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Drainage Basin Morphometric Analysis of Mountain-Plain (Kosi, Bihar) and Plateau-plain (Kangsabati, WB) Regions of Tropical Environment: A Comparative Analysis

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ABSTRACT
Morphometric analysis is an important indicator to understand the geomorphic, geologic, hydrological and evolutionary characteristics of any region. In this study, morphometric analysis has been carried out to compare the drainage basin characteristics of mountain-plain and plateau-plain region of tropical India. The Kosi basin of the mountain-plain area and Kangsabati basin of the plateau-plain area, are selected for the present study. The geological, geomorphological, hydrological, fluvial characteristics have been traced from different morphometric parameters for these two different morpho-climatic settings. Different drainage morphometric parameters and measurements related to linear, areal, and relief characteristics have been determined through Shuttle Radar Topography Mission (SRTM GDEM, 90m.) and ARC GIS 10.1. The mean Bifurcation ratio indicates that Kosi has greater flood potentiality than Kangsabati Basin. Kosi carries large amount of water due to its near-circular basin shape, compared to Kangsabati basin which has an elongated shape. All the relief characteristics indicate that the Kosi basin is rejuvenated or at the young stage of geomorphic development, than the mature Kangsabati River basin of plateau region. Most of the morphometric characteristics indicate that there are high geologic and geomorphological controls on river basin characteristics.

Key words: Evolutionary characteristics, Tropical India, Fluvial characteristics, Kosi Basin, Kangsabati basin, Morpho-climatic settings, Relief characteristics, SRTM, Geomorphic development.

INTRODUCTION

The morphometric characteristics of any drainage basin play a significant in understanding the underlying structure, geology, geomorphology, as well as the hydrological characters of any basin. Erosion and deposition of connected stream network produces different fluvial landforms (Joji et al., 2013). Morphology, hydrology and evolutionary history of any basin can be best understood through mathematical morphometric characteristics of such basins (Sharma and Sarma, 2013), wherein the size of the basin, shape and dimension can be evaluated through different morphometric indicators. The relationship between various drainage parameters and its underlying geology, geomorphology, hydrology and structure had been well established through the work of Strahler (1952). Different hydrological behaviour (like peak flow and flooding) of any basin, can be understood through different morphometric indicators of linear, areal and relief parameters. Among the different morphometric characteristics, linear drainage parameters (stream order, stream number, bifurcation ratio, strength length, mean stream length), basin parameters (circularity ratio, elongation ratio, drainage density, drainage frequency), relief parameters (dissection index, ruggedness index, hypsometric characteristics) are considered important. Drainage morphometric analysis is also an important tool to understand the fluvial processes (Chorley et al., 1985; Leopold et al., 1969). Stages of geomorphological evolution or the erosional characteristics can also be well understood through their morphometric characteristics (Strahler, 1952). It provides enormous idea to identify the morphological and hydrological problems and helps with related management procedures. The remote sensing and GIS toll is considered important to study such morphometric characteristics. Recently, several workers have used such data in the analysis of drainage morphometric characteristics (Nag and Lahiri, 2012; Ansari et al., 2012; Magesh and Chandrasekar, 2014).

The Kosi basin, which is representative of the mountain-plain region, is an important basin which has been associated with frequent channel shifting (Singh et al., 1993). Many studies have attributed morphometric characteristics for frequent flooding and river course changes (Sinha, 2009; Shrestha et al., 2010). Further, the distribution of flooding is also suggested to be geological and geomorphological controlled (Jain and Sinha, 2008). Similarly, the Kangsabati basin, which is representative of plateau-plain fringe river basin, has distinct types of morphometric characteristics, where erosional features dominate over an extensive part of the basin. Most of the study in recent past indicate that its mature geomorphological evolution condition is related to its morphometric characteristics (Dutta and Roy, 2012). The changes of morphometric characteristics, together with

Table 1. Morphometric parameters of a river basin

	Parameters	Formula
Linear Aspect	Stream No. (Nu)	Nu = No. of streams of a particular order 'u'
	Bifurcation Ratio (Rb)	Rb = (Nu/Nu+1); where, Nu= Number of streams of a particular order 'u', Nu+1= Number of streams of next higher order 'u+1'
	Mean Bifurcation Ratio (Rbm)	Rbm = Mean of bifurcation ratios of all orders.
	Stream Length (Lu)	Lu = Total length of streams (km) of a particular order 'u'
	Mean Stream Length (Lum)	Lum = Lu/Nu; where, Lu = Total length of streams (km) of a particular order 'u', Nu = Total no. of streams of a particular order 'u'.
	Stream Length Ratio (Rl)	Rl = Lum/Lum+1; where, Lu = Mean stream length of a particular order 'u', Lu + 1= Mean stream length of next higher order 'u+1'.
Areal Aspect	Basin Perimeter (P)	P = Outer boundary of a drainage basin (km)
	Basin Area (A)	Total area of a basin (km^2)
	Form Factor (Ff)	Ff= A/L^2; where, A= Area of the basin (km^2), L = Basin length (km).
	Circularity Ratio (Rc)	Rc = $4\pi A / P^2$; where, A = Area of the basin (km^2), P = Outer boundary of a drainage basin (km).
	Elongation Ratio (Re)	Re = $P / \pi L$; P = Outer boundary of a drainage basin (km), L = Basin length(km).
	Compactness constant (Cc)	Cc = 0.2821 $P/A^{0.5}$, where, A = Bain area (km^2), P = Basin perimeter (km).
	Constant of channel maintenence (CCM)	CCM = 1/Dd; where, Dd = Drainage density
	Stream Frequency (Sf)	Sf = $\sum$Nu/A; where, Nu = Total no of streams of a given basin, A = Total area of basin (km^2)
	Drainage Density (Dd)	Dd = $\sum$Lu/Au; where, Lu= length of streams (km), Au=Basin area (km^2).
	Texture ratio (Rt)	Rt = Nu/p, where, Nu = No. of streams, p = Perimeter of the basin (km).
Relief Aspect	Absolute Relief (R)	Hihest height of the basin
	Relative Relief (H)	H = R-r, where,R = Heighest relief, r = Lowest relief.
	Relief Ratio (Rr)	Rr = (H/L max); where, H= Relative relief (m), L= Length of basin (m)
	Dissection Index (Di)	Di = H/R; H = Relative relief (m), R = Absolute relief (m)
	Ruggedness Index (Ri)	Ri = Dd * H/1000; where, Dd= Drainage density, H = Relative relief.

the changes in geomorphology over this basin, is well-established (Pan, 2013; Gayen et al., 2013).

