Determination of Stages of Evolution: A Comparative Study of Mountain-Plain (Kosi, Bihar) and Plateau-plain (Kangsabati, WB) Regions of Tropical India

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***Abstract*- The major aim of quantitative geomorphology is to understand the geomorphological stages of evolution of any area. This trend has more intensified after quantitative revolution and development of remote sensing and GIS. Morphometric analysis is an important indicator to understand the geomorphic stages of evolution of any drainage basin. In this study morphometric analysis has been carried out to compare the drainage basin characteristics and related stages of evolution of a mountain-plain and plateau-plain drainage basin of tropical India. The Kosi basin for mountain-plain area and Kangsabati basin for plateau-plain area has been selected for present study. Different drainage morphometric parameters and measurements related to linear, areal, relief characteristics have been determined through the use of SRTM (Shuttle Radar Topographic Mission) GeoDEM and ARC GIS 10.1. Area-altitude relationship, as well as hypsometric characteristics, have been accessed in this work to identify the stages of geomorphic evolution. All the relief characteristics indicate Kosi is in young or rejuvenated stage than mature plateau region river of Kangsabati. Most of the morphometric characteristics indicate there are high geologic and geomorphological controls on river basin characteristics.**

***Keywords*- Quantitative geomorphology, Geomorphological stages of evolution, Morphometric analysis, Tropical India, Kosi Basin, Kangsabati basin, Area-altitude relationship, Hypsometric characteristics, Geomorphological control.**

I. Introduction

The major paradigm shift after Second World War was the development of statistical and quantitative geomorphology. Analysis of interrelationship between forms and processes in different spatial and temporal scale is a major thrust. Erosion and deposition of connected stream network produced different fluvial landforms as per 'Strahler' (Joji, et al., 2013). Morphology, hydrology and evolutionary history of any basin can be best understood through different mathematical morphometric characteristics of such basin (Sharma and Sarma, 2013). The basin size, shape, dimension can be evaluated through different morphometric indicators. The relationship between various drainage parameters and its underlain geology, geomorphology, hydrology and structure had been well established through the work of different geologist and geomorphologist (Strahler, 2012). Different hydrological behaviour (peak flow, flood) of any basin can be understood through different morphometric indicators. Among the different morphometric characteristics- 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 important. It provides enormous idea to identify the morphological evolution and stages of development of any basin.

The remote sensing and GIS toll is important to measures the morphometric characteristics as well as to understand the evolutionary stages of any basin. Recently several workers have used remote sensing data and GIS on morphometric parameters and have concluded that remote sensing has emerged as a powerful tool in analyzing the drainage morphometric characteristics (Nag and Lahiri, 2012; Ansari, et al., 2012; Magesh and Chandrasekar, 2014).

The Basin of Kosi and Kangsabati has been taken for present study (Fig. 1). Kangsabati is an area under eastern Chotanagpur plateau which is more or less stable. After originating from 'Ajodhya hill' of eastern Chotanagpur plateau, it flows through the plateau fringe regions of West Bengal in eastward direction (Nag and Lahiri, 2012). Different geomorphic characteristics of Kangsabati indicates that the basin is in mature stage of geomorphic development (Pan, 2013; Dutta and Roy, 2012).The basin is also less flood-prone due to its elongated areal characteristics (Gayen et al., 2013). Whereas, Kosi basin is an area of neo-tectonic upliftment of Himalayan region. The frequent flood and rapid avulsion changes is a well-known fact about Kosi (Sinha, 2009). The River is also known as 'Sorrow of Bihar'. Kosi

