THE FAILURE OF KOSI RIVER EMBANKMENT AND FLOOD POTENTIALITY IN RELATION TO ITS MORPHOMETRIC CHARACTERISTICS: A REMOTE SENSING AND GIS BASED APPROACH

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***Abstract*: The Kosi River is important regarding its geological settings, basin characteristics, flow characteristics and its dynamism. The large upper catchment area, high number of first and second order streams, large Himalayan glacier sources makes the river high flood prone. The present study strongly suggests that morphometric characteristics of Kosi River helps for frequent flooding and related embankment failure. All of these characteristics has been accessed through remote sensing and GIS techniques.**

***Keywords*: Kosi River, Basin characteristics, Morphometric characteristics, Embankment failure**

I. Introduction

Drainage Morphometry is the mathematical techniques that indicates the morphological and hydrological characteristics of basin. The basin size, shape, dimension and evolutionary stages can be accessed through different morphometric indicators. It provides enormous idea to identify the morphological and hydrological problems and helps with related management procedures. The remote sensing and GIS toll is important to measures the morphometric characteristics.

The Kosi basin lies on the Himalayan foothills of India and Nepal. The upper course lies in Nepal and lower portion in India (Fig. 1). The rapid avulsion changes and frequent flood is a well-known fact about Kosi (Sinha, 2009). The River is also known as 'Sorrow of Bihar'. Kosi originated in northern Himalaya and formed one of the major tributaries of Ganga. Kosi enters 'Bhimnagar' after crossing Nepal Himalaya. 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). A lot of destruction has been causedby lateral movement and extensive flooding by the Kosi River in north Indian plain. As its water carry heavy silt load and the river has a steep gradient, the river tends to move sideways. Embankment on both sides has been constructed to check the lateral movement. Though within embankment, the lateral shifting of River is confined the problem of flooding is still prominent. There should be a realization that rather than constructing structural measures, it would be better to minimize the flooding effect.

The flooding of Kosi River had breached its embankment in August 2008 (Fig. 2). The Kosi River took the path which is 100 Km eastward from its channelled course. Kosi had abandoned this path before 200 years ago. The channel movements of the Kosi River can be 'avulsive' shifts. It is necessary to discuss 'avulsive' processes before going to discuss channel morphometry and shifting. The sudden movement happened in a nodal point leads to avulsion. It needs a sufficient magnitude event (like flood) in any river of near avulsion threshold. If any small river is close to avulsion threshold, a small flood can cause avulsion. 'Channel reoccupation' or replacing of preexisting channel by new channel is one of the most common channel avulsion processes.

The August flood of Kosi basin is primarily due to failure of river embankment (Sinha, 2009). Thisresulted flooding in large areas of basin. Many river geomorphologiststake that this is a 'human disaster' rather than regular flooding (Shrestha, et al., 2010). Most analysts suggest that significant aggradation of Kosi within the channel belt will happen due to its confinement within the embankment (Sinha, et al., 2008). A number of breaches have happened in previous times also. Wells and Dorr (1987) not find any correlation between major earthquakes and major changes of Kosi tracks. Even local southward and westward tilting near head of Kosi fan and the Kosi river flood events couldn't be correlated.Shillingfield first introduce the dynamics of Kosi River followed several other workers who supported westward Kosi movement. Some geomorphologist suggests topographic control, tributary influence, neotectonic, abandonment of channels are the major reasons for the flooding (Jain and Sinha, 2008). Water hazard is more prominent in Kosi basin. Facies characteristics are also responsible for Kosi flood (Singh, et al., 1993).
The present study tries to establish the relations among morphometric characteristics to its flood potentiality and related embankment failure of Kosi River.

