Journal of Geographical Studies
Homepage: www.gathacognition.com/journal/gcj5
http://dx.doi.org/10.21523/gcj5

Original Research Paper

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

Avijit Mahala*, Varuni Pathak
Centre for the study of Regional Development, Jawaharlal Nehru University, New Delhi, India, 110067.

Abstract

The major aim of quantitative geomorphology is to understand the geomorphological stages of evolution of any area. The quantitative revolution and the development of remote sensing and GIS techniques have brought greater attention to this field of analysis. We have used a morphometric analysis, which is an important indicator to understand the geomorphic stages of evolution of any drainage basin, to compare the drainage basin characteristics and related stages of evolution of a mountain-plain and plateau-plain drainage basin in tropical India. The Kosi basin has been selected for the mountain-plain area and Kangsabati basin is the chosen region for the plateau-plain area. 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 and hypsometric characteristics have also been accessed to identify the stages of geomorphic evolution. All the relief characteristics indicate Kosi in a young or rejuvenated stage when compared to the mature plateau region of the river of Kangsabati. Morphometric characteristics also indicate that there are high geologic and geomorphological controls on river basin characteristics.

Article history
Received: 22 October 2018
Revised: 1 February 2019
Accepted: 16 February 2019

Keywords
Hypsometric Characteristics:
Geomorphic Control;
Kangsabati;
Kosi;
Quantitative Geomorphology;
Geomorphological Stages;
Morphometric Analysis:
Tropical India.

Editor(s)
M. A. Siddiqui

1 INTRODUCTION

A major paradigm shift which occurred after the Second World War was the development of statistical and quantitative geomorphology. Analysis of interrelationships between forms and processes in different spatial and temporal scale is a major thrust area of this field.

As per Strahler, erosion and deposition of connected stream networks produces different fluvial landforms (Joji, *et al.*, 2013). The 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 size of the basin, its shape and other dimensions can also be evaluated through different morphometric indicators. The relationship between various drainage parameters and its underlying geology, geomorphology, hydrology and structure has also been well established through the work of different geologists and geomorphologists (Strahler, 1952). Finally, it is also possible to explain the difference in hydrological behaviour of any basin using these techniques.

Among the different morphometric characteristics: drainage parameters (stream orders, stream numbers, bifurcation ratio, strength length, mean stream length), basin parameters (circularity ratio, elongation ratio, drainage density and drainage frequency), relief parameters (dissection index, ruggedness index, hypsometric characteristics) are the most important. Thus, it is clear that identifying the morphological evolution and stages of development of any basin provide significant opportunities for further research into this field.

Several scholars have used remote sensing data and GIS on morphometric parameters and have concluded that remote sensing can be used as a powerful tool to analyzing drainage morphometric characteristics (Nag and Lahiri, 2012; Ansari, *et al.*, 2012; Magesh and Chandrasekar, 2014). Remote sensing and GIS techniques have also been used to measure the morphometric characteristics of the region (Figure 1). The Kangsabati basin lies in the eastern part of the Chotanagpur plateau which is more or less stable.

* Author's address for correspondence
Centre for the study of Regional Development, Jawaharlal Nehru University, New Delhi, India, 110067.
Mob.: +91 813002990
Emails: mahala.avijit@gmail.com (*A. Mahala* -Corresponding author); *V. Pathak* (varunirajpathak@gmail.com)

http://dx.doi.org/10.21523/gcj5.18020104

Originating from the 'Ajodhya hill' of the eastern Chotanagpur plateau, it flows eastwards through the plateau fringe regions of West Bengal (Nag and Lahiri, 2012). Different geomorphic characteristics of the Kangsabati basin indicate that it is in a mature stage of geomorphic development (Pan, 2013; Dutta and Roy, 2012). It is also less prone to flood calamities due to its elongated areal characteristics (Gayen *et al*., 2013). As opposed to Kangsabati, the Kosi basin covers an area of neo-tectonic upliftment in the Himalayan lowlands. Frequent flooding and rapid avulsion are known characteristics of this basin (Sinha, 2009). Known also as 'Sorrow of Bihar' it enters Bhimnagar after crossing the part of the Himalayas which lie in Nepal. It then joins Ganga near Kursela after flowing 320 km through northern Bihar. Kosi is also an example of an inland delta building agent (Gole and Chitale, 1966). It also seems to have changed its main course eastward by a hundred kilometers in August 2008 due to a major avulsion process there (Sinha *et al*., 2008) Which some geomorphologist have referred as disaster (Shrestha *et al*., 2010). However, earlier, it had followed the same path before it was abandoned 200 years ago. Also, while the Kosi Basin area comes under the Indo-Gangetic plain geologically, the Kangsabati basin lies under Archean Gneiss and Schist.

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. These are regions for which no detailed work of this kind is presently known. The study also aims to understand the geologic, geomorphic and hydrologic influence on basin morphometry and construct the geomorphic evaluation stage of this two different morpho-climatic setting.

2 MATERIALS AND METHODS

The broad methodology used for the present study includes the measurement of basin morphometry through remote sensing and GIS techniques, followed by interpretation. For this, 'SRTM-GDEM' (30 m.) data has been used for river morphometric analysis followed by the construction of a longitudinal profile.