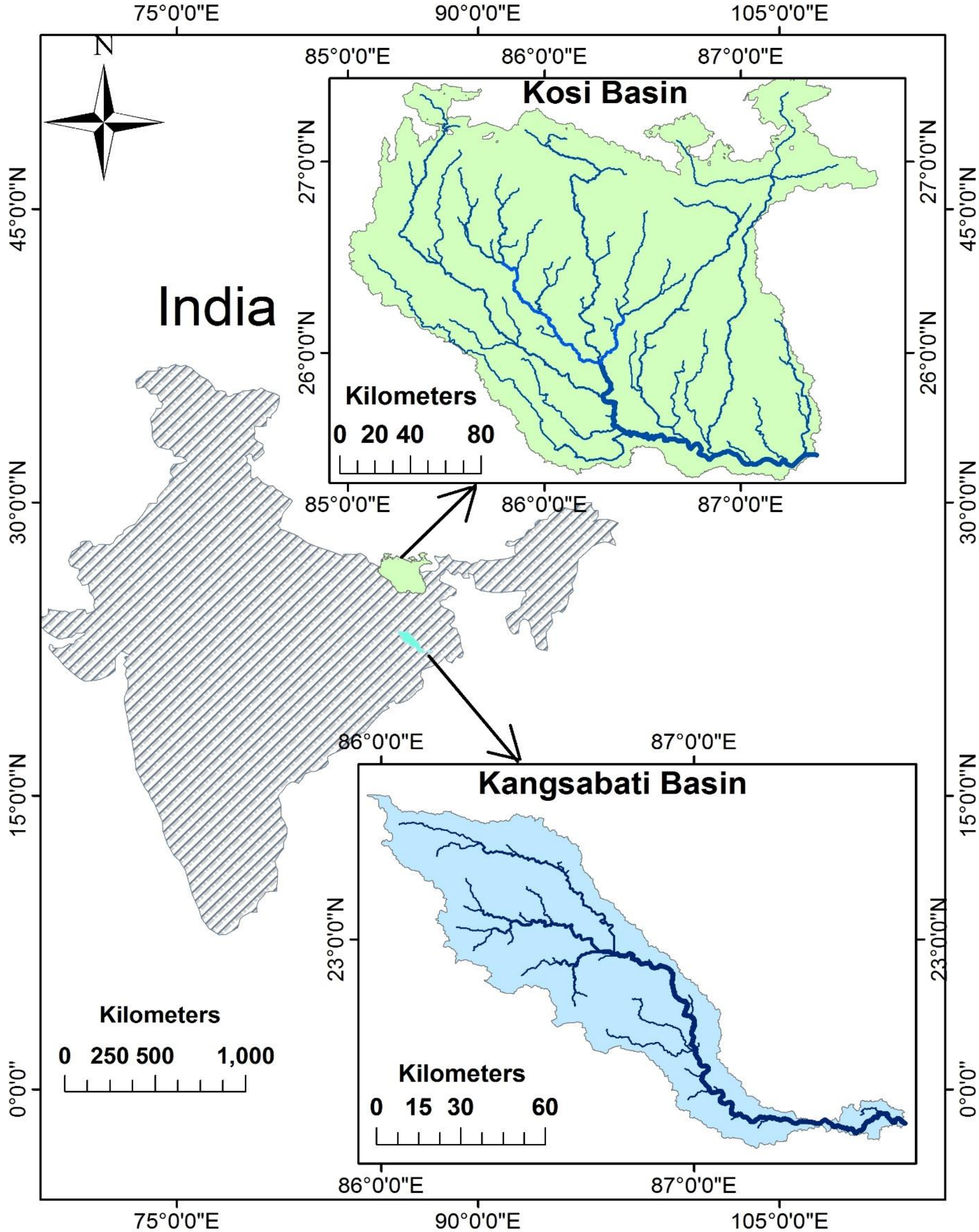

Figure 1: Location map of Kosi and Kangsabati

enters Bhimnagar after crossing Nepal Himalaya. Then it joins Ganga near Kursela after flowing 320km in northern Bihar. Kosi is also an example of inland delta building agent (Gole and Chitale, 1966). Kosi changed its main course eastward around 100 km. through the major avulsion process in August 2008 (Sinha et al., 2008). Kosi had abandoned this path before 200 years ago. Though some geomorphologist called this flood of August 2008 as human disaster (Shrestha et al., 2010).

The present study mainly aims to understand the evolutionary stages of development for two different morpho-climatic settings namely Kosi river basin for mountain-plain region and Kangsabati river basin for plateau-plain region. As yet, no detailed work on the comparison of morphometric Characteristics as well as evolutionary stages of development for this two area has so far been carried out. The study also aims to understand the geologic, geomorphic, hydrologic influence on basin morphometry and construct the geomorphic evaluation stage of this two different morpho-climatic setting.

II. Materials and Methods

The measurement of basin morphometry through remote sensing and GIS techniques followed by interpretation are the broad methodology for present study. To fulfil the above-stated objective 'SRTM-GDEM' (30 m.) data has been used for river morphometric analysis followed by construction of longitudinal profile. The different basin morphometric parameters have been accessed through remote sensing techniques (Table 1) (Fig. 2). Like, 1. Linear aspect (stream order, bifurcation ratio, mean bifurcation ratio, stream length, mean stream length, stream length ratio) 2. Areal aspect (stream frequency, drainage density, texture ratio, form factor, circularity ratio, elongation ratio) 3.Relief Aspect (Relative Relief, Relief Ratio, Dissection Index, Ruggedness Index).