The present study aims to make a comparative study of different morphometric attributes of these two different basins, which has not yet been carried out. The study also aims to understand the geologic, geomorphic, hydrologic influence on basin morphometry of two basins that fall under two different morpho-climatic setting.

STUDY AREA

The Kosi and Kangsabati basins can be considered environmentally and anthropologically distinct, with spectacular environment (Figure 1). Kosi basin lies in an area of neo-tectonic uplift, associated with Himalayan region. The frequent floods and rapid avulsion changes associated with the Kosi basin are well-known (Sinha, 2009). The River is also known as 'Sorrow of Bihar'. Kosi River enters Bhimnagar after crossing Nepal Himalaya and then it joins Ganga near Kursela, after flowing 320 km in northern Bihar. Kosi is also an example of inland delta building agent (Gole and Chitale, 1966). Kosi changed its main course towards 100 km eastward, through the major avulsion process in August 2008 (Sinha et al., 2008). Kosi had abandoned this path before 200 years ago. Some geomorphologist called the flood of August 2008 as human disaster (Shrestha et al., 2010). In comparision, Kangsabati basin lies in an area under eastern Chotanagpur plateau fringe, which is more or less stable geomorphologically. After originating from 'Ajodhya hill' of eastern Chotanagpur plateau, the river associated with this basin flows through the plateau fringe regions of West Bengal, in an eastward direction (Nag and Lahiri, 2012). Different geomorphic characteristics indicate that the basin is in the mature stage of geomorphic development (Pan, 2013; Dutta and Roy, 2012). Compared to Kosi, Kangsabati basin is less flood-prone, due to its elongated areal characteristics (Gayen et al., 2013).

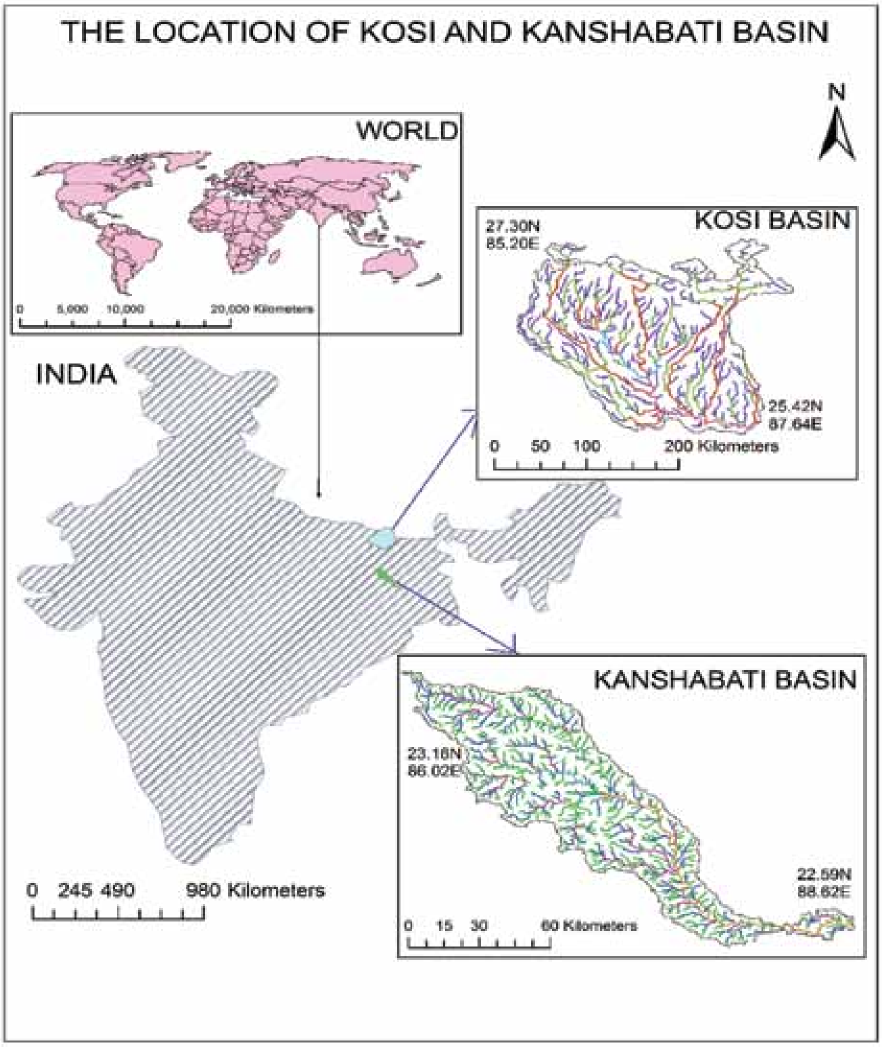

Figure 1. The Location map of Kosi and Kangsabati basins

METHODOLOGY

The measurement of basin morphometry through remote sensing and GIS techniques, followed by their interpretation, are the broad methodology used in the present study. To fulfil the above-stated objective, 'SRTM-GDEM' (30 m.) data has been used for river morphometric analysis, followed by the construction of longitudinal profile. The different basin morphometric parameters have been accessed and calculated through remote sensing and GIS techniques (Table 1) (Figure 2) like, (i) Linear aspect (stream order, bifurcation ratio, mean bifurcation ratio, stream length, mean stream length, stream length ratio, (ii) Areal aspect (stream frequency, drainage density, texture ratio, form factor, circularity ratio, elongation ratio), and (iii) Relief aspect (Relative relief, Relief ratio, Dissection index, Ruggedness index).