The different basin morphometric parameters have been accessed through remote sensing techniques (Table 1; Figure 2). 1. Linear aspects: stream order,

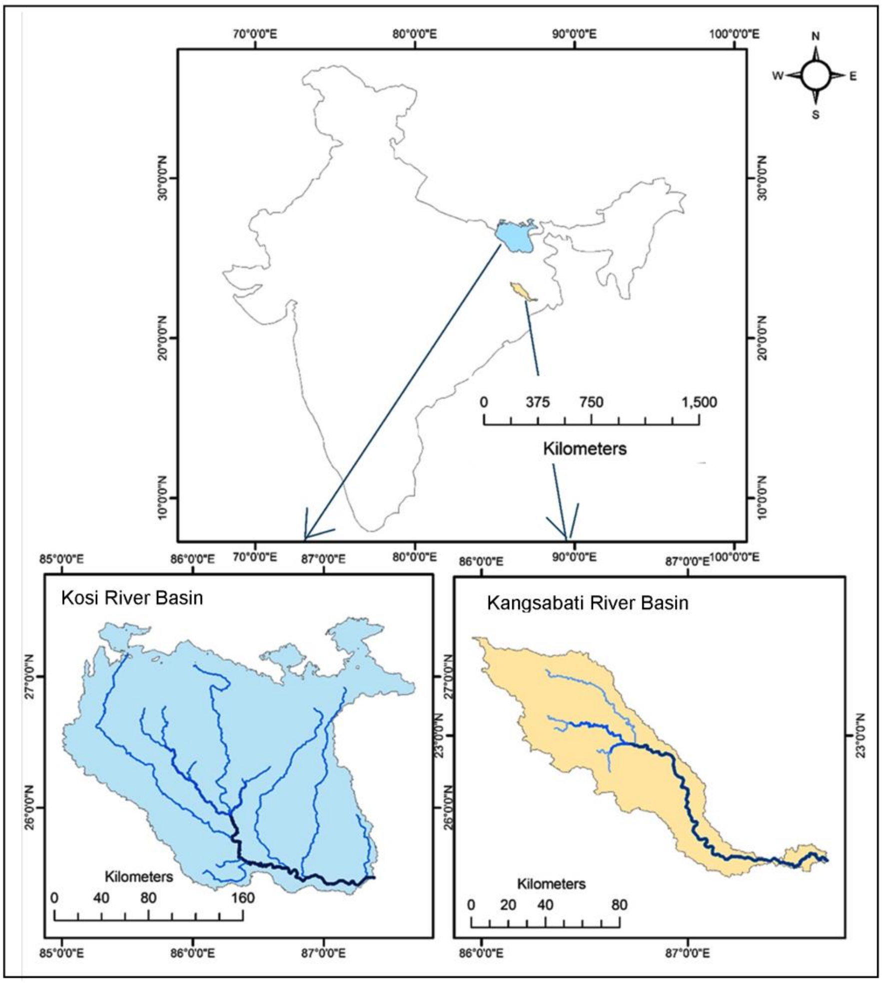

Figure 1. Study area: Kosi and Kangsabati River basins

bifurcation ratio, mean bifurcation ratio, stream length, mean stream length and stream length ratio; 2. Areal aspects: stream frequency, drainage density, texture ratio, form factor, circularity ratio and elongation ratio; and 3. Relief aspects: relative relief, relief ratio, dissection index and ruggedness index have been listed below.

3 RESULTS AND DISCUSSIONS

Both Himalayan glaciers and precipitation deeply influence the hydrology of Kosi River. The Kosi is notorious for its high sediment load and migratory trends with antecedent river characteristics. The failure of the Kosi embankments to control floods and the recent avulsions are characteristics of the Kosi basin which can be explained through the local geological adjustment, plate motions, geotectonic etc. (Arogyaswamy, 1971; Agarwal and Bhoj, 1992). Recently, Kosi has left its westward extension to flow directly through the north-south extension from the Himalayan foothills up till the Ganga confluence. On the othe hand, the Kangsabati river receives water from rainfall only. It flows through the semi-arid region of Chotanagpur plateau. In fact, it remains dry often (Gayen *et al*., 2013).

As argued before, the morphometric analysis is a useful tool to understand the hydrological behaviour of any river basin (Castillo *et al*., 1988; Thomas *et al*., 2010). Hydro-sedimentary characteristics are also determined by basin characteristics (Raux *et al*., 2011).

3.1 Linear Aspects

Stream order (N_u) is designated as the first step of morphometric analysis as introduced by 'Strahler' in 1952. The smallest tributaries of the upper reaches of any basin are named as its 1st order streams. A 2nd order stream is formed when two 1st order stream join (Magesh and Chandrasekar, 2014). The stream order depends on the basin shape, size and relief characteristics of the basin under consideration (Haghipour and Burg, 2014). The total number of streams of Kosi basin add up to 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). The greater number of the1st and 2nd order streams is due to its mountain origin. The number of streams decreases as stream-order increases. After its Himalayan course (upper reaches), Kosi enters the plain area of North Indian causing a sudden change of slope which is reflected in the sudden decrease in the number of 3rd and 4th order treams. The high number of lower order streams (1st, 2nd, 3rd order) collects great amount of water which ultimately creates pressure on higher order streams in the lower basin. (5th, 6th order).

The total number of streams of the Kangsabati basin add up to 1216 of which 609, 279, 152, 68, 25 and 83 streams which belong to the 1st, 2nd, 3rd, 4th, 5th and 6th order streams, respectively (Table 2; Figure 3). The 1st, 2nd and 3rd order streams of the Kangsabati basin are less in number as it originates from a mature plateau formation with multiple dissected hills marking its surface.. The 4th and 6th order streams are also less in number as it enters the plain Higher order streams face less water pressure due to low number of lower order streams which are also of a rainfed origin.

