basin length	(Horton)
	Compactness Coefficient (Cc)	Cc = 0.2821 P/ A 0.5; where, P=Perimeter of basin, A = Area of basin	(Horton)
	Shape factor (Bs)	Lb^2/A; where, A=Area of basin, Lb=Basin length	(Horton)

Areal features of the study area and its main tributaries include measurements of basin area, basin shape, drainage density, infiltration number, drainage texture, infiltration number, drainage intensity, stream frequency, length of overland flow, and other related factors.

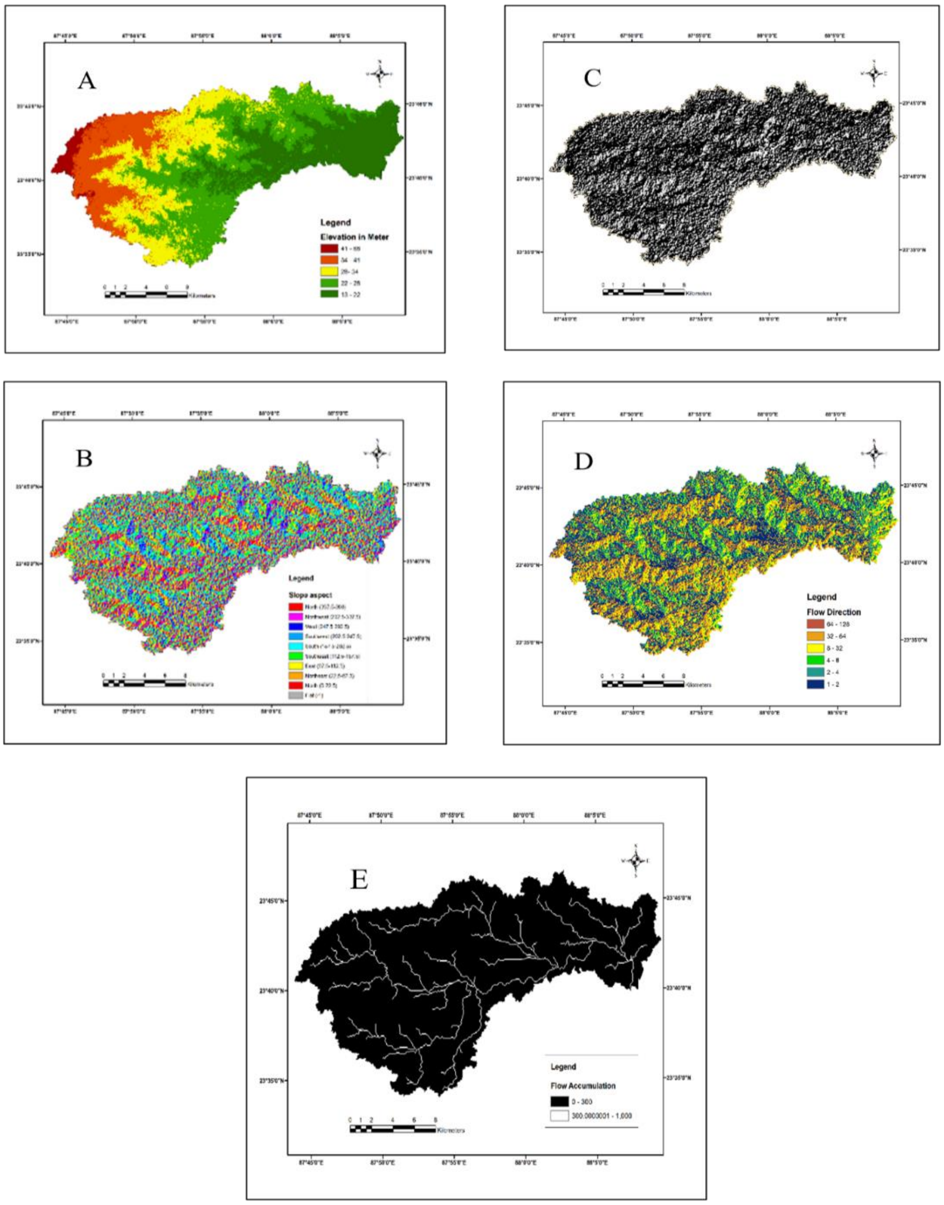

figure 3: general morphological attributes of the kandar basin (a) filled in dem, b) aspect map, c) hill-shade map, d) flow direction map, e) flow accumulation map

2.1 DRAINAGE FREQUENCY (DF):

It refers to the total number of stream segments per unit area of a river basin. It affects the permeability of soil, infiltration capacity of the river, and relief of a watershed, which together influence water discharge. High Drainage Frequency values are caused by impermeable subsurface material, limited vegetation, high relief conditions, and low infiltration capacity (Bhat et al.; Reddy et al.).