RESULTS AND DISCUSSION

Morphometric analysis is a useful tool to understand the hydrological behaviour of sedimentary basins (Castillo et al., 1988; Thomas et al., 2010). It is also useful to understand the underlying geology, structure and geomorphology of the basin (Sharma and Sarma, 2013). Hydro-sedimentary characteristics is also used to quantify the basin characteristics (Raux et al., 2011). Geologically, Kosi basin comes under the Indo-Gangetic plain. Both Himalayan glaciers, as well as precipitation, deeply influence the hydrology of the Kosi River, which is highly notorious due to its high sediment load and migratory trends with antecedent river characteristics. Failure of Kosi embankment and changes in avulsion characteristics is major concerns of recent past. Such phenomena have been interpreted through the local geological adjustment,

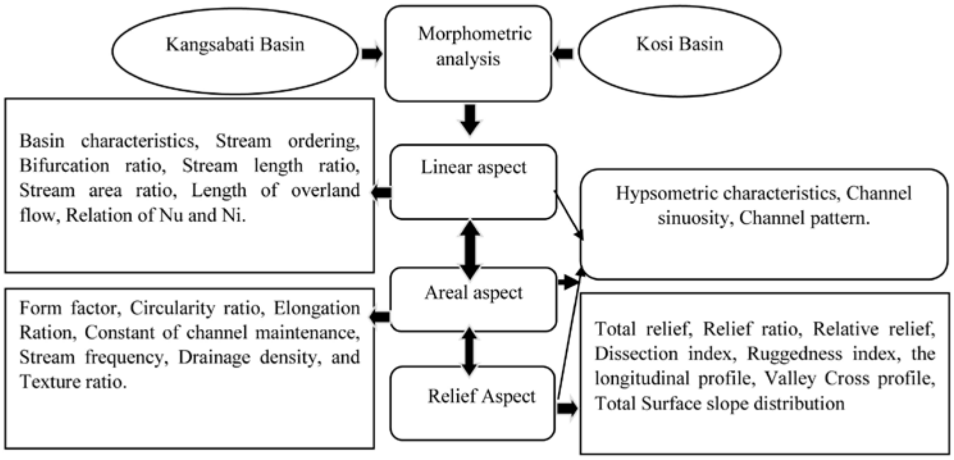

Figure 2. Flow diagram of methodology for drainage morphometric analysis.

Table 2. Linear morphometric aspect of river basins

Morphometric Parameters	Kangsabati Basin						Kosi Basin						
Stream order (u)	I	II	III	IV	V	VI	I	II	III	IV	V	VI	VII
Stream no. (Nu)	609	279	152	68	25	83	5315	2449	1338	768	551	71	99
Bifurcation ratio (Rb)	-	2.18	1.83	2.23	1.30	0.30	-	2.17	1.83	1.74	1.39	7.76	0.71
Mean bifurcation ratio (Rbm)	1.56						2.6						
Stream length (Lu) in km.	1559	790	350	154	62	194	12396	6595	3463	1756	1327	162	216
Mean stream length (Lum)	2.55	2.83	2.30	2.26	2.48	2.33	2.33	2.69	2.59	2.29	2.41	2.28	2.18
Stream length ratio (Rl)	-	0.90	1.23	1.01	0.91	1.06	-	0.86	1.04	1.13	0.95	1.06	1.04

plate motions and regional geotectonic etc. (Arogyaswamy, 1971; Agarwal and Bhoj, 1992). Recently, Kosi has left its westward extension and flow directly through north-south extension, from Himalayan foothills to Ganga confluence. Whereas, plateau-fringe Kangsabati basin is located in Archaean Gneissic and Schistose terrain. It flows through the semi-arid region of Chotanagpur plateau and receives water from rainfall only. Most of the times, it remains dry (Gayen et al., 2013).

Linear aspects of river basin morphometry

Stream order (Nμ): It is treated as first step of morphometric analysis (Strahler 1952). The smallest tributaries of upper reaches of any basin are named as 1st order streams. The 2nd order of stream forms when two 1st order stream join (Magesh and Chandrasekar, 2014). This stream order depends on basin shape, size and relief characteristics of such basin (Haghipour and Burg, 2014). The total number of streams of Kosi basin are 10591 of which 5315, 2449, 1338, 768, 551, 71, and 99 streams belongs to 1st, 2nd, 3rd, 4th, 5th, 6th, and 7th order respectively (Table 2) (Figure 3). Lower order streams are in higher number due to its mountaineous origin. In general, the number of streams decreases as stream order increase. Kosi enters in north Indian plain after covering Himalayan course. There is sudden decrease in 3rd and 4th order of streams due to this sudden change of slope characteristics. High number of lower order streams (1st, 2nd and 3rd order) increase water receiving amount, which ultimately creates huge water flux on higher order streams (5th, 6th order). On the other hand, Kangsabati basin has total 1216 no. of streams of which 609, 279, 152, 68, 25 and 83 no. of streams belongs to 1st, 2nd, 3rd, 4th, 5th and 6th order respectively (Table 2) (Figure 3). The 1st, 2nd and 3rd order of streams of Kangsabati basin, show less number due to its origin from a matured dissected plateau region. Higher order streams (4th, 5th, 6th order) are less in number due to its plain course. Kangsabati region faces low water pressure or most of times deficient water in its lower reaches due less no. of lower order streams, as well as low water receiving from rainfall.

Bifurcation ratio (Rb): This parameter is defined as the ratio of stream segments of an order to its next higher order. It is considered an important parameter denoting the flood potentiality of any basin. The value normally ranges between 2 to 5 (Joji et al., 2013). High bifurcation value of 1st and 2nd order streams indicate its origin from higher altitude. Less Rb reflects less distorted drainage network and structurally mature condition (Kim and Jung, 2015). The bifurcation ratio for different order of streams in Kosi