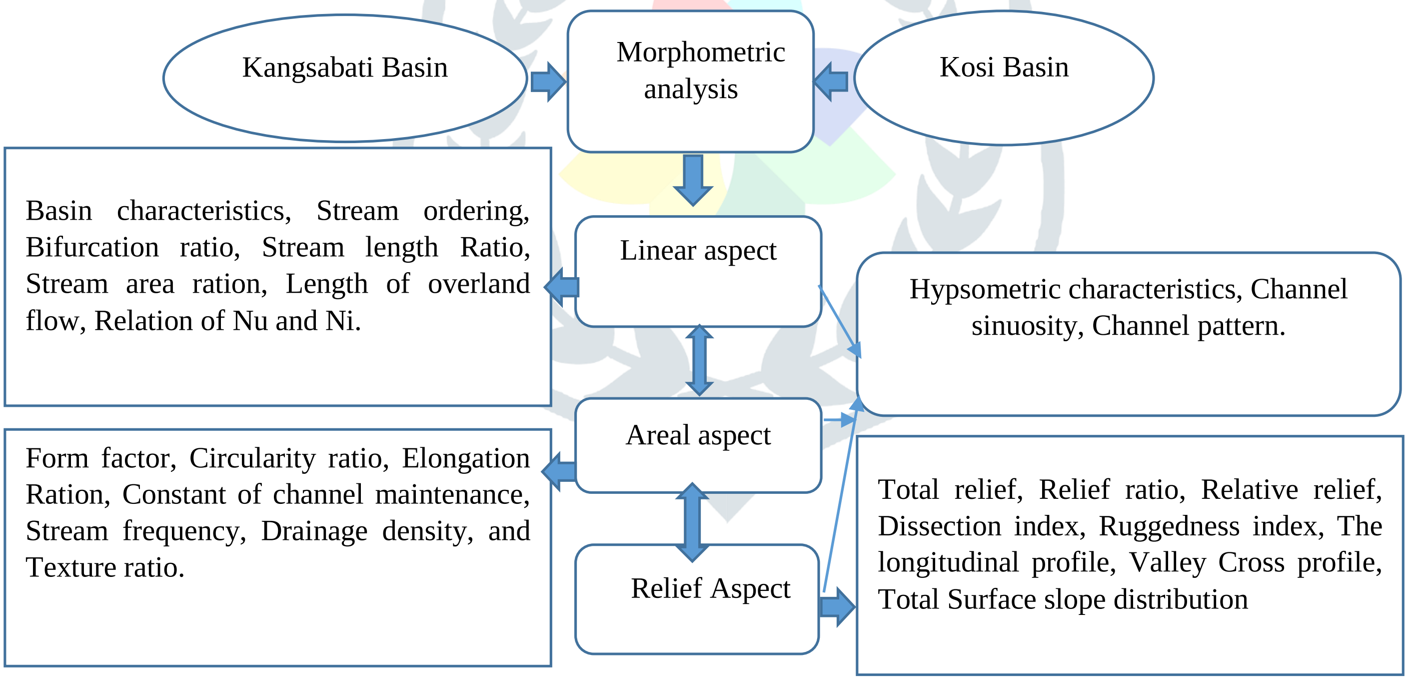

Figure 2: Flow diagram of methodology

III. Results and Discussion

Both Himalayan glaciers and precipitation deeply influence the hydrology of Kosi River. The Kosi is highly notorious due to its high sediment load and migratory trends with antecedent river characteristics. The failure of Kosi embankment and recent changes in avulsion characteristics of Kosi basin can be interpreted through the local geological adjustment, plate motions, geotectonic etc. (Arogyaswamy, 1971; Agarwal and Bhoj, 1992). Recently, Kosi has left its westward extension and flow through direct north-south extension from Himalayan foothills up to Ganga confluence. Whereas, Kangsabati river receives water from rainfall only. It flows through the semi-arid region of Chotanagpur plateau. And most of the times it remains dry (Gayen, et al., 2013).

Morphometric analysis is a useful tool to understand the hydrological behaviour of any Basin (Castillo, et al., 1988; Thomas, et al., 2010). It is useful for geology, structure, geomorphology, and prevailing climate understanding (Sharm and Sharma, 2013). Hydro sedimentary characteristics are determined by basin characteristics (Raux, et al., 2011). The present study aims to trace out the different morphometric parameters in plain and plateau fringe settings. Geologically Kosi Bain area comes under Indo-Gangetic plain and Kangsabati basin comes under Archean Gneiss and Schist.

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)	Highest 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.