In this study, drainage frequency ranges from 0.195 to 0.240, which is very low. This indicates that the basin has a low relief with highly permeable rocks, leading to less surface runoff during rainfall (Table 4).

table 4: areal aspects of morphometric parameters of kandar river and its sub-watershed

SL NO.	Name of the Basins	Drainage density	Drainage frequency	Drainage texture	Elongation ratio	Form factor	Shape factor	Circulatory ratio	Infiltration number	Compactness co-efficient	length of overland flow
1	Kandar River	0.519	0.217	0.286	0.594	0.277	3.609	0.159	0.112	2.509	0.259
2	SW-A	0.455	0.24	0.141	0.711	0.397	2.516	0.18	0.109	2.36	0.228
3	SW-B	0.513	0.231	0.144	0.543	0.232	4.316	0.156	0.118	2.53	0.257
4	SW-C	0.625	0.237	0.07	0.723	0.411	2.436	0.076	0.148	3.627	0.313
5	SW-D	0.531	0.195	0.149	0.646	0.328	3.05	0.213	0.104	2.169	0.266
6	SW-E	0.546	0.221	0.123	0.692	0.376	2.662	0.165	0.121	2.46	0.273

2.2 DRAINAGE DENSITY (DD):

'Drainage density is the stream length per unit area in the region of the watershed' (Horton). Drainage density is an important controlling factor of surface runoff that influences the flood peak discharges (Islam and Deb Barman). High and low (DD) values are obtained due to sub-surface material (impermeable/ permeable), vegetation (sparse/good), relief (high/ low), runoff/infiltration (high/low), and flood volumes (high/ low) (Bhat et al.).

As shown in Table 4, the drainage density of the Kandar River is less than 1 km per square km, representing low relief, which means that the river basin has a low runoff even during the monsoon periods.

2.3 DRAINAGE TEXTURE (DT):

It is defined as the ratio between the total number of stream segments and the perimeter of the basin. Based on drainage density, Smith (1950) classified drainage texture into five categories, including very coarse texture.

The drainage texture varies from 0.07 to 0.28 in the basin area along with its five sub–watersheds, which is very low. According to Smith's (1950) classification, this indicates a very coarse drainage texture (Table 4).

2.4 INFILTRATION NUMBER (IN):

This number represents how easily the catchment water can soak into the basin. It has an inverse relationship with infiltration capacity—meaning, when the infiltration number is high, infiltration capacity is low and surface runoff increases, and when the infiltration number is low, infiltration capacity is high (Farhan et al.).

In the Kandar River Basin, the infiltration number is 0.11, which is very low. Its sub-watersheds also have very low values (Table 4). These results depict that the basin area has very little surface runoff with high infiltration capacity.

2.5 CIRCULATORY RATIO (CR)

The circulatory ratio is identified because the ratio of the catchment basin to the world of a circle having an equivalent circumference, because the perimeter of the basin (Miller). The high Circulatory ratio refers to the basin features a circular shape with moderate-to-high relief and permeable surface, which causes peak flows during a shorter time, whereas a low Circulatory ratio indicates the elongated basin with low relief and impermeable surface, leading to lower peak flow for an extended period (Sreedevi et al.).

As per the Table.4 river basins, along with its sub – watershed represents a low circulatory ratio varying (0.213 to 0.076), which describes that the size of the basin area is elongated with low relief, comprising mostly impermeable surface.

2.6 ELONGATION RATIO (ER)

This ratio describes the overall shape of a river basin. It is calculated by juxtaposing the longest length of basin area with the diameter of a circle that has the same area. Its value ranges from 0 to 1. It represents that the basin area has a circular shape as it goes towards the value 1, while values towards 0 depict an elongated basin. Circular basins have high Elongation ratio values, which are regarded as dangerous because they expose peak flow in a short time compared to elongated basins with low Elongation ratio (Bhat et al.).

This study shows that the Kandar basin, along with its sub – basins have an elongated shape that comprises sudden peak flow as the value of the elongation ratio is closer to 1, as shown in Table 4.