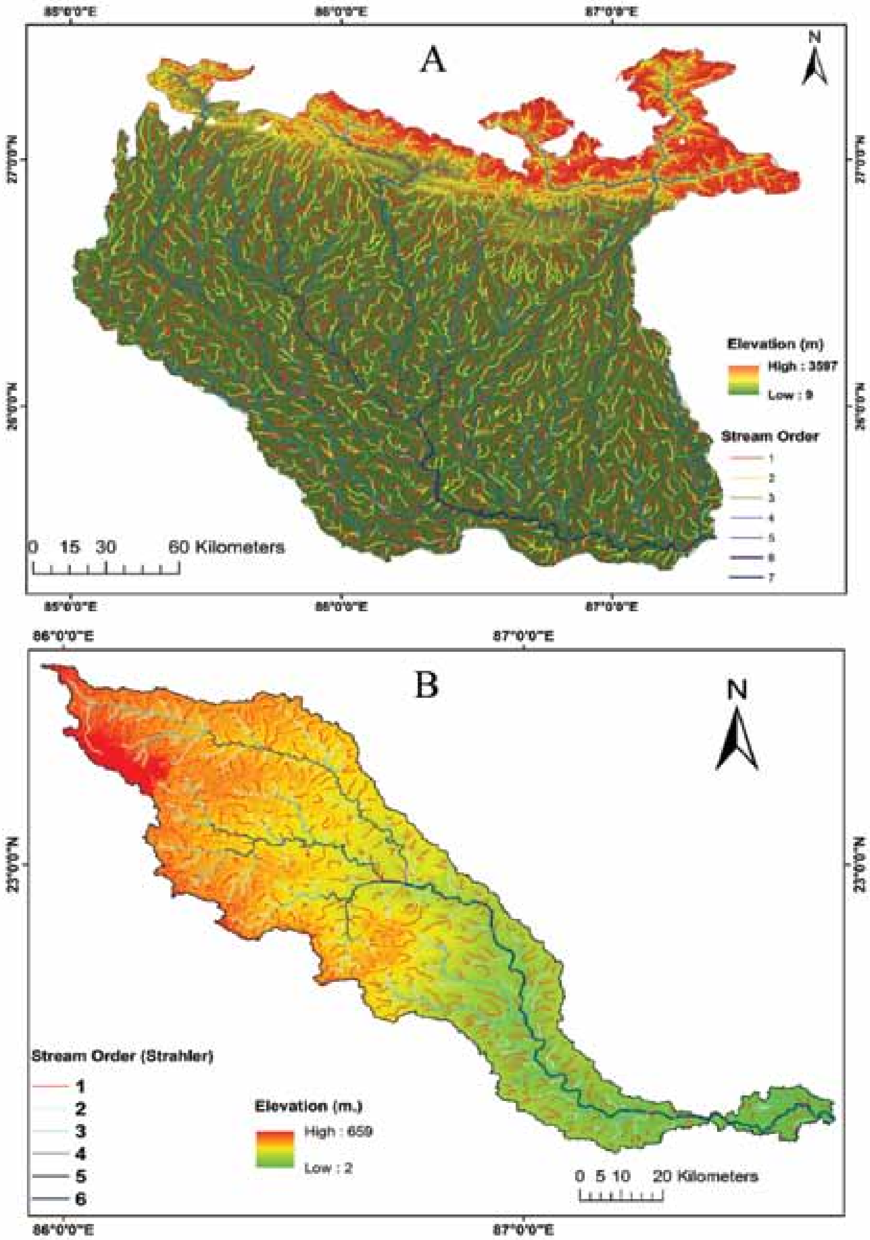

Figure 3. Linear aspect of river basin morphometry. A: Kosi, B: Kangsabati

basin is 2.17 for 1st to 2nd, 1.83 for 2nd to 3rd, 1.74 for 3rd to 4th, 1.39 for 4th to 5th, 7.76 for 5th to 6th, 0.71 for 6th to 7th respectively (Table 2). These values are indicative of inconsistency in structral characteristics. The irregularities are due to geological and lithological discrepancies of the basin. Hence, high bifurcation ratio in higher order streams represent large amount of water collectivity. But, less number of streams available in lower reaches indicates low water carrying capacity. These are supported by its mean bifurcation value which is 2.60. All these ultimately causes heavy flood potentiality in Kosi basin. Whereas, in Kangsabati basin, the bifurcation values are 2.18 for 1st to 2nd, 1.83 for 2nd to 3rd, 2.23 for 3rd to 4th, 1.30 for 4th to 5th and 0.30 for 5th to 6th order stream (Table 2). All these are indicative of its existance in geomorphologically mature area. A constant decrease of Rb throughout the different stream order as well as low mean Rb (1.56) indicates low flood potentiality for the basin.

Stream length (Lu): It is indicative of successive stages of development of stream segments (Castillo et al., 1988). A direct geometric sequence can be approximated from different order stream lengths. The stream length for different stream orders of the present basin is 1st (12396 km), 2nd (6595 km), 3rd (3463 km), 4th (1756 km), 5th (1327 km), 6th (162 km), and 7th order (216 km) (Table 2). The inconsistency of stream length between 6th and

Table 3. Areal morphometric aspect of river basins

Areal aspect	Kosi basin	Kangsabati basin
Basin perimeter (P) (km)	1392	736
Basin area (A) (km^2)	38689	7073
Form factor (Ff)	0.45	0.12
Circularity ratio (Rc)	0.26	0.16
Elongation ratio (Re)	1.52	1.00
Compactness constant (Cc)	2.00	2.46
Constant of channel maintenance (CCM)	1.49	2.27
Stream frequency (Sf)	0.27	0.17
Drainage density (Dd)	0.67	0.43
Texture ratio (Rt)	7.60	1.65

7th order indicates irregularities in basin characteristics. This is also indicative of lithological control on drainage basin. For Kangsabati basin, these are- 1st (1559 km), 2nd (790 km), 3rd (350 km), 4th (154 km), 5th (62 km) and 6th (194Km) (Table 2). The sequence of stream lengths for Kangsabati basin indicates its mature stage of geomorphological evolution.

Mean stream length (Lum): It indicates the characteristic size of drainage network component, which is an important dimensionless component of linear morphometric characteristics. Lum increases with increasing order_of streams in general (Haghipour and Burg, 2014). Table 2 shows the mean stream length of Kosi basin in 1st order (2.33 km), 2nd (2.69 km), 3rd (2.59 km), 4th (2.29 km), 5th (2.41 km), 6th (2.28 km), to 7th order (2.18 km). It indicates youth or rejuvenated stage of geomorphic development. The anomalies are suggesting slope changes and changes in the geological setup, which in turn denotes abrupt changes in flow characteristics. This has also bearing on discrepancies of surface flow discharge and sedimentation. Similarly, the mean stream length for Kangsabati basin are 2.55 km in 1st, 2.83 km in 2nd, 2.30 km in 3rd, 2.26 km in 4th , 2.48 km in 5th and 2.33 km in 6th order respectively (Table 2). The Lum values are more or less similar for plain and plateau areas.