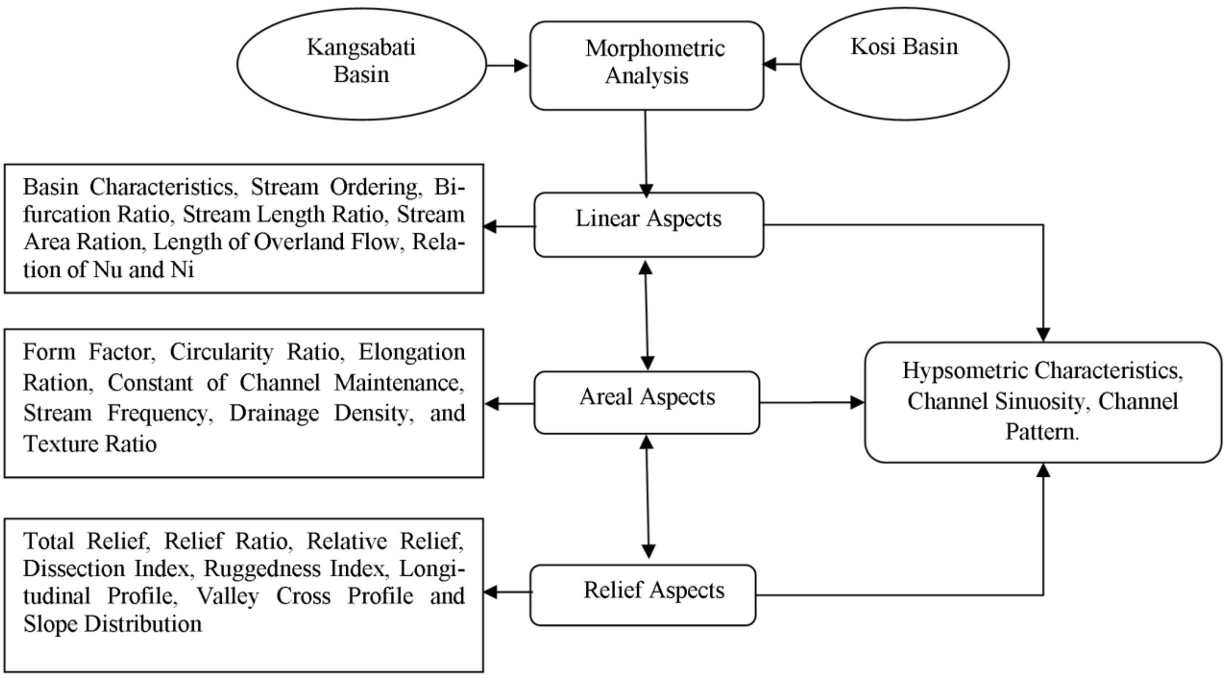

Figure 2. Methodology

Table 1. Morphometric Parameters

	Parameters	Formula
Linear Aspect	Stream Numbers (N_u)	N_u = Nunber of streams of a particular order 'u'
	Bifurcation Ratio (R_b)	$R_b = (N_u/N_u + 1)$; Where, N_u= Number of streams of a particular order 'u', N_u+1= Number of streams of next higher order 'u+1'
	Mean Bifurcation Ratio (R_{bm})	R_{bm} = Mean of bifurcation ratios of all orders.
	Stream Length (L_u)	L_u = Total length of streams (km) of a particular order 'u'
	Mean Stream Length (L_{um})	$L_{um} = L_u/N_u$; Where, L_u = Total length of Streams (km) of a particular order 'u', Nu = Total no. of streams of a particular order 'u'.
	Stream Length Ratio (R_l)	$R_l = L_{um}/L_{um} + 1$; Where, L_{um} = Mean stream length of a particular order 'u', L_{um} + 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 (F_f)	$F_f = A/L^2$; Where, A= Area of the basin (km^2), L = Basin length (km).
	Circularity Ratio (R_c)	$R_c = 4\pi A / P^2$; Where, A = Area of the basin (km^2), P = Outer boundary of a drainage basin (km).
	Elongation Ratio (R_e)	$R_e = P / \pi L$; P = Outer boundary of a drainage basin (km), L = Basin length(km).
	Compactness Constant (C_c)	$C_c = 0.2821\, P/A^{0.5}$; Where, A = Basin area (km^2), P = Basin perimeter (km).
	Constant of Channel Maintenence (CCM)	$CCM = 1/Dd$; Where, D_d = Drainage density
	Stream Frequency (S_f)	$S_f = \sum N_u/A$; Where, (N_u = Total no of streams of a given basin, A = Total area of basin (km^2)
	Drainage Density (D_d)	$D_d = \sum L_u/A$; where, L_u= length of streams (km), A = Basin area (km^2).
	Texture Ratio (T_r)	$T_r = Nu/P$, Where, N_u = 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 (R_r)	$R_r = H/L_{max}$; Where, H= Relative relief (m), L= Length of basin (m)
	Dissection Index (D_i)	$D_i = H/R$; H = Relative relief (m), R = Absolute relief (m)
	Ruggedness Index (R_i)	$R_i = D_d \times H/1000$; Where, D_d= Drainage density, H = Relative relief.

Table 2. Linear Morphometric Aspects

Morphometric Parameters	Kangsabati Basin						Kosi Basin						
Stream Order (u)	I	II	III	IV	V	VI	I	II	III	IV	V	VI	VII
Stream numbers (N_u)	609	279	152	68	25	83	5315	2449	1338	768	551	71	99
Bifurcation Ratio (R_b)	-	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 (R_{bm})	1.56						2.6						
Stream Length (L_u) in km.	1559	790	350	154	62	194	12396	6595	3463	1756	1327	162	216
Mean Stream Length (L_{um})	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 (R_l)	-	0.90	1.23	1.01	0.91	1.06	-	0.86	1.04	1.13	0.95	1.06	1.04

Bifurcation ratio (R_b) is defined as the ratio of stream segments of an order in relation to the next higher order. It is considered to be 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, 5th and 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 the large amount of water collected by the low order streams as well as high water flow. The less number of streams which mark the lower reaches denote their low water carrying capacity.which is supported by its mean bifurcation value which is 2.60. This ultimately results in a heavy flood potentiality in Kosi Basin.

For the Kangsabati basin the bifurcation value, is 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 and 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 a low mean Rb (1.56), indicate a low flood potentiality for this basin.