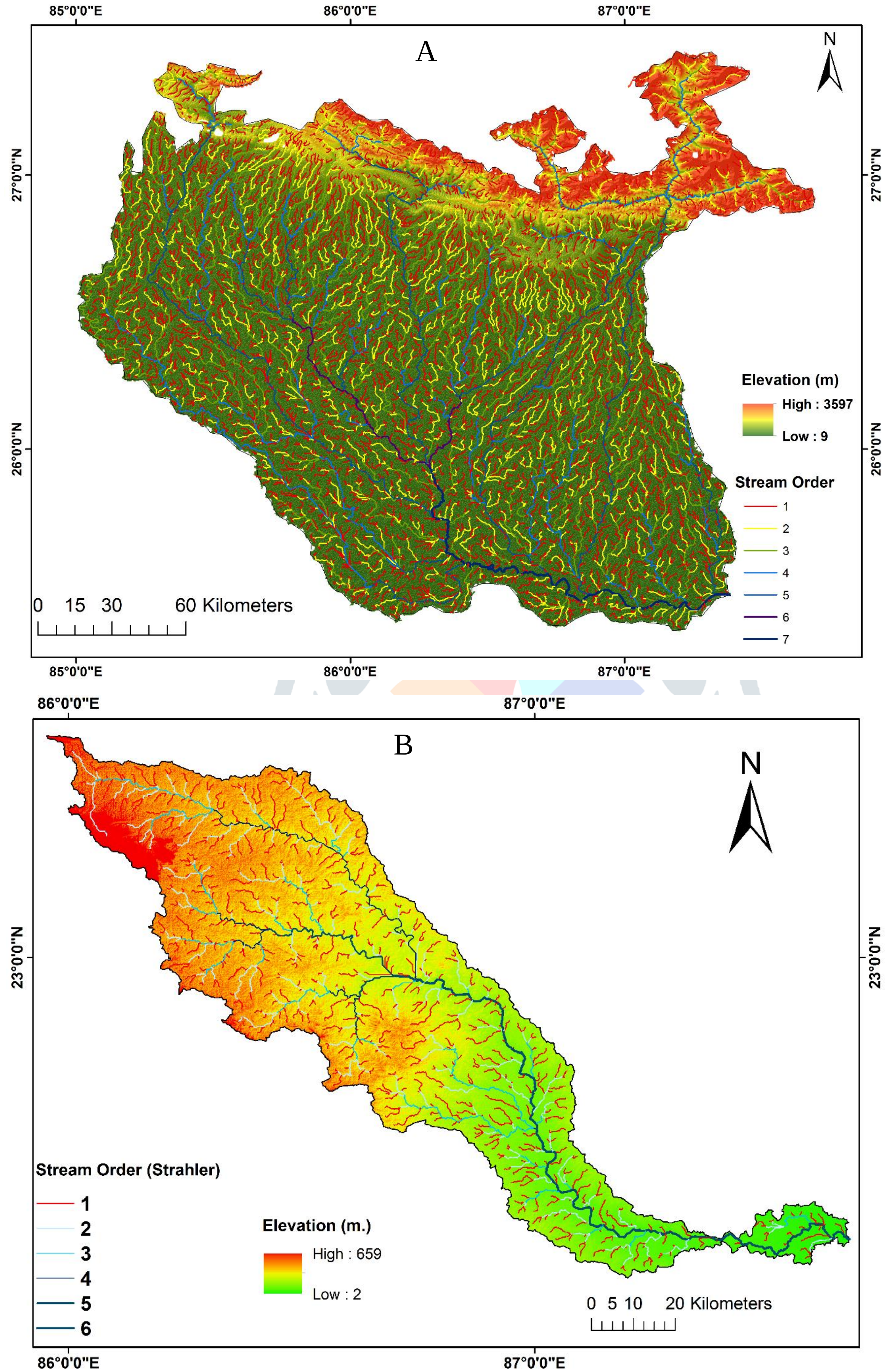

Figure 3: Linear aspect of River basin morphometry a. Kosi b. Kangsabati

III.a Linear aspects of River basin morphometry

Stream order (Nμ) designated as first step of morphometric analysis introduced by 'Strahler' in 1952. The smallest tributaries of upper reaches of any basin are named as 1st order streams. A 2nd order of stream forms when two 1st order stream join (Magesh and Chandrasekar, 2014). The 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) (Fig. 3). The 1st and 2nd order of streams in Kosi basin shows higher number due to its mountain origin. The number of streams decreases as order increases. After Himalayan course (upper reaches), Kosi enters plain area in North Indian plain. 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, 3rd order) increase water receiving amount which ultimately creates pressure on higher order streams (5th, 6th order). The total number of streams of Kangsabati basin is 1216 of which 609, 279, 152, 68, 25 and 83 streams belongs to 1st, 2nd, 3rd, 4th, 5th and 6th order streams respectively (Table 2) (Fig. 3). The 1st, 2nd and 3rd order of streams of Kangsabati basin show less number due to its origin from mature plateau dissected hill areas. The 4th and 6th order of streams shows less number due to its enter in plain areas. Higher order streams face less water pressure due to less number of lower order streams as well as its rainfed characteristics.

Table 2: Linear morphometric aspect of River basin

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) inkm.	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

Bifurcation ratio (Rb) is defined as the ratio of stream segments of an order to its next higher order. It is considered an important parameter which denotes the flood potentiality of any basin. It normally ranges between 2 to 5 (Joji, et al., 2013). High bifurcation value of 1st and 2nd order stream indicates origin from higher altitudes. 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 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 6th, 7.76 for 5th to 6th, 0.71 for 6th to 7th respectively (Table 2). These values indicate that the watershed does not fall under normal category. The irregularities are indicative of geological and lithological discrepancies of the basin. Hence, high bifurcation ratio in higher order streams represents large amount of water collectivity and high water flow. But very less number of streams available in lower reaches which denotes low water carrying capacity. These are supported by its mean bifurcation value which is 2.60. This ultimately causes heavy flood potentiality in Kosi Basin. Whereas, in Kangsabati basin 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). These values indicate watershed falls under geomorphologically mature areas. A constant decrease of Rb through out the different stream order, as well as low mean Rb (1.56), indicates low flood potentiality for the basin.

Stream length (Lu) 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 length. The stream length for different 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 7th order indicate irregularities in basin characteristics.

This 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 (194 km) (Table 2). Sequence of stream length for Kangsabati basin indicates its mature geomorphological condition.

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

Stream length ratio (Rl) is an important indicator of surface flow, erosional stage, and discharge characteristics of the basin. It is the ratio between mean stream lengths of one order to the next higher order. It tends to be similar throughout the different 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 plain area (Kosi basin).

III.b Areal aspects of River basin morphometry

Stream frequency (Sf) 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 rock, drainage density of the 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 plain area. 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 of Kangsabati basin is very low (0.17). The granite-gneiss geology dominated plateau course of river 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) is the ratio of stream length to the basin area. It is a key factor of draining in any area. It ranges from 0.27 to 8km/km^2 (Joji, et al., 2013). The capability of any basin to drains its excess water in monsoon season is depends upon the drainage density of such area. Drainage density itself depends upon underlain geology, relief, geomorphology, climate, vegetation etc. In particular high drainage density increases the draining capacity of any region and highly dissected characteristics and 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 found in upper reaches of the basin (Fig.4). It is due to Himalayan location and related high relative relief. Very low drainage density observed in lower reaches plain areas of the basin. Thus higher runoff with greater flow velocity resulting potentiality of downstream flooding of the basin. Whereas, for Knagsabati basin the overall Dd is 0.43 which is very low (Fig. 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 river to increase drainage density. Low drainage density, as well as frequency, is indicative of low draining capacity and frequent flood.