Stream length ratio (Rl): This parameter is an important indicator of surface flow, and discharge characteristics of the basin. It is the ratio between mean stream lengths of one order to the next higher order. Generally, it tends to be similar throughout the different stream orders. The stream length ratio of Kosi basin starts with 0.86 for 1st to 2nd order, 1.04 for 2nd to 3rd order, 1.13 for 3rd to 4th order, 0.95 for 4th to 5th order, 1.06 for 5th to 6th order, and 1.04 for 6th to 7th order (Table 2). The changes in stream length ratio denote that the area is in early stage of geomorphic development and the area have high potentiality of frequent changes in future. Whereas for Kangsabati basin, the Rl is 0.90 for 1st to 2nd, 1.23 for 2nd to 3rd, 1.01 for 3rd to 4th, 0.91 for 4th to 5th and 1.06 for 5th to 6th order of streams respectively. The Rl is more constant in plateau areas (Kangsabati basin) than the plain areas (Kosi basin).

Areal aspects of river basin morphometry

Stream frequency (Sf): It is the number of streams presents in per unit area. It provides drainage basin response to runoff processes. Stream frequency depends on the rainfall, relief, initial resistivity of rocks as well as drainage density of the basin. Lower value of Sf indicates poor drainage network (Thomas et al., 2010). Stream frequency of the Kosi basin is 0.27 (no./km^2), which can be categorized as a moderate stream frequency (Table 3). Such a lower stream frequency is the result of its plain course. Also, lower stream frequency of Kosi basin is the indicative of frequent flood due to its inability to drain the water from large basin. Whereas, the Sf for Kangsabati basin is very low (0.17). The granite-gneiss terrain of this plateau does not permit river to create higher stream frequency. Also semi-arid environment, low relative relief helps for lower Sf in Kangsabati basin.

Drainage density (Dd): This is defined as the ratio of stream length to the basin area. It ranges from 0.27 to 8 km/ km^2 (Joji et al., 2013). The capability of any basin to drains its excess water in monsoon season depends upon the drainage density of the region, which itself depends upon underlain geology, relief, geomorphology, climate and vegetation. In particular, high drainage density increase the water draining capacity of any region or vice-versa. The overall drainage density of Kosi basin is 0.67 (km/km^2), which is very low (Table 3). It shows a direct relationship between drainage frequency and drainage density. High drainage density is found in upper reaches of the basin (Figure 4). It is due to Himalayan location and related high relative relief. Very low drainage density is observed in lower reaches of the plain areas of the basin. Thus, higher

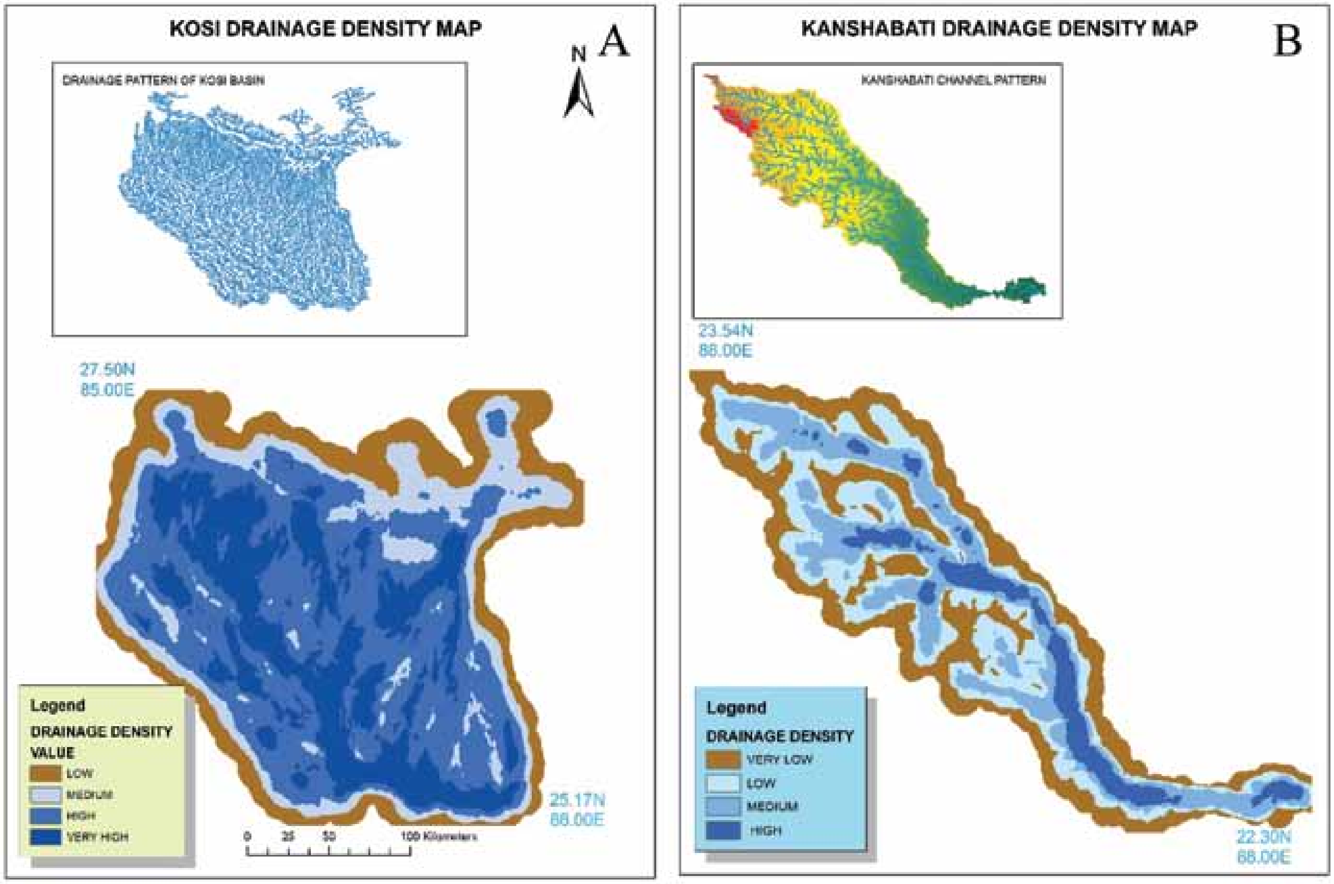

Figure 4. Drainage density characteristics of river basin. A: Kosi, B: Kangsabati.

runoff with greater flow velocity potentiality results into downstream flooding of the basin. Whereas, for Kangsabati basin, the overall Dd is 0.43, which is very low (Figure 4) (Table 3). As discussed earlier, the low relief, low drainage frequency, granite-gneiss geology as well as low vegetation cover and rainfall does not allow the river to increase drainage density. Low drainage density, as well as frequency, is indicative of low draining capacity and frequent flood.