II. Materials and Methods

The interpretation of geological data followed by measurement of basin morphometry through remote sensing and GIS techniques are the broad methodology for present study. To fulfil the above-stated objective 'ASTER-GDEM' (30 m.) data has been used for river morphometric analysis followed by constructing of longitudinal profile. The different basin morphometric parameters have been accessed through remote sensing techniques (Table 1). Like, 1. Drainage network (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)

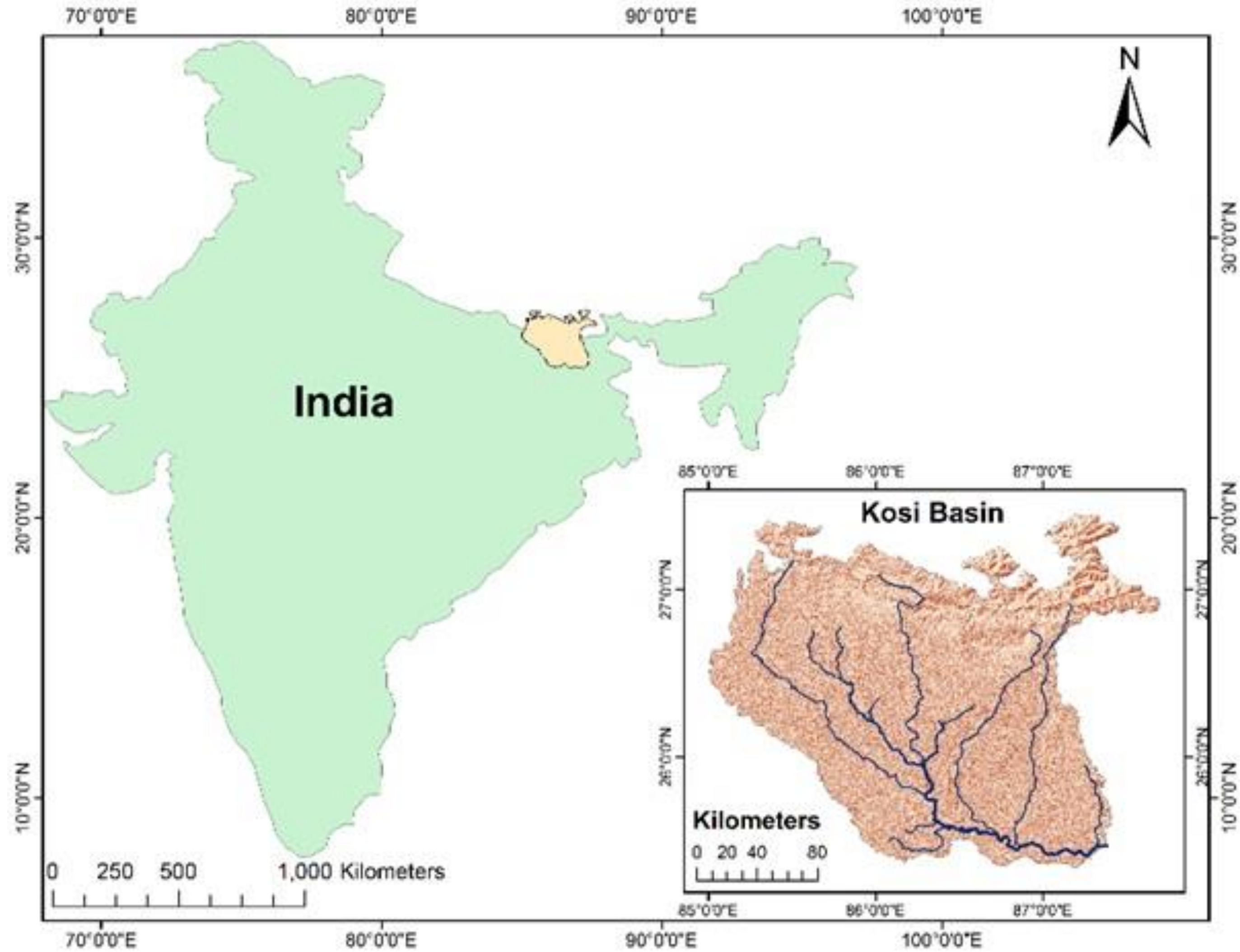
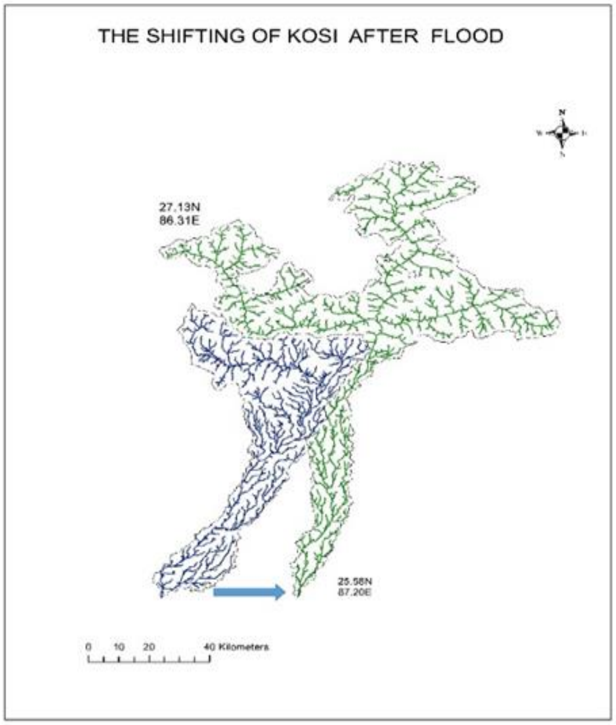