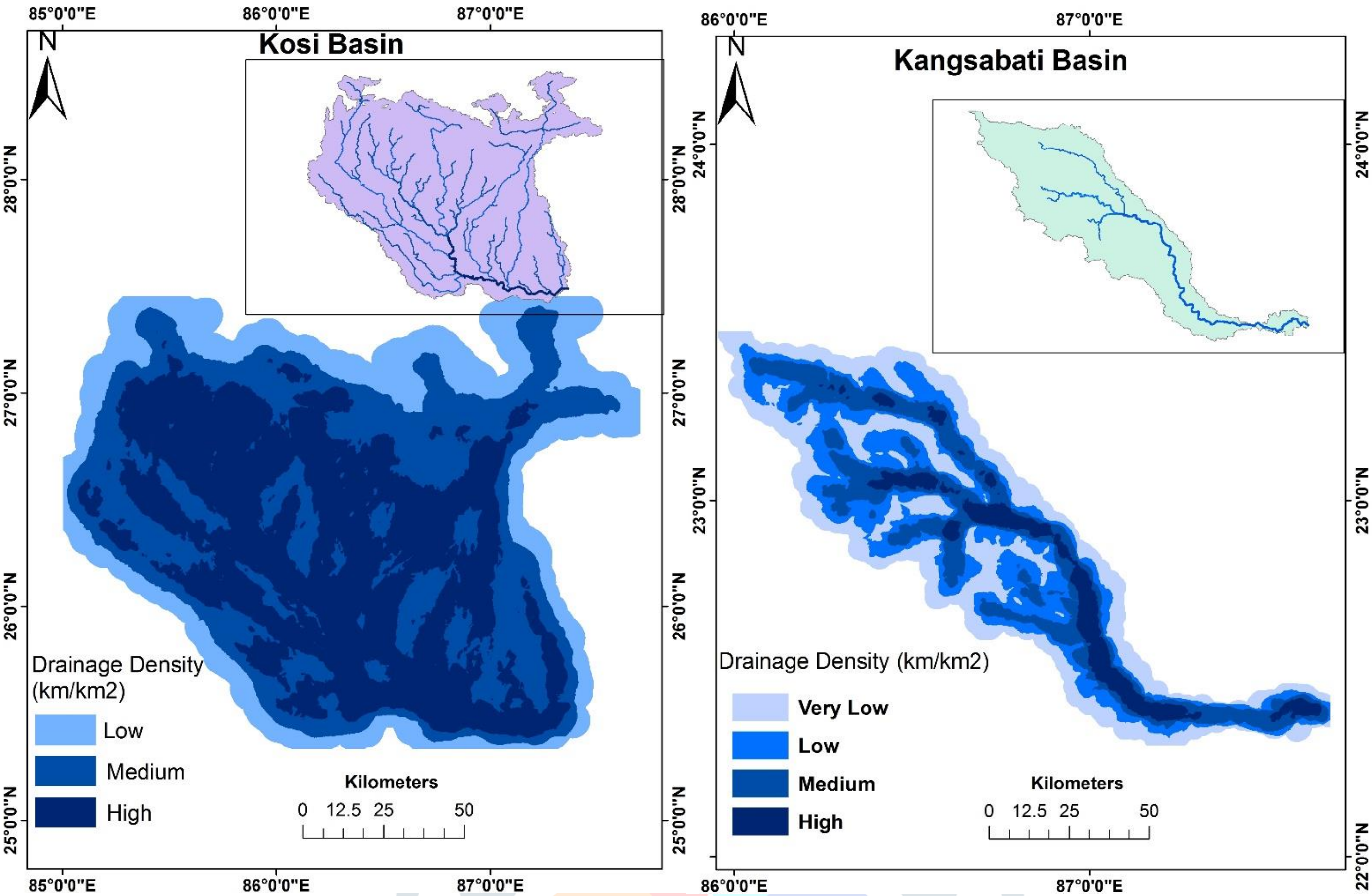

Figure 4: Drainage density characteristics Kosi and Kangsabati River basin

Table 3: Areal morphometric aspects of River basin

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

Texture ratio (Rt) 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, Archean geology as well as semi-humid environment.

Form factor (Ff) is the ratio of the area of basin to the square of basin length. It indicates the flow characteristics of a basin (Castillo, et al., 1988; Horton, 1932). 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 cause 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 less basin area, low rainfall, elongated shape of Kangsabati basin helps low frequency of flood.

Elongation ratio (Re) is the ratio of diameter of a circle having the same area as of basin to the maximum basin length. It is also a significant index of basin shape (Gayen, et al., 2013). It helps to give the idea about 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). Due to greater catchment area and low drainage frequency, circular basin has greater flood potentiality. The Re characteristics of Kosi basin reflects its flood potentiality. The Re value of Kangsabati basin is 1.00 which indicates its elongated characteristics. Less drainage catchment area and low amount of rainfall help Kangsabati to become less flood-prone.

Circularity ratio (Rc) is the ratio of area of drainage basin to the area of a circle having the same perimeter as of basin (Joji, et al., 2013). It is dimensionless and express outline of basin. Higher circular basin will affect by peak discharge in 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) 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 near to 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, or it indicates less compacted which ultimately help for low flood potentiality.

Constant of channel maintenance (CCM) is 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 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 which ultimately creates flood situation. The CCM value for Kangsabati basin is 2.27 which indicates slight large area available to feed a tributary than Kosi basin. But low rainfall in Kangsabati basin does not create any flood situation.

III.c Relief aspects of River basin morphometry

Basin relief (R, H) which includes absolute relief (R) and relative relief (H) is important parameters to understand basin evolutionary characteristics. For overall basin characteristics Relative relief is used (Gayen, et al., 2013). Basin relief depends upon the underlain geology, geomorphology and dissection characteristics of the region. The highest relief of Kosi basin is 3597 m. Which 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 in 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, occasional scrapes 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.

Table 4: Relief morphometric aspects of River basin

Relief ratio (Rr) denotes the ratio between total relief to the length of principle drainage line (Lindsay and Seibert, 2013).

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

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 decreases. The Rr value for Kangsabati basin is as low as 0.0028. Rr is such because Kangsabati flows through the plateau fringe region and enters into extensive plain. The basin is prone to waterlogging due to its low Rr value.

Dissection index (Di) 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 stage of geomorphic evolution (Table 4). It is also indicative of its further development. Whereas, the Di value of Kangsabati basin is also around nine not because of its young stage of evolution but due to its plain land extension. Kangsabati enters in more or less mature stage.