Texture ratio (Rt): It is also an important fluvial parameter, which denotes the relative spacing of drainage network of any basin. It is the product of stream frequency and drainage density (Gayen et al., 2013). Collectively, drainage density and drainage frequency can be called drainage texture. It depends upon number of geological and geomorphological factors. The drainage texture of Kosi basin is 7.60, which indicates coarse drainage texture (Table 3). It is indicative of lower capacity of basin to drain the extra amount of water. Whereas, the Rt of Kangsabati basin is very low as 1.65. It is the result of its elongated basin characteristics, low stream frequency, Archaean geology as well as semi-humid environment.

Form factor (Ff): It is the ratio of the area of basin to the square of basin length, which the flow characteristics of a basin (Castillo et al., 1988). The value '0' indicates elongated characteristics of basin and '1' indicates near circular characteristics of basin, with high peak flow. Flood flows of elongated basin can be easily managed than that of circular basin. The Ff value of Kosi basin is 0.45, which indicates the basin is near circular (Table 3). It also indicates higher peak flow in limited times. Large basin area, with near circular shape and low drainage density, helps Kosi to become an important flood-prone basin in India. Whereas, the Ff value of Kangsabati basin is 0.12. It indicates an elongated shape with less peak flow. Comparatively, small basin area, low rainfall and elongated shape of Kangsabati basin results in low frequency of flood.

Elongation ratio (Re): It is referred as the ratio of diameter of a circle having the same area as of the basin to the maximum basin length (Gayen et al., 2013). It provides idea about the hydrological character of a drainage basin. The value '0' indicates its elongation characteristics, whereas '1' indicates near circularity. The Re value of the Kosi basin is 1.52, which denotes perfect circular characteristics of the basin (Table 3). Kosi have high flood potentiality due to its circular basin shape as well as large

Table 4. Relief morphometric aspects of river basins.

Relief Aspect	Kosi Basin	Kangsabati Basin
Absolute relief (R)	3597	659
Relative relief (H)	3588	657
Relief ratio (Rr)	0.012	0.0028
Dissection index (Di)	0.990	0.996
Ruggedness index (Ri)	2.40	0.282

catchment area. The Re value of Kangsabati basin is 1.00, which indicates its elongated characteristics. Small drainage catchment area and low amount of rainfall helps Kangsabati to become less flood-prone.

Circularity ratio (Rc): It is defined as the ratio of the area of drainage basin to the area of a circle, having the same perimeter as of basin (Joji et al., 2013). It is a dimensionless quantity. Higher circular basin will be affected by peak discharge in a high rainfall season. The Rc value is mainly concerned with the perimeter and total area of the basin, which ultimately depends upon underlain geology, relief, geomorphology, climatic and edaphic characteristics of the region. The Rc value of the Kosi basin is 0.25, which denotes high peak flood runoff in monsoon season (Table 3). The Rc value of Kangsabati basin is 0.16, which indicates elongated characteristics.

Compactness constant (Cc): It denotes the relationship of circular basin with that of its hydrological characteristics (Haghipour and Burg, 2014). It gives the value equal to unity, if watershed would is nearly circular. The Cc value of the Kosi basin is 2.00, which denotes the flooding potentiality (Table 3). For Kangsabati basin, the Cc value is 2.46.

Constant of channel maintenance (CCM): It refers to the required minimum area for the maintenance and development of a channel (Dutta and Roy, 2012). It denotes the basin area amount needed for a linear length of the channel. The CCM of the Kosi basin is 1.49 (Table 3). The value shows less channel availability to drain out the excess amount of water. In other words, excess area availability for channel maintenance creates flood situation. The CCM value for Kangsabati basin is 2.27, which indicates slight larger area available to feed a tributary than the Kosi basin. But low rainfall in Kangsabati basin does not create any flood situation.

Relief aspects of river basin morphometry

Basin relief (R, H): Absolute relief (R) and relative relief (H), are important parameters to understand evolutionary characteristics of a basin. For overall basin characteristics, relative relief is important (Gayen et al., 2013). Basin relief depends upon the underlying geology, geomorphology and dissection characteristics of the region. The highest relief of Kosi basin is 3597 m, which is found near Himalayan peak (Table 4). The relative relief is 3588 m., which seems very high for erosional activity. The H value of Kosi shows abrupt changes, when it enters into plain areas of Himalayan foothills whereas, Kangsabati flows through the plateau fringe region. The R and H value for Kangsabati is as lower as 659 and 657 respectively. Dissection hills, undulating plateau are the main landform features in upper reaches of Kangsabati basin. These types of landform increase some amount of relief undulation. But in lower reaches, it is almost flat.

Relief ratio (Rr): *It* denotes the ratio between total relief to the length of principle drainage line (Lindsay and Seibert, 2013). It indicates the overall steepness of the drainage basin and related degradation processes. The Rr of Kosi basin is 0.012, which falls under moderate category (Table 4). Rr is highest in its Himalayan reaches, but as it enters in plain areas, it decrease. The Rr value for Kangsabati basin is as low as 0.0028. Rr is low as it flows the plateau fringe region and enters into the extensive plain in lower reaches. The basin is also prone to waterlogging due to its low Rr value.