Stream length (L_u) is indicative of the successive stages of development of stream segments (Castillo *et al.*, 1988). A direct geometric sequence can be approximated from the varying lengths of the different stream orders. The stream length for different orders of the present basin are: 1st stream order (12396 km), 2nd stream order (6595 km), 3rd stream order (3463 km), 4th stream order (1756 km), 5th stream order (1327 km), 6th stream order 162 km), and 7th stream order (216 km) (Table 2). The inconsistency of the stream length between 6th and 7th order indicates irregularities in basin characteristics. This is also indicative of a lithological control on drainage basin.

The stream length values for the Kangsabati basin are: 1st stream order (1559 km), 2nd stream order (790 km), 3rd stream order (350 km), 4th stream order (154 km), 5th stream order (62 km) and 6th stream order (194 km) (Table 2). Sequence of stream length for Kangsabati basin also indicates its mature geomorphological condition.

Mean stream length (L_{um}) 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 stream order (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 stream order (2.18 km) (Table 2). The mean stream length of the Kosi basin denotes the youthful stage of its geomorphic development. The anomalies are due to the change in slope and geological setup. These anomalies themselves, cause discrepancies in surface flow discharge and sedimentation.

The mean stream length for the Kangsabati basin are: 1st stream order (2.55 km), 2nd (2.83 km), 3rd (2.30 km), 4th (2.26 km), 5th (2.48 km) and 6th stream order (2.33), respectively (Table 2). Lum values are more or less similar to plain and plateau areas.

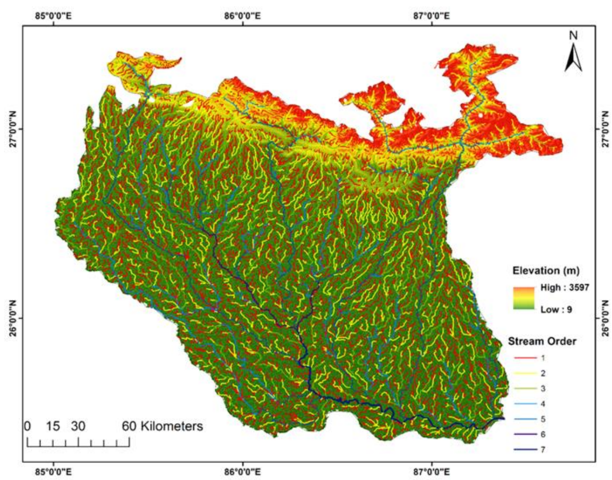

Figure 3a. Sream orders: Kosi basin

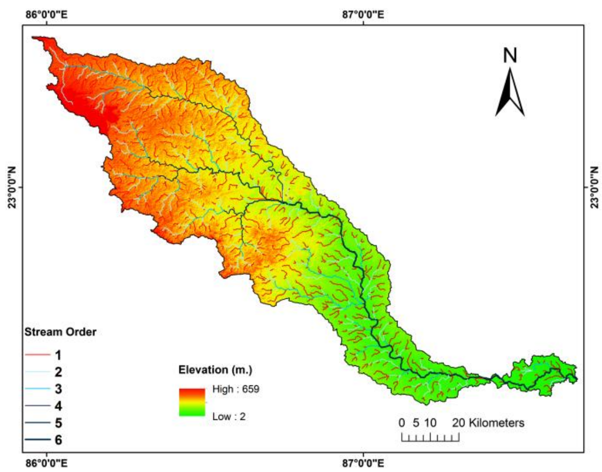

Figure 3b. Sream orders: Kangsabati basin

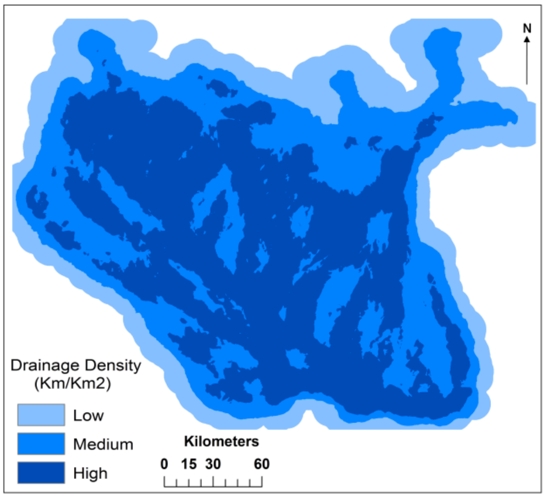

Figure 4a. Drainage density: Kosi basin

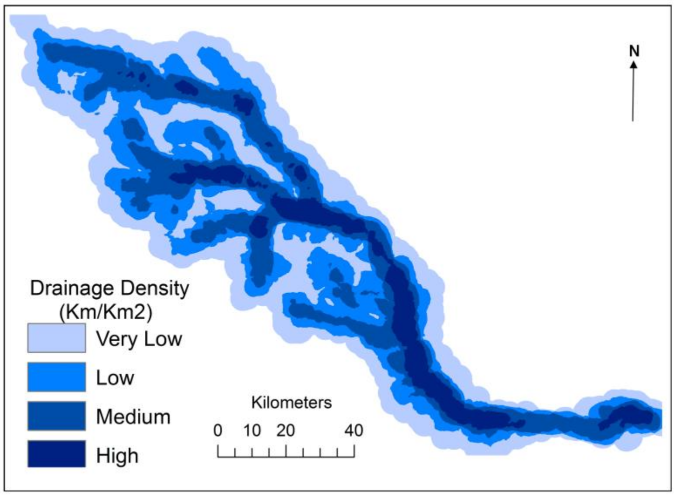

Figure 4b. Drainage density: Kangsabati basin

Stream length ratio (R_l) 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 relative 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 that the area has a high potentiality for frequent changes in the future.

For the 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 stream, respectively. The Rl is more constant in plateau areas (Kangsabati basin) than in plain areas (Kosi basin).