Ruggedness index (Ri) 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 large, and sloe is also steep (Ansari, et al., 2012; Chorley, et al., 1985). The Ruggedness index depends upon underlain geology, geomorphology, slope, steepness, vegetation cover, climate etc. of that region. It is measured in consideration of relative relief and drainage density. Higher the value of Ri more youthful the area is in physiographically or vice-versa. High value of Ri (2.40) for Kosi basin showing its youthful stage of basin development (Table 4). The Ri value of Kangsabati is as low as 0.282. After originating from plateau top areas of eastern Chotanagpur plateau, Kangsabati flows through the dissected plateau fringe region in eastward direction. The area is under the Precambrian gneiss and schist geology. From millions of years the area converted into a rolling plateau fringe through the erosion of different river and lay in old stage of geomorphic development.

Channel gradient indicates the stages of geomorphic evolution as well as its potentiality for further erosion. The greater channel gradient is seen in mountainous course of river and least in plain course of river. It is because of valley deepening is more 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. Whereas, it is near horizontal from Himalayan foothills up to river mouth. Such types of gradient characteristics have the potentiality of frequent flooding and consequent embankment failure. Whereas, Kangsabati River shows constant slope characteristics in upper reaches of the basin and near flat in lower reaches. 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 (>40º) dominated upper reaches of Kosi basin is the true representative of young geomorphic areas (Fig. 5). But slope dramatically decreases as Kosi enters in foothill plain areas. This phenomenon leads Kosi a high potentiality for further development. Whereas for Kangsabati the slope is more or less low (< 10º) throughout the basin indicates low potentiality for further development (Fig. 5).

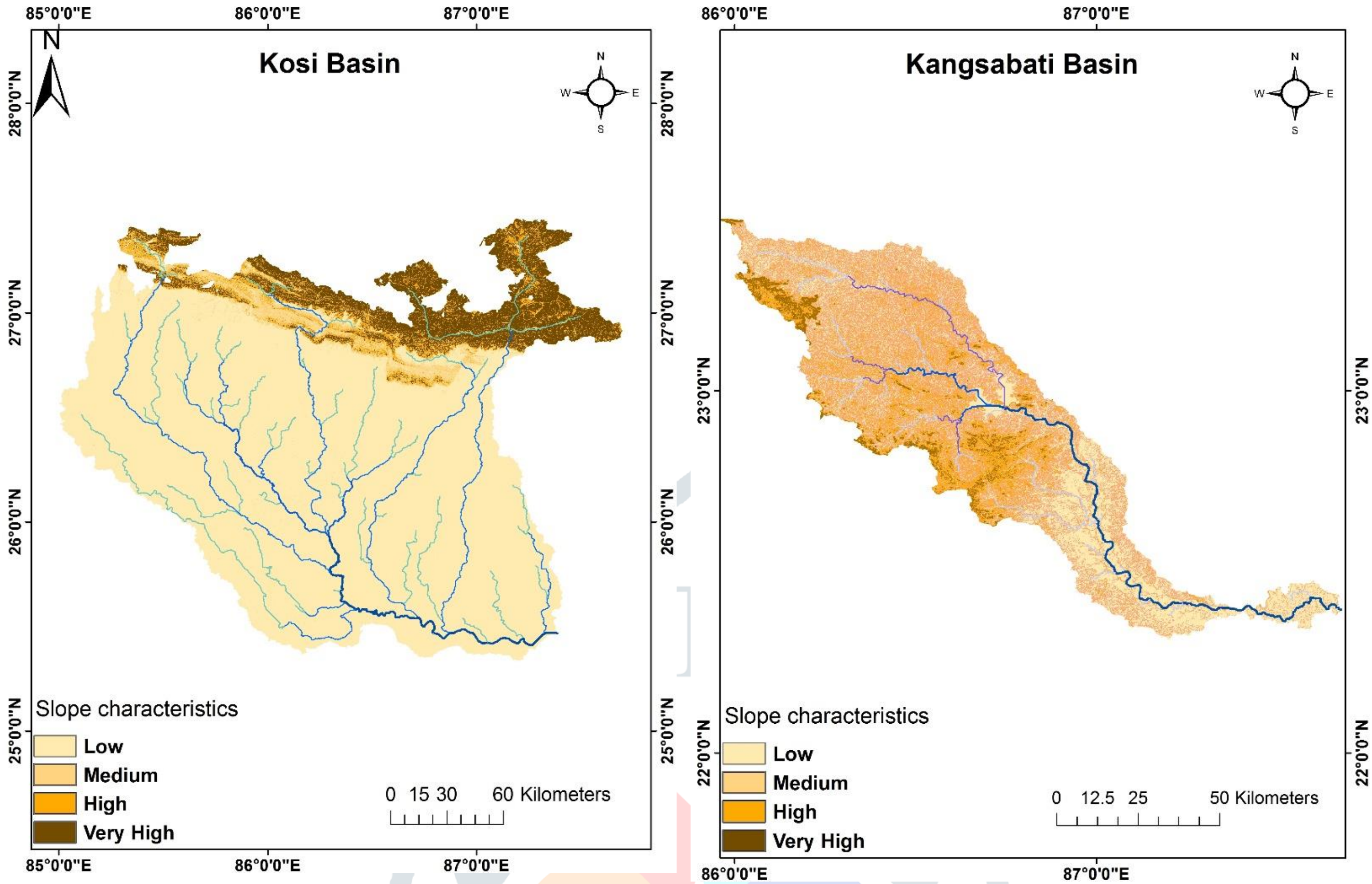

Figure 5: Slope map of Kosi and Kangsabati River basin

III.d Determination of geomorphic stages of development

Through the use of area-altitude relationship in general and hypsometric curve in particular, the geomorphic stages of erosional surface have been greater understanding. The hypsometric curve is expressive of youthful, mature and old topography through the assessing of different elevation zones along with corresponding areal coverage. Area-altitude relationship depicts that >70% of area of Kosi river basin falls under <100-meter elevation (Fig. 6). It indicates the basin belongs to mature stages of geomorphic evolution. But the Kosi River has experienced multicycle erosional surface due to its high mountain origin and frequent river course changes.