2.7 FORM FACTOR (FF):

It also describes the shape of a river basin in the same way as an Elongation Ratio. The contour of a basin is defined by a ratio between the circumference of the catchment area and the square of the basin length (Horton). This parameter determines the link between drainage basin flow intensity and peak discharge (Horton). High values of Form Factor occur within the basins having the potential to supply high peak flows during a short time and low values of Form Factor are the other way around (Reddy et al.).

As shown in Table 4, its value varies from 0.23 to 0.41 in the river basin, which indicates that the basin has an elongated shape and comprises lower peak runoff spread throughout a longer period of time.

2.8 SHAPE FACTOR (SF):

It is another method used to describe the geometry of a drainage basin area. It is described as the ratio of the river basin area to the square of the basin length. If a is a value greater than 1, then it indicates that the river basin is elongated along its main axis, while a value less than 1 shows that the basin is wider across its width.

As depicted in the Table.4 the value of shape factor varies from 2.4 to 4.3 in the Kandar Basin along with its five sub - basins, the Shape Factor ranges from 2.4 to 4.3 (Table 4). It represented that the highest value is observed in SW – B, while sub-basin SW-C has the lowest value. The results describe that SW – B has the most elongated shape in this river basin.

2.9 COMPACTNESS COEFFICIENT (CC)

It is calculated by contrasting the boundary length of the basin with the perimeter of a circle, which has the same area as the river basin. A circular basin has a CC value close to 1 and reaches peak flow quickly, while basins with CC values greater than 1 take longer to reach peak flow (Bhat et al.).

In this study, the Kandar basin and its sub-basins all have CC values greater than 1 (Table 4), which suggests they have higher infiltration and lower surface runoff.

2.10 LENGTH of OVERLAND FLOW (LOF):

It is described that the length of overland flow drops with increasing channel slope, which is closely related to the sheet flow length. It is roughly equal to half of the reciprocal of drainage density (Das). The study shows that the value of overland flow length is 0.259 (Table 4) in the Kandar river basin, which indicates moderate surface runoff.

3. RELIEF ASPECTS:

It is described as the three-dimensional features of a drainage basin. The measures of the relief properties connote the different spatial characteristics of the landform pattern, about its altitude, alignment, degree of dissection, slope values and aspect, nature of drainage network, and their spacing apart from many other interrelated factors like lithology, climate, tectonics, vegetation, and so forth (table 5) (Datta, 2019: pg. 42).

table 5: laws and methods used to find out the relief aspects of the basin

Aspect	Parameter	Formula / Laws	Reference
RELIEF	Absolute Relief / Maximum Relief (Rmax)	The maximum elevation in a watershed	---------
	Minimum Relief (Rmin)	The minimum elevation in a watershed	---------
	Basin Relief (Bh) / Relative Relief (RR)	H = Rmax-Rmin, Where, Rmax = Maximum elevation Rmin = Minimum elevation	(Schumm)
	Relief Ratio (Rh)	Rh= BhLb where, Bh = Basin relief Lb = Maximum length	(Schumm)
	Ruggedness number (Rn)	Rn = Bh x Dd Where, Bh = Basin relief; Dd = Drainage density	(Schumm)
	Dissection index (DI)	DI = RR/Hx× 100 Where, Hx = Maximum relief; RR = Relative relief	(Schumm)