3.2 Areal Aspects

Stream frequency (S_f) is the number of streams present in per unit area. It provides the response of the drainage basin to the runoff processes. Stream frequency depends on the rainfall, relief, initial rock resistivity, 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, which can be categorized as a moderate stream frequency (Table 3). Such a lower stream frequency is the result of its lying in the plain area. Also, lower stream frequency of Kosi basin is indicative of its frequent flood state due to its inability to drain the water from the large basin.

In contrast, the S_f of Kangsabati basin is very low (0.17). The granite-gneiss geology dominated plateau course of river does not permit rivers to create a higher stream frequency. Also semi-arid environment and low relative relief contributes to the lower Sf in Kangsabati basin.

Drainage density (D_d) is the ratio of stream length to the basin area. It is a key factor in determining the drainage of any area. It ranges from 0.27 to 8 km/km^2 (Joji *et al.*, 2013). The capability of any basin to drain its excess water in the monsoon season is dependent upon the drainage density of the area. Drainage density itself depends upon the underlying geology, relief, geomorphology, climate, vegetation etc. Specifically, a high drainage density means an increase in the draining capacity of any region 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 is found in upper reaches of the basin (Figure 4). It is due to its Himalayan location and the relative high relief. Low drainage density can be observed in the lower reaches of the plain areas of the basin. This causes a higher runoff with great velocity, resulting in increased flood potentiality in the downstream basin.

For Kangsabati basin the overall D_d 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 rivers to have a high drainage density. Low drainage density, as well as frequency, is indicative of low draining capacity and frequent flood.

Texture ratio (T_r) 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 a number of geological and geomorphological factors. The drainage texture of Kosi basin is 7.60 which is indicative of a coarse drainage texture (Table 3), indicative of the low capacity of the basin to drain out the extra amount of water.

T_r for Kangsabati basin is as low as 1.65. It is the result of its elongated basin characteristics, low stream frequency, Archean geology as well as its semi-humid environment.

Form factor (F_f) 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 the near to circle characteristics of the basin with high peak flow. Flood flows of an elongated basin can be easily managed in comparison to a circular basin. F_f value of Kosi basin is 0.45 which indicates the basin is close to a circle shape (Table 3). It also indicates higher peak flow in limited times. Large basin area with a greater circular shape and a low drainage density cause the Kosi to become a critical flood-prone basin in India.

On the other hand, F_f value of Kangsabati basin is 0.12, which is indicative of an elongated shape with less peak flow. Its comparatively less basin area, low rainfall and elongated shape of the basin results in a low frequency of floods occurring here.

Elongation ratio (R_e) 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 the hydrological character of a drainage basin. The value '0' indicates its elongation characteristics whereas '1' indicates its closeness to a circular pattern. The Re value of the Kosi basin is 1.52 which denotes the perfect circular characteristics of this basin (Table 3). Due to its greater catchment area and low drainage frequency, this circular basin has greater 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 causes the Kangsabati to become a less flood-prone.

Circularity ratio (R_c) 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 and forms an express outline of the basin. Higher circular basin is affected by peak discharge in high rainfall season. R_c 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. R_c value of the Kosi basin is 0.25 which denotes its high peak flood runoff in monsoon season (Table 3). R_c value of Kangsabati basin is 0.16 which indicates its elongated characteristics.

Compactness constant (C_c) 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 its flooding potentiality (Table 3). For Kangsabati basin, Cc value is 2.46, and it indicates its less compacted nature which ultimately helps give it a 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 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 will ultimately create a flood situation. The CCM value for Kangsabati basin is 2.27 which indicate that a slightly large area is available to feed a tributary than in the Kosi basin. But low rainfall in Kangsabati basin does not create any flood situation.

3.3 Relief Aspects

Basin relief (R, H) which includes absolute relief (R) and relative relief (H) provides an important parameter to understand basin evolutionary characteristics. Relative relief is used for determining overall basin characteristics. (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 is found near the Himalayan peaks (Table 4). The Relative relief is 3588 m. which seems very high for erosional activity. H value of Kosi shows abrupt changes when it enters into plain areas in Himalayan foothills. On the other hand, Kangsabati flows through the plateau fringe region. Therefore, the R and H value for Kangsabati is as low as 659 and 657 respectively. Dissection hills, undulating plateau, occasional scrapes are landform features in upper reaches of Kangsabati basin. These types of landform cause a greater degree of relief undulation but the lower reaches of the basin are, almost flat.

Table 3. Areal Aspects

Areal Aspects	Kosi Basin	Kangsabati Basin
Basin Perimeter (P) (km)	1392	736
Basin Area (A) (km^2)	38689	7073
Form Factor (F_f)	0.45	0.12
Circularity Ratio (R_c)	0.26	0.16
Elongation Ratio (R_e)	1.52	1.00
Compactness constant (C_c)	2.00	2.46
Constant of channel maintenance (CCM)	1.49	2.27
Stream Frequency (S_f)	0.27	0.17
Drainage Density (D_d)	0.67	0.43
Texture ratio (T_r)	7.60	1.65

Relief ratio (R_r) denotes the ratio between total relief to the length of principal 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). R_r is highest in its Himalayan reaches but as it enters in plain areas it decreases. R_r value for Kangsabati basin is as low as 0.0028. The reason for this low R_r is that Kangsabati flows through the plateau fringe region and enters into extensive plain. The basin is prone to waterlogging due to its low R_r value.

Dissection index (D_i) 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 understood through D_i . The value of D_i ranges between '0' (absence of vertical dissection) to '1' (Vertical areas). D_i value of Kosi basin is 0.99 which indicates its young or rejuvenated stage of geomorphic evolution (Table 4). It is also indicative of the possibility of its further development. D_i value of Kangsabati basin is also around nine, but this is indicative not of a young stage of evolution but of its plain land extension. Kangsabati is in more or less a mature stage as opposed to the Kosi basin.