Figure 1: Location map of Kosi Basin

III. Results and Discussion



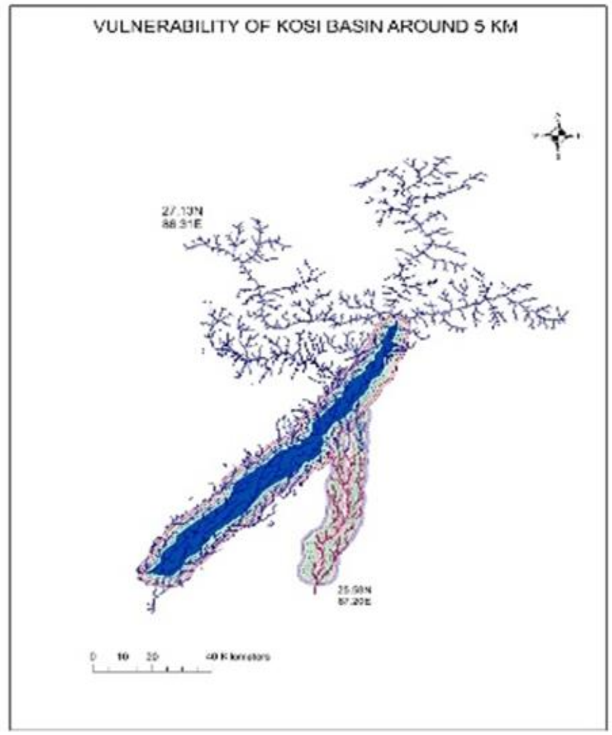


Figure 2: Shifting of Kosi main channel

The hydrology of Kosi River is deeply influenced by both Himalayan glaciers and precipitation. 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, 2003; 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.

Morphometric analysis is a useful tool to understand the hydrological behaviour of any Basin (Castillo, et al., 1988; Thomas, et al., 2010). It is also useful to understand the geology, structure, geomorphology, and prevailing climate (Sharma and Sarma, 2013). This relationship between above factors and drainage morphometric parameters is well established and well-known fact (Joji, et al., 2013; Ansari, et al., 2012). The present study aims to trace out the morphometric parameters of the Kosi Riverine relation to its embankment failure and flood potentiality (Magesh and Chandrasekar, 2014). Geologically this area (Kosi Bain) comes under Indo-Gangetic plain.
Stream order (Nµ) which is introduced by 'Strahler' designated the first step of drainage basin analysis. The smallest tributaries of fingertips are designated as 1'st order stream. The stream order number is proportional to channel dimension, size of watershed, and discharge of stream of that place of river system. The total no's of streams of Kosi basin are 10591 of which 5315, 2449, 1338, 768, 551, 71, and 99 streams belongs to 1'st, 2'nd, 3'rd, 4'th, 5'th, 6'th, and 7'th order respectively(Table 2) (Fig. 3). As Kosi originates from highly elevated Himalayan region, so its 1'st and 2'nd order streams shows increasing number. The number of streams decreases