Dissection index (Di): It is the ratio between relative reliefs to its absolute relief. It indicates the vertical erosion and dissected characteristics of a basin (Haghipour and Burg, 2014). The stages of landform development of any basin or physiographic region can be accessed through Di. The value of Di ranges between

'0' (absence of vertical dissection) to '1' (Vertical areas). The Di value of Kosi basin is 0.99, which indicate its young or rejuvenated stage of geomorphic evolution (Table 4). It is also indicative of its further development. Whereas, the Di value of Kangsabati basin is around 0.99, which is not because of its young stage of evolution, but due to its greater plain land extension.

Ruggedness index (Ri): This parameter indicates the stages of landform development, as well as instability of the region or basin. The high value of Ri occurs when both drainage density and relative relief are high and slope is also steep (Ansari et al., 2012). This index depends upon underlying geology, geomorphology, slope, steepness, vegetation cover, climate etc. It is measured in consideration of relative relief and drainage density. High values of Ri denotes that the area is more youthful in respect of geomorphic evaluation or vice-versa. The high value of Ri (2.40) for Kosi basin indicates its youthful or

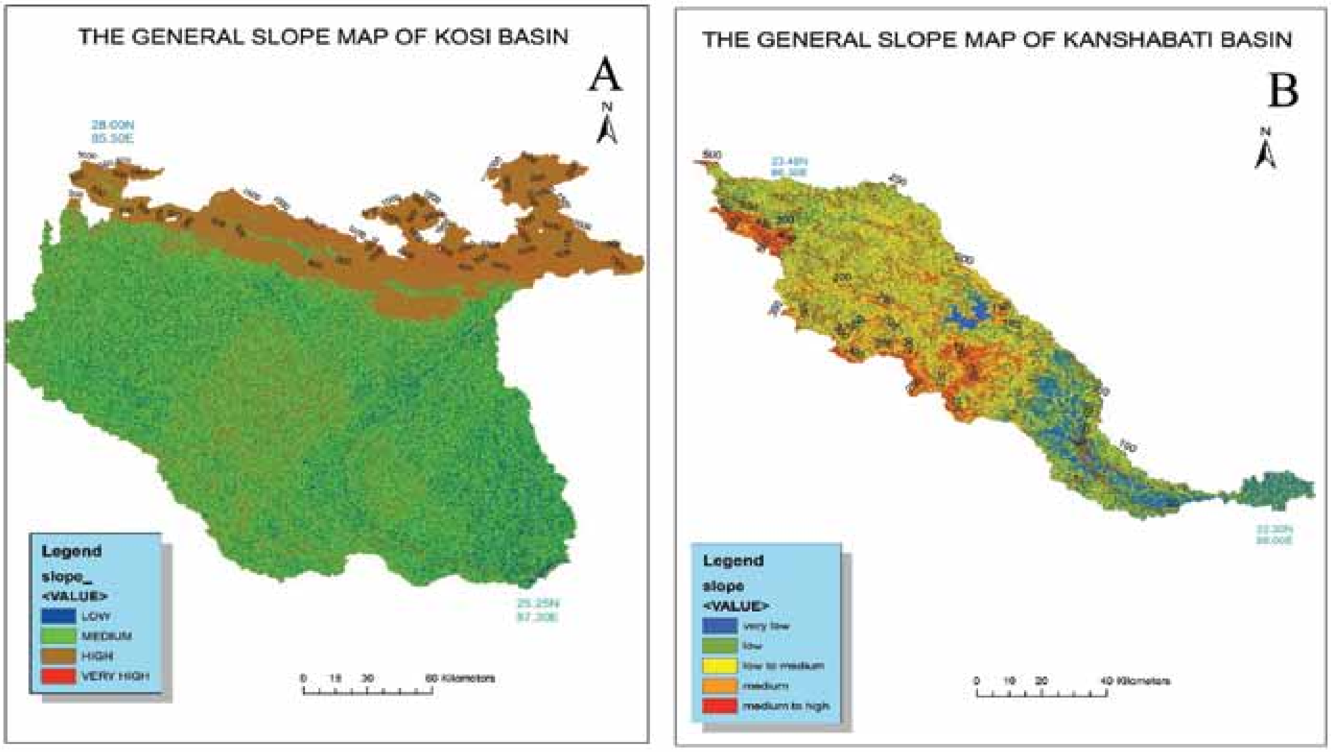

Figure 5. Channel gradient of river basin, A: Kosi, B: Kangsabati.