Ruggedness index (R_i) indicates the stages of landform development as well as instability of the region or basin. The high value of R_i occurs when both drainage density and relative relief are large, and slope 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 R_i, the more youthful the area is physiographically and vice-versa. High value of R_i (2.40) for Kosi basin showing a youthful stage of basin development (Table 4). R_i value of Kangsabati is quite low at 0.282. This is explainable because after originating from plateau top areas of eastern Chotanagpur plateau, Kangsabati flows through the dissected plateau fringe region in an eastward direction fallings under the Precambrian gneiss and schist geology. The erosion caused by different rivers over millions of years has transformed the area into a rolling plateau fringe. Thus, it shows an old stage of geomorphic development.

Channel gradient indicates the stages of geomorphic evolution as well as its potentiality for further erosion. A greater channel gradient is seen during the mountainous course of a river and the number reduces during the plain course of river. As a consequence, valley deepening is a more prominent phenomenon in mountainous course of a river while valley widening is extensive in the plain. The Kosi River is almost vertical from source region up to Himalayan foothill areas. It is near horizontal from Himalayan foothills up to the river mouth. These kind of gradient characteristics have the potentiality of frequent flooding and consequent embankment failure. On the other hand, Kangsabati River shows constant slope characteristics in upper reaches of the basin and is near flat in its lower reaches. As Kangsabati is a representative of the 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) which dominates the upper reaches of the Kosi basin is a true representative of a young or rejuvenated geomorphic area (Figure 5). However, the slope of the basin decreases dramatically as Kosi enters in the foothill plain areas. This decreasing slope tendency in indicates a high potentiality for further geomorphic evolution of the Kosi basin. On the other hand, for the Kangsabati basin the slope is more or less low (< 10º) throughout the basin indicating low potentiality for further geomorphic evolution (Figure 5).

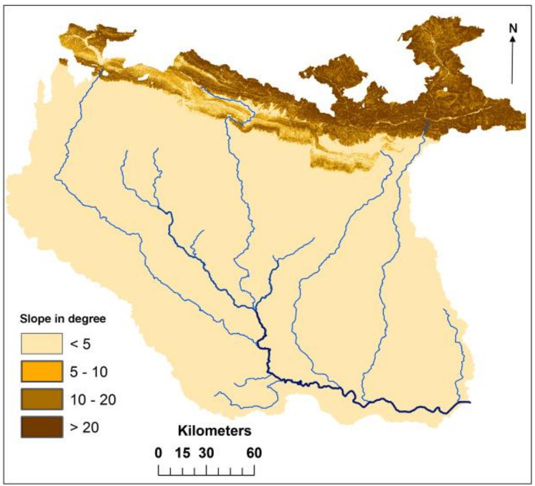

Figure 5a. Slope map: Kosi basin

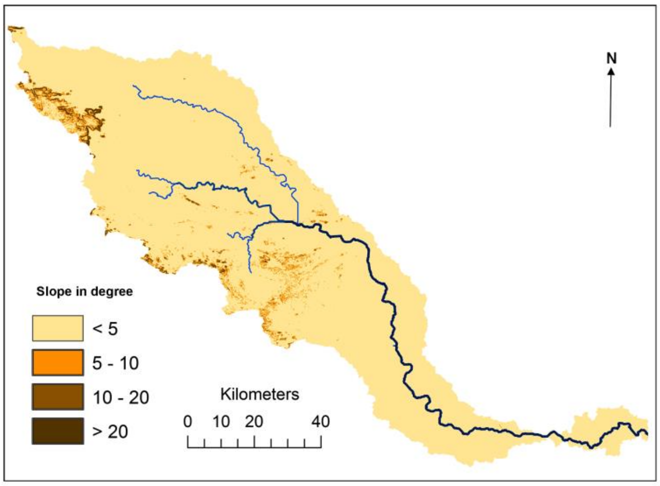

Figure 5b. Slope map: Kangsabati Basins

Table 4. Relief Aspects

Relief Aspect	Kosi Basin	Kangsabati Basin
Absolute Relief (R)	3597	659
Relative Relief (H)	3588	657
Relief Ratio (R_r)	0.012	0.0028
Dissection Index (D_i)	0.990	0.996
Ruggedness Index (R_i)	2.40	0.282

3.4 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 better understood. The hypsometric curve provides assessmemt of different elevation zones along with corresponding areal coverage expressing it through youthful, mature and old topography parameters. Area-altitude relationship depicts that >70% of area of Kosi river basin falls under <100-meter elevation (Figure 6). Though it indicates that the basin belongs to mature stages of geomorphic evolution the Kosi River has experienced multicycle erosional surface due to its high mountain origin and frequent river course changes, reflecting a more youthful stage of evolution.

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 that the whole basin belongs to a range of mature to senile topography (Figure 7). Kangsabati river flows through one of old plateau fringe regions of tropical India, i.e. Chotanagpur plateau. Upper reaches of the basin have been transformed to dissected erosional plateau fringe region through continuous erosion, whereas the lower reaches have suffered particularly from sand deposition. As Kangsabati River flows through one of the most stable regions of India, it has not experienced any large upliftment in its geological history. As a result, this basin does not bear any evidence of multi-cyclic landforms.

4 CONCLUSION

The application of different morphometric techniques for any river basin is an effective tool for planning. The present study is primarily conducted to focus on the morphometric characteristics as well as hypsometric characteristics of two different morpho-climatic settings. We also tried to identify the factors which influenced these characteristics and vice-versa.

Kosi basin which is representative of mountain-plain area of tropical India has the highest number stream order (VII) 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 an increase in order stream carries the susceptibility of high flooding. Anomaly in bifurcation ratio between 6th and 7th order streams brings strong assumption that Kosi has a recent topographic development. The irregular changes of stream length of Kosi River indicate changes in topography which in turn indicates the multi-cyclic development or rejuvenation of the Kosi basin.