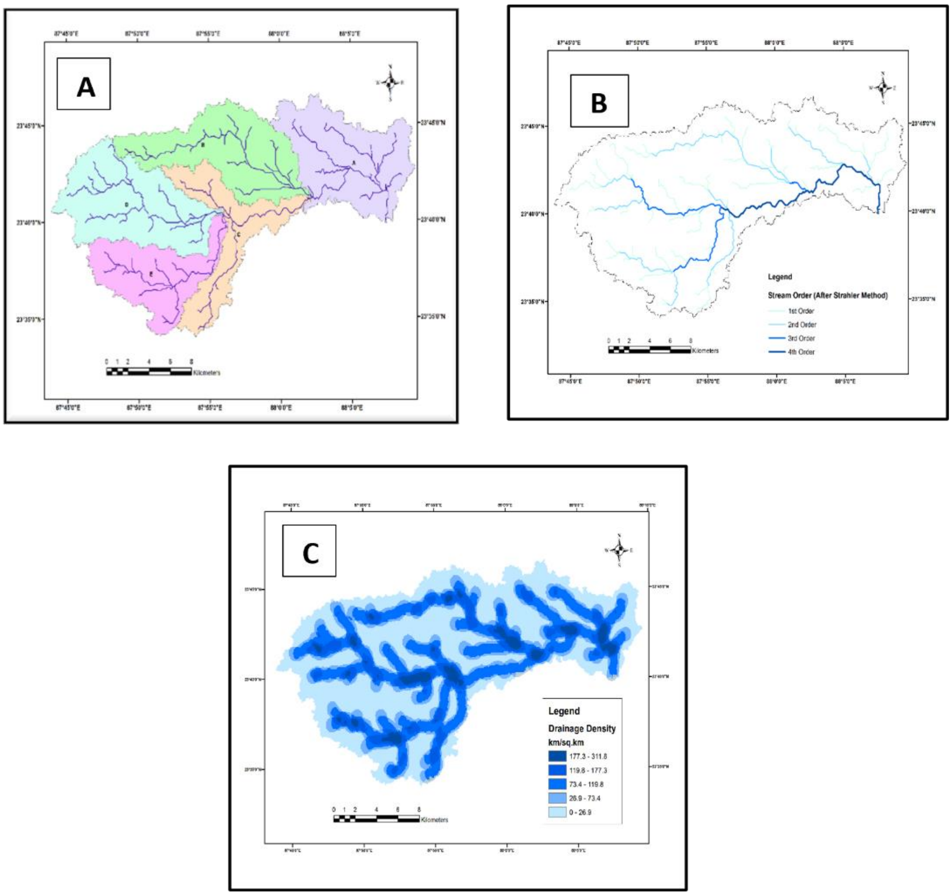

figure: 4 A. sub-watershed of kandar basin; B. stream order (after strahler method); C. drainage density map

3.1 RELATIVE RELIEF (RR):

The relative relief, often known as basin relief, is described as the difference between the lowest and highest water surface elevation in a river basin. It provides important information about erosion, runoff, landform development, and the nature of the drainage network (Patton). As per Table 6, this study shows that the Kandar river basin area has a 40-metre elevation, while the values of elevation vary from 10 to 30 metres in the sub–watershed areas.

table 6: relief aspects of morphometric parameters of kandar river and its sub-watershed

SL NO.	Name of the Basins	Relative relief	Slope	Dissection Index	Ruggedness number	Relief Ratio
1	Kandar River	40	5.081	66.667	20.76	0.914
2	SW-A	10	2.671	33.33	4.55	0.573
3	SW-B	20	5.082	50	10.26	0.89
4	SW-C	10	2.552	33.33	6.25	0.716
5	SW-D	30	2.707	50	15.93	1.518
6	SW-E	10	2.576	25	5.46	0.661

3.2 RELIEF RATIO (RO):

The relief ratio is the ratio of the overall relief of a basin to its longest dimension parallel to the principal drainage line (Schumm,609). The relief ratio is the same as the tangent of the slope angle in the horizontal plane and is identical to that of a right-angled triangle (Strahler, 1964). Relief decreases when the relief ratio becomes lower and increases when the value of the relief ratio increases. There is an inverse relationship between the relative ratio and the drainage basin. Drainage basins with a high relief ratio indicate a short basin lag time, high peak discharge, high erosion, and high sediment yield (Bhat et al.).

As shown in Table 6, the relief ratio of the Kandar basin is 0.914, while the value varies from 0.573 to 1.518 in sub–watershed regions. These relatively low values indicate low relief and simple topography, which results in slower water flow. This suggests that the Kandar basin is mostly flat, has a long basin length, and is less prone to flooding.

3.3 RUGGEDNESS NUMBER (RN):

The Ruggedness Number (RN) is a component of maximum basin relief and drainage density that is usually determined by adding slope steepness and length together (Strahler 1968).

Basins with steep slopes, as well as smooth texture, have a high Ruggedness value, making them vulnerable to erosion with a surge peak discharge. (2019, Bhat et al.) SW-B and SW-D have the greatest ruggedness number (Table 6) in the Kandar River basin, illustrate that they have a smooth texture and the potential for significant surface flow. These sub-basins are also prone to erosion, resulting in higher peak discharge (Bhat et al., 2019).

In this main watershed, sub-basins SW-B and SW-D have the highest values (Table 6), which suggests they may experience higher surface runoff. These areas are also more likely to face erosion and produce higher peak discharge. On the other hand, SW-A, SW-C, and SW-E belong to the lower ruggedness numbers due to their simpler terrain with low relief. This means they generate less water flow within the basin.