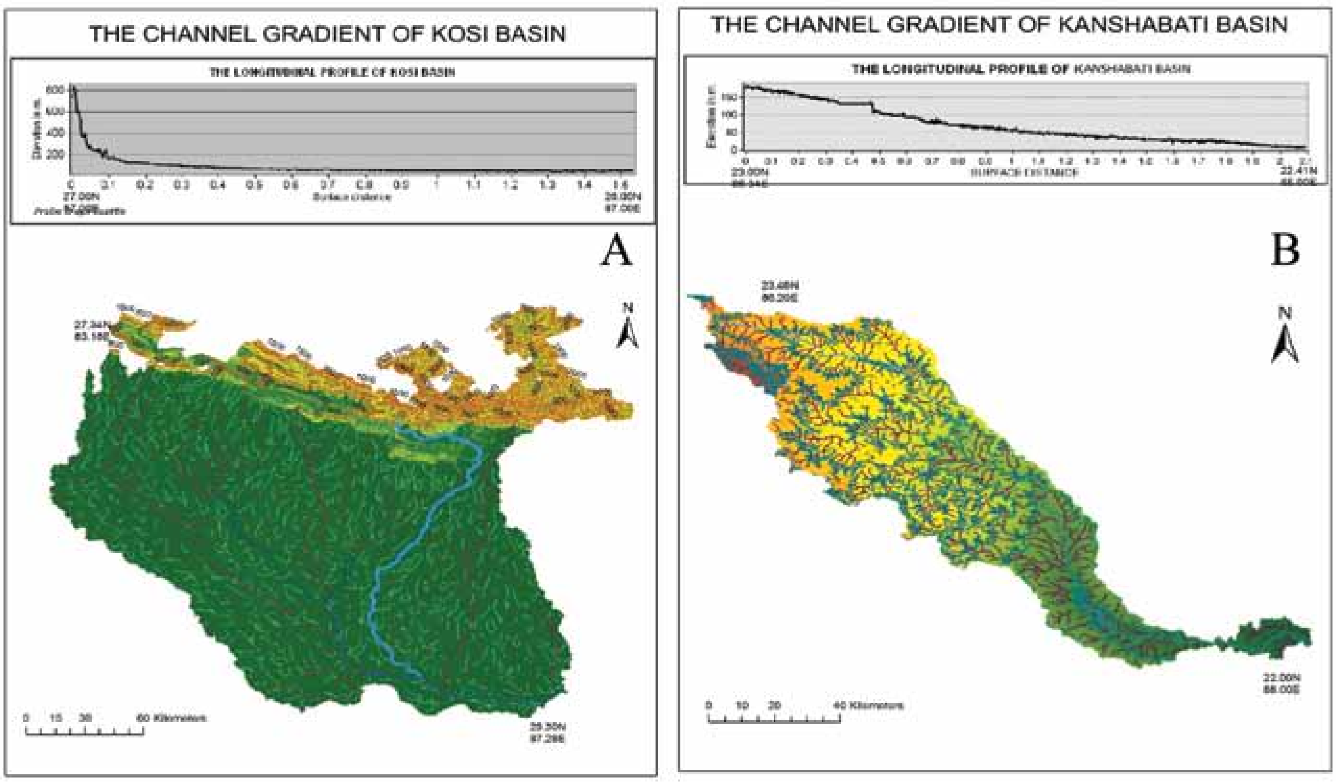

Figure 6. Slope map of river basin, A: Kosi, B: Kangsabati.

rejuvenated stage of basin development (Table 4). The Ri value of Kangsabati is as low as 0.282. After originating from the areas of eastern Chotanagpur plateau, Kangsabati flows through the dissected plateau fringe region in eastward direction. The area is covered by Precambrian gneiss and schists. From millions of years the area converted into a rolling plateau fringe through the erosion of different river and lay in the old stage of geomorphic development.

Channel gradient: This parameter is indicative of the stages of geomorphic evolution, as well as its potentiality for further erosion. The high channel gradient is seen in mountainous course of river and least in plain course of river. It is because of valley deepening is prominent in mountainous course and valley widening is extensive in plain course of river. The Kosi River is almost vertical from source region up to Himalayan foothill areas in its mountain course (Figure 5). Whereas, it is nearly horizontal from Himalayan foothills up to river mouth in its plain course. Such types of gradient characteristics have the potentiality of frequent flooding and consequent embankments failure. Whereas, Kangsabati River, which flows through the plateau fringe, indicates constant slope characteristics in upper reaches of the basin and near flat in lower reaches (Figure 5). As Kangsabati is the representative of mature plateau fringe region, its slope is more or less constant throughout the reaches.

Slope characteristics of any basin represent its overall geomorphic condition. The very high slope (>40^{o}) dominated in the upper reaches of Kosi basin is the true representative primary geomorphic evolution (Figure 6). But slope dramatically decreases as Kosi enters in foothill plain areas. This phenomenon indicates that Kosi high potentiality for further geomorphic development. Whereas for Kangsabati the slope is more or less low (< 10^{o}) throughout the basin indicating low potentiality for further development (Figure 6).

CONCLUSION

The present study is primarily conducted to trace out the morphometric characteristics of two different morpho-climatic settings. From the present study, it can be inferred that different morphometric parameters of any basin are the best representative of geology, geomorphology, relief, slope, climate etc. It is also indicative of the stages of geomorphic evolution of any area. Kosi basin which is representative of the mountain-plain area of tropical environment, has highest number stream order (up to 7th order) related with high amount of water discharge and low-velocity flow, indicating that the basin is highly susceptible to flooding. Rapid decline of bifurcation ratio with increasing order, bears the indication of high susceptible flooding. An anomaly in bifurcation ratio between 6th and 7th order streams, brings strong assumption of current topographic development. The irregular changes of stream length of Kosi river further indicates changes in topography which in turn indicates the younger or rejuvenated stage of Kosi basin development. Whereas, Kangsabati basin which is representative of the plateau-plain region of tropical environment, has low number of stream order and related lower susceptibility to flooding. Less decline of bifurcation ratio, with increasing stream order is indicative of semi-dry region of tropical environment. The mean bifurcation ratio of plateau-plain region of Kangsabati basin is also indicative of low flood susceptible region. The mean stream length and regular changes of stream length ratio are also indicative of mature stages of plateau fringe development.

The calculated value of low drainage density (0.67 km/km^2), low stream frequency (0.27/km^2), and moderate drainage texture (7.60) of Kosi basin indicates the basin has very low relief (plain areas), and low water carrying capacity. All these lead to high overland flow and flood situation. The form factor (0.45), circularity ratio (0.26), elongation ratio (1.52), indicates that the basin is near circular, suggesting it has high flood potentiality and related embankment failure due its large water catchment area. Whereas, very low drainage density (0.43 km/km2), low stream frequency (0.17/km^2) and low texture ratio (1.65) indicates the basin has very mature relief and less water availability about its carrying capacity in Kangsabati basin of plateau fringe region. The form factor (0.12), circularity ratio (0.16), elongation ratio (1.00) indicates the basin is elongated, which is more common in undulating plateau fringe region. The compactness constant (2.46) and constant of channel maintenance (2.27) also supports this view.

The values of relative relief (3588 m.), dissection index (0.990), and ruggedness index (2.40) of mountain-plain flowing Kosi basin indicates the basin is in primary or rejuvenated stages of geomorphic development. The geomorphic and hydrological instability will be more common in future. Whereas in Kangsabati basin, the values of relative relief (657 m.), dissection index (0.996) and ruggedness index (0.282), are indicative of mature stages of geomorphic development.

It can also be concluded that the characteristics of an area regarding its physical (geology, geomorphology, relief, slope), climatological (rainfall, temperature), biological (forest characteristics), can be better accessed through the different morphometric parameters of the basin. These morphometric parameters are the result of aforesaid factors. Remote sensing and GIS can play a significant role in accessing these characteristics. The result can be better utilise for planning and construction purpose.

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Compliance with Ethical Standards

The author declares that he has no conflict of interest and adheres to copyright norms.

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