Area-altitude relationship for Kangsabati basin depicts the fact that major area coverage i.e. >65% area is under the elevation zones 300-100 m. which indicates the whole basin belongs to mature to senile topography (Fig. 7). Kangsabati river flows through the one of old plateau fringe region of tropical India, i.e. Chotanagpur plateau. Upper reaches of basin converted to dissected erosional plateau fringe region through the continuous erosion, whereas lower reaches are particular in sand deposition. As Kangsabati River flows through one of the most stable regions of India, so it did not experience any large upliftment in its geological history. As a result, Kangsabati River does not bear any evidence of multicyclic landforms.

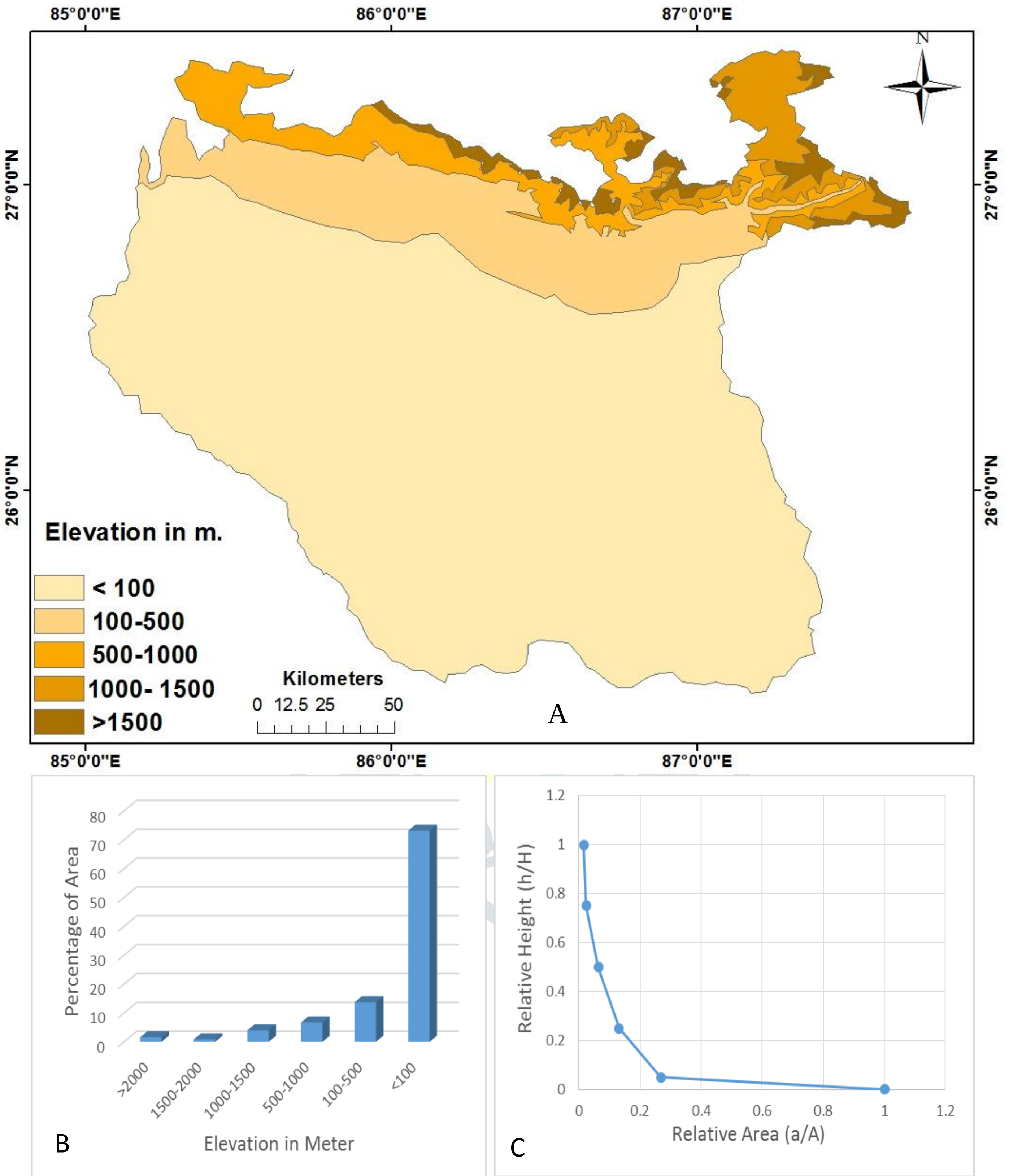

Figure 6: Hypsometric characteristics of Kosi River basin A. Absolute altitude map B. Area-height relationship C. Hypsometric curve.