3.4 SLOPE (S):

The slope is another significant parameter of the relief aspect. In geomorphological studies, the slope is considered not only the basic component of landform analysis but also an ecological site where the operation of geomorphic, climate and other physical forces maintains the slope in a state of equilibrium (Sen, 1993). It is a three-dimensional characteristic of a drainage basin. If the basin slope is steep, runoff should be very fast and have the shortest lag time, and vice versa.

The Kandar river basin has a low or very gentle mean slope of 5.082 degrees (Table 6). Among its watersheds, the highest degree of slope is found in SW-B and the lowest one is found in SW-C. This result defines that after rainfall, there is a slow process of runoff and this area faces a major problem of waterlogging.

Bifurcation Ratio (BR), Drainage Density (DD), Drainage Frequency (DF), Drainage Texture (DT), Elongation Ratio (ER), Form Factor (FF), Shape Factor (SF), Circulatory Ratio (CR), Compactness Coefficient (CC), Relative Relief (RR), Dissection Index (DI), Ruggedness Number (RN), Relief Ratio (RO), Slope (S).

B. CORRELATION BETWEEN MORPHOMETRIC PARAMETERS:

Towards determining the structural interrelationships among the fourteen derived morphometric variables, a bivariate Pearson analysis of correlation was performed using SPSS 22.0 (Table 7). The correlation matrix shows statistically significant relationships at the probability levels of 0.05 and 0.01, which means that the associations are systematic and geometric and do not occur as a result of random parameter interactions.

table 7 correlation matrix of morphometric parameters

CORRELATION CO-EFFICIENT MATRIX														
	BR	DD	DF	DT	ER	FF	SF	CR	CC	RR	DI	RN	RO	S
BR	1													
DD	-0.424	1												
DF	0.487	-0.040	1											
DT	0.327	-0.847	-0.431	1										
ER	-0.725	0.258	0.214	-0.560	1									
FF	-0.706	0.263	0.243	-0.575	0.999**	1								
SF	0.783	-0.236	-0.112	0.498	-0.995**	-0.990**	1							
CR	-0.038	-0.743	-0.633	0.931*	-0.294	-0.324	0.213	1						
CC	-0.092	0.805	0.523	-0.963**	0.374	0.395	-0.298	-0.980**	1					
RR	0.008	-0.123	-0.821	0.566	-0.591	-0.610	0.515	0.594	-0.498	1				
DI	0.433	-0.182	-0.445	0.498	-0.771	-0.777	0.741	0.364	-0.310	0.875	1			
RN	-0.063	0.010	-0.839	0.456	-0.548	-0.567	0.474	0.504	-0.396	0.991**	0.851	1		
RO	-0.238	0.049	-0.899*	0.407	-0.389	-0.412	0.306	0.521	-0.389	0.966**	0.756	0.983**	1	
S	0.908*	-0.232	0.160	0.367	-0.929*	-0.917*	0.963**	0.030	-0.143	0.290	0.618	0.246	0.063	1

**correlation is significant at the 0.01 level, which means at the 99% level of significance (2-tailed)
*correlation is significant at the 0.05 level, which means at the 95% level of significance (2-tailed)

In quantitative geomorphometric analysis, this presented correlation matrix explains the underlying interdependencies of the drainage basin morphology. The structural and topographic controls that exist between basin evolution and hydrological response are indicated in the relationships below, which are indicated in Table 8.

table 8: relationships between all morphometric parameters

Correlation Strength	Type	Parameter Pairs Showing Relationship
Strong Positive (r > 0.65)	↑ Positive	BR–SF, BR–S, DD–CC, DT–CR, ER–FF, SF–DI, SF–S, RR–DI, RR–RN, RR–RO, DI–RN, DI–RO, RN–RO
Moderate Positive (r = 0.55–0.65)	↑ Positive	RR–DT, RR–CR, DI–S
Weak Positive (r < 0.55)	↑ Positive	BR–DF, BR–DT, BR–DI, DD–ER, DD–FF, ER–DF, FF–DF, CC–DF, SF–DT, DT–DI, DT–RN, DT–RO, DT–S, ER–CC, FF–CC, RR–SF, SF–CR, SF–RN, SF–RO, CR–DI, CR–RN, CR–RO, RR–S, RN–S
Strong Negative (r < –0.65)	↓ Negative	BR–ER, BR–FF, DT–DD, DD–CR, DF–RR, DF–RN, DF–RO, DT–CC, ER–SF, ER–DI, ER–S, FF–SF, FF–DI, FF–S, CR–CC
Moderate Negative (r = –0.55 to –0.65)	↓ Negative	DD–SF, DD–S, DT–DF, DF–CR, DF–DI, DT–ER, DT–FF, ER–CR, ER–RR, ER–RN, ER–RO, FF–CR, FF–RR, FF–RO, FF–RN, SF–CC, CC–DI, CC–RN, CC–RO
Very Weak / No Correlation (r ≈ 0)	—	BR–RN, DD–DF, DD–RN, DD–RO, DF–S, CC–S, CR–S, RO–S