On the other hand, the Kangsabati basin which is representative of a plateau-plain region of tropical India has low number of stream order and consequently lower susceptibility to flooding. Fewer decline in bifurcation ratio with increasing stream order is indicative of a semi-dry region. The mean bifurcation ratio of plateau-plain region of Kangsabati basin is also indicative of low flood susceptibility. The mean stream length and regular changes of stream length ratio are also indicative of the 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 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 causes embankment failure in its large water catchment area. Whereas, the Kangsabati basin of a plateau fringe region, has very low drainage density (0.43 km/km^2), low stream frequency (0.17/km^2) and low texture ratio (1.65) indicating that the basin has undergone mature stages of geomorphic evolution. The form factor (0.12), circularity ratio (0.16), elongation ratio (1.00) indicates that 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 support 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 is bound to become more common in the 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 be helpful to determine those parts of basin which are useable for economic activity. We should classify the whole basin into different geomorphic units like, hilly region, erosional plain, and flood plain. On the other hand, we can foresee the possible spatial changes which can take place in the future through the evolutionary stages of geomorphic evolution.

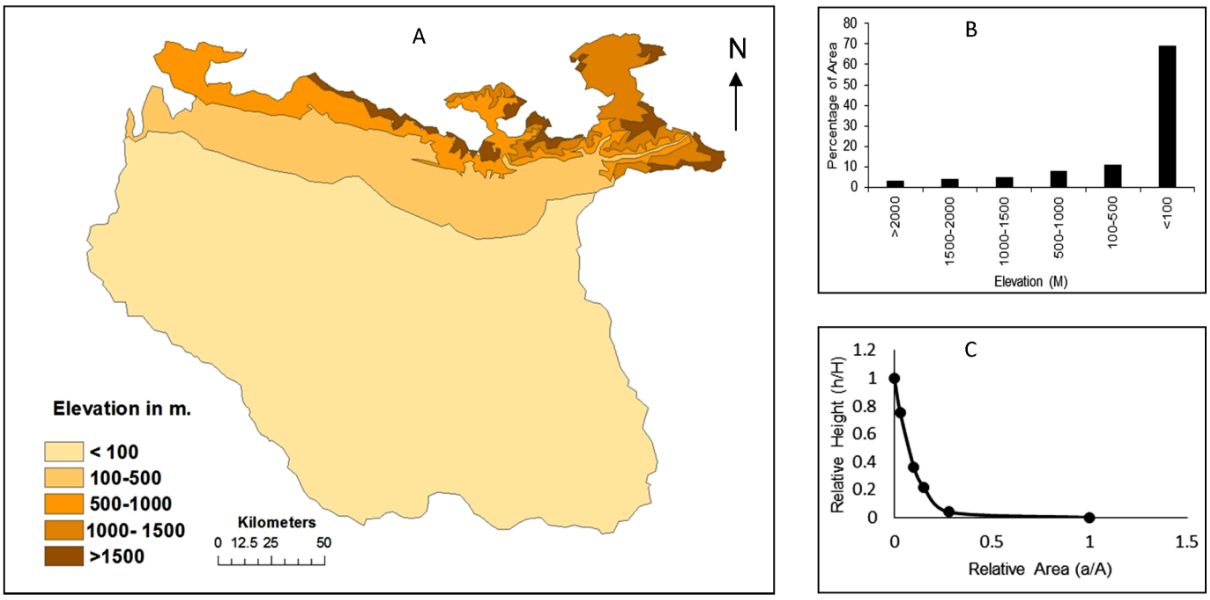

Figure 6. Hypsometric Characteristics of Kosi River Basin: A. Absolute altitude map, B. Area-height relationship and C. Hypsometric curve.

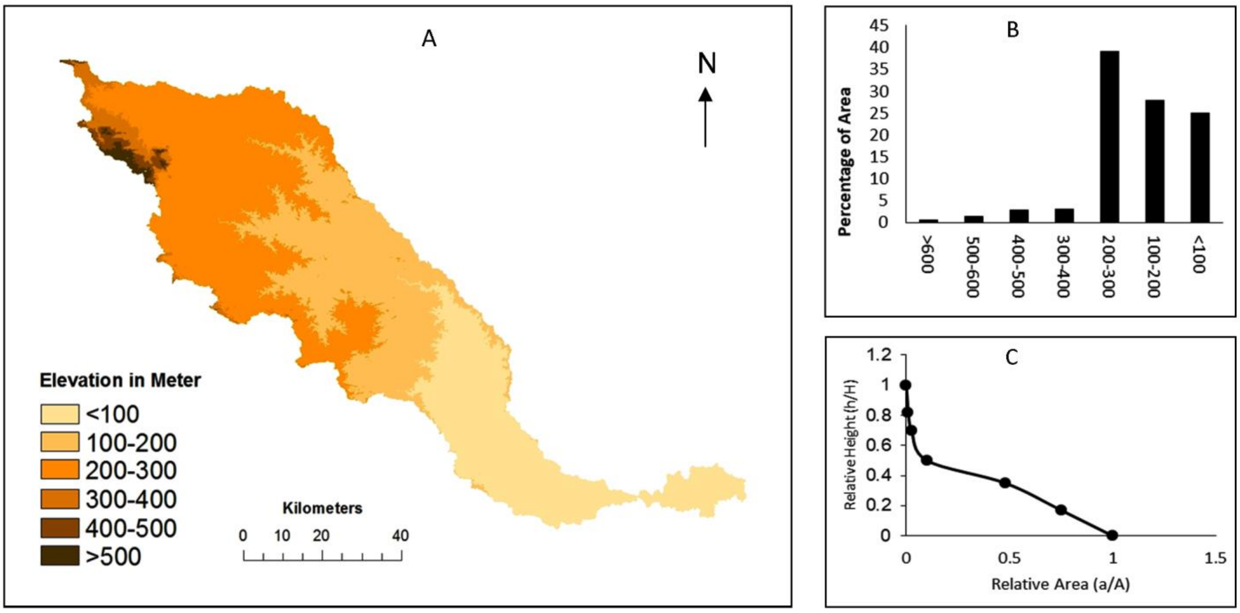

Figure 7. Hypsometric Characteristics of Kangsabati Basin: A. Absolute altitude map, B. Area-height relationship and C. Hypsometric curve

CONFLICT OF INTEREST

Authors proclaimed no conflict of interest.