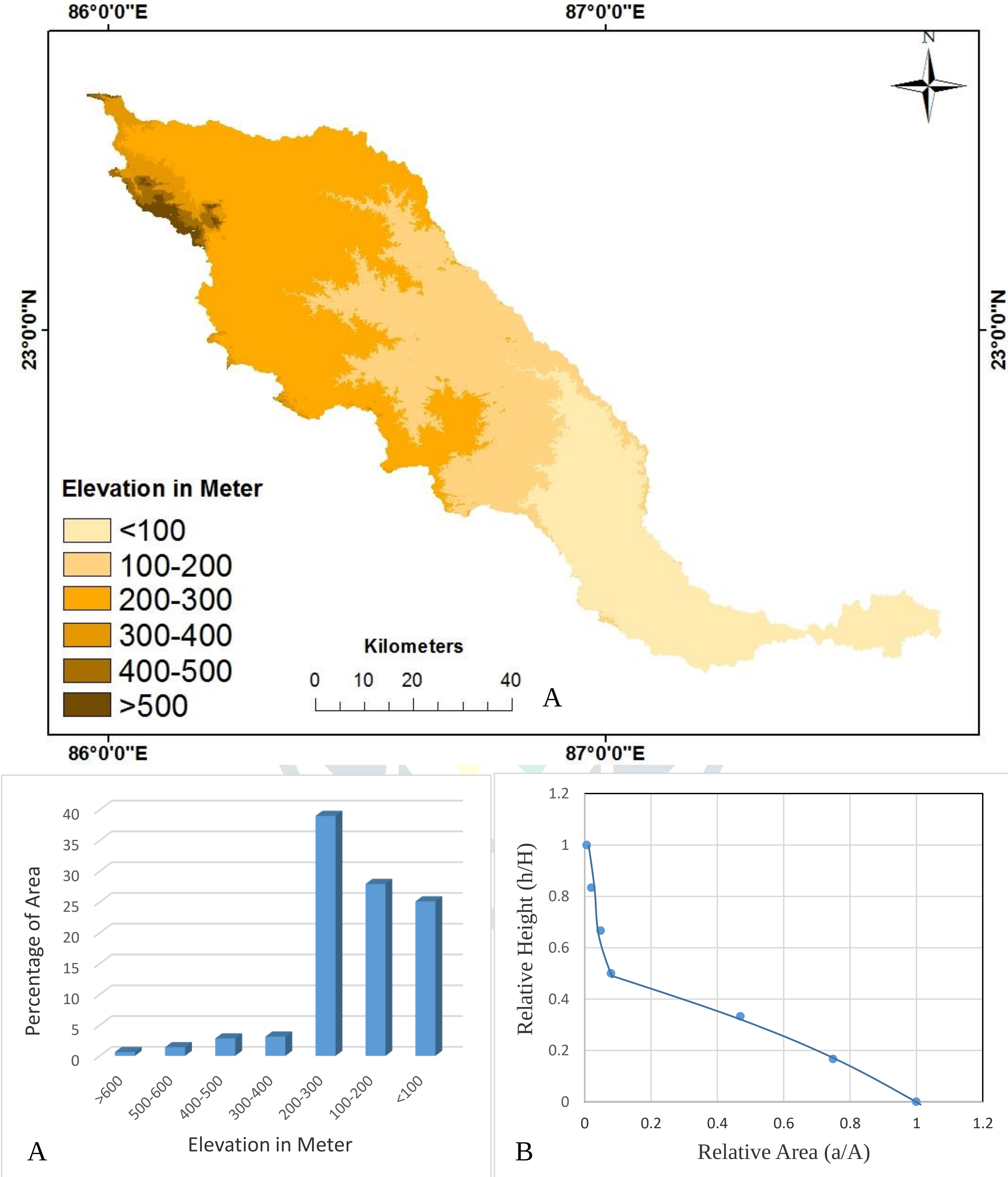

Figure 7: Hypsometric characteristics of Kangsabati River basin A. Absolute altitude map B. Area-height relationship C. Hypsometric curve.

IV. Conclusions

Land classification into different erosional areas is an effective tool for any types of planning. Application of different morphometric techniques for any river basin is an effective tool for this. The present study is primarily conducted to stress out the morphometric characteristics as well as hypsometric characteristics for two different morpho-climatic settings. And also to identify the factors influence on it and vice-versa. Kosi basin which is representative of mountain-plain area of tropical India has highest number stream order (VII) related with high amount of water discharge and low-velocity flow indicating the basin is highly susceptible to flooding. Rapid decline of bifurcation ratio with increasing order bears the indication of high susceptible flooding. Anomaly in bifurcation ratio between 6^{th} and 7^{th} order streams brings strong assumption that Kosi has current topographic development. The irregular changes of stream length of Kosi River indicate changes in topography which in turn indicates the multicyclic development or rejuvenation of Kosi basin. Whereas, Kangsabati basin which is representative of plateau-plain region of tropical India 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 India. The mean bi-furcation ratio of plateau-plain region of Kangsabati basin is also indicative of low flood susceptibility water stress 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 (0.67km/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 leads to mature stages of geomorphic development. 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, in Kangsabati basin of plateau fringe region, the very low drainage density (0.43km/km^2), low stream frequency (0.17/km^2) and low texture ratio (1.65) indicates the basin has very mature stages geomorphic evolution. 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 supported this view. The values of relative relief (3588 m.), dissection index (0.999), and ruggedness index (2.40) of mountain-plain flowing Kosi basin indicates the basin is in rejuvenated stage. The geomorphic and hydrological instability will 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. This works will help to know, which parts of basin are useable for which economic purpose. For this purpose we should classify the whole basin into different geomorphic units like, hilly region, erosional plain, and flood plain. On the other hand, we can conclude the possibilities of future spatial changes through the evaluative stages of geomorphic evolution.

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