BR: Bifurcation Ratio; DD: Drainage Density; DF: Drainage Frequency; DT: Drainage Texture; ER: Elongation Ratio; FF: Form Factor; SF: Shape Factor; CR: Circulatory Ratio; CC: Compactness Coefficient; RR: Relative Relief; DI: Dissection Index; RN: Ruggedness Number; RO: Relief Ratio; S: Slope.

Drainage Network Dynamics: In this correlational analysis, the Bifurcation Ratio is strongly positively correlated with the Stream Frequency and Slope, which means a Bifurcation basin with a strong structural complexity has highly dissected channel networks and steepened topographic gradients. In addition, Drainage Texture is also strongly correlated with Circulatory Ratio, which proves that finely textured basins should be circularly morphometric.

Relief Integration: Morphometric parameters such as basin relief, relative relief, ruggedness number, relief ratio and Dissection Index constitute a closely-knit set of measures, all of which exhibit good positive correlations with each other. This statistical consistency validates the fact that high relief energy is one of the natural forces that causes a high level of landscape dissection and topographic roughness. These relief measures also show that Drainage Texture is positively moderately correlated with them, which supports the fact that when relief is high, finer drainage networks tend to be encouraged.

Morphological Controls: Shape parameters also have important inverse relationships with relief characteristics. Elongation Ratio and Form Factor have a negative correlation with Bifurcation Ratio, Stream Frequency and all relief parameters. This conclusively proves that elongated basins are seen to have a higher structural complexity and greater intensity of dissection, as compared to circular basins, which are seen in tectonically stable and low-relief environments. The Compactness Coefficient and Circularity Ratio have expected negative correlation, hence confirming their negative mathematical association.

Parameter Independence: It is very significant to indicate that the Bifurcation Ratio has almost no correlation with Ruggedness Number, whereas the Drainage Density is independent of Drainage Frequency and Relief Ratio. These statistical voids suggest that there are morphometric dimensions that develop by essentially distinct geomorphic mechanisms.

4. CONCLUSION:

Basin morphometry, according to Horton (1945), is the mathematical measurement of the drainage basin's geometry. This research used three aspects of morphometric variables obtained from SRTM DEM and topographic maps to investigate the hydrological patterns of the Kandar and its sub-watersheds. The Bifurcation Ratio, Dissection Index, and mean slope indicate that the Kandar River basin has highly dissected alluvial terrain with very flat topography, which often leads to waterlogging. Most of the basin lies below 40 m elevation. The basin is located in a subtropical humid climate, where rainfall is intense but lasts for a short period. The Kandar River is a fourth-order stream (Strahler) with a total of 115 streams. In this basin, the length of the stream and its orders are positively correlated with each other. The drainage density (0.519 km/square kilometres) and the drainage frequency (0.217 km/square kilometres) are very low, which reflects the permeable nature of the basin's surface materials. Low form factor and elongation ratio indicate that the shape of this Kanadar river watershed is elongated. Most parts of this basin have a low value of relative relief, dissection index, ruggedness number, and a gentle slope of less than 5°, indicating extremely flat terrain. As a result, the area is highly prone to waterlogging during heavy rainfall. These characteristics suggest that the basin is part of a younger alluvial plain. Almost every monsoon, the low-relief and low-slope areas experience waterlogging, which often leads to localised flooding. The correlation analysis further helps in understanding how different morphometric parameters are related to each other.

In essence, therefore, the research provides a good scientific basis for the management of the watersheds and for planning flood mitigation in the Kandar basin. It also provides a parallel model to low-gradient alluvial basins in the monsoon-dominated areas across the world. The study introduces some new concepts through the integration of digital morphometry with statistical correlation of the parameter and decodes geomorphic-hydrological relationships at the sub-basin level. However, the analysis is rather limited in nature as it uses secondary data of elevation and lacks direct discharge data. Further development of work would involve work at a higher resolution of DEMs and hydrology modelling, to refine the forecasts.

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