ACKNOWLEDGEMENTS

The author is thankful to UGC for providing NET-JRF Scholarship (Ref No-3713 June, 2013), as well as Jawaharlal Nehru University for providing research opportunity.

REFERENCES

Agarwal, R. P. and Bhoj, R., 1992. Evolution of Kosi river fan, India: structural implications and geomorphic significance. *International Journal of Remote Sensing*, 13(10), 1891-1901. DOI: https://doi.org/10.1080/01431169208904238

Ansari, Z. R. Rao, L.A. and Yusuf, A. 2012. GIS-based morphometric analysis of Yamuna drainage network in parts of Fatehabad area of Agra District, Uttar Pradesh. *Journal of Geological Society of India*, 79, 505-514. DOI: https://doi.org/10.1007/s12594-012-0075-2

Arogyaswamy, R. N. P., 1971. Some geological factors influencing the behaviour of the Kosi. *Records of Geological Survey of India*, 96, 42-52.

Castillo, V., Diazsegovia, A. and Alonso, S. G., 1988. Quantitative Study of fluvial landscapes, case study in Madrid, Spain. *Landscape and Urban Planning*, 16, 201-217. DOI: https://doi.org/10.1016/0169-2046(88)90043-6

Chorley, R. J. Schumm, S. A. and Sugden, D. E., 1985. Geomorphology. London: Methuen and Co. Ltd.

Dutta, S. and Roy, S., 2012. Determination of erosion surfaces and stages of evolution of Sangra drainage basin in Giridih district, Jharkhand, India. *International Journal of Geomatics and Geosciences*, 3(1), 63-73.

Gayen, S., Bhunia, G. S. and Shit, P. K., 2013. Morphometric analysis of Kangsabati-Darkeswar interfluves area in West Bengal, India using ASTER DEM and GIS techniques. *Geology and Geosciences*, 2(4): 1-10. DOI: https://doi.org/10.4172/2329-6755.1000133

Gole, C. V. and Chitale, S. V. 1996. Inland delta building activity of Kosi River. *Journal of the Hydraulics Division*, 92, 111-126.

Haghipour, N. and Burg, J. P., 2014. Geomorphological analysis of the drainage system on the growing Makran accretionary wedge. *Geomorphology*, 209, 111-132. DOI: https://doi.org/10.1016/j.geomorph.2013.11.030

Horton, R. E., 1932. *Drainage Basin Characteristics* (1'st ed.). New York: Trans. Amer. Geophys.

Joji, V. S., Nair, A. S. and Baiju, K. V., 2013. Drainage basin delineation and quantitative analysis of Panamaram Watershed of Kabani River Basin, Kerala using remote sensing and GIS. *Journal of Geological Society of India*, 82, 368-378. DOI: https://doi.org/10.1007/s12594-013-0164-x

Kim, J.C. and Jung, K., 2015. Fractal tree analysis of drainage patterns. *Water Resour. Manage*., 29, 1217-1230. DOI: https://doi.org/10.1007/s11269-014-0869-7

Lindsay, J. B. and Seibert, J., 2013. Measuring the significance of a divide to local drainage patterns. *International Journal of Geographical Information Science*, 27(7), 1453-1468.

Magesh, N. S., and Chandrasekar, N. 2014. GIS model-based morphometric evaluation of Tamiraparani sub basin, Tirunelveli district, Tamil Nadu, India. *Arab. J. Geosci.*, 7, 131-141. DOI: https://doi.org/10.1007/s12517-012-0742-z

Nag, S. K. and Lahiri, A., 2012. Hydro chemical characteristics of groundwater for domestic and irrigation purposes in Dwarakeswar Watershed Area, India. *American Journal of Climate Change*, 1, 217-230.

Pan, S., 2013. Application of Remote Sensing and GIS in studying changing river course in Bankura District, West Bengal. *International Journal of Geomatics and Geosciences*, 4(1), 149-163.

Raux, J. Copard, Y. Laignel, B. Fournier, M. and Masseï, N., 2011. Classification of worldwide drainage basins through the multivariate analysis of variables controlling their hydro sedimentary response. *Global and Planetary Change*, 76, 117-127. DOI: https://doi.org/10.1016/j.gloplacha.2010.12.005

Sharma, S. and Sarma, J. N., 2013. Drainage analysis in a part of the brahmaputra valley in Sivasagar District, Assam, India, to detect the role of nontectonic activity. *J. Indian Soc. Remote Sens*., 41(4), 895-904.

Shrestha, R. K. Ahlers, R. Bakker, M. and Gupta, J., 2010. Institutional Dysfunction and Challenges in Flood Control: A Case Study of the Kosi Flood 2008. *Economics and Political Weekly*, 2, 45-53.

Sinha, R. Bapalu, G. V. Singh, L. K. and Rath, B., 2008. Flood Risk Analysis in the Kosi River Basin, North Bihar using Multi-Parametric Approach of Analytical Hierarchy Process (AHP). *J. Indian Soc. Remote Sens.*, 36, 335-349. DOI: https://doi.org/10.1007/s12524-008-0034-y

Sinha, R., 2009. Dynamics of a River System – the Case of the Kosi River in North Bihar. *Earth Science India*, 2, 33-45.

Strahler, A. N., 1952. Hypsometric analysis (area-altitude) of erosional topography. *Bulletin of Geological Society of America*, 63,117-142.

Thomas, J. Joseph, S. and Thrivikramaji, K. P., 2010. Morphometric aspects of a small tropical mountain river system, the southern Western Ghats. *India. International Journal of Digital Earth*, 3(2), 135-156. DOI: https://doi.org/10.1080/17538940903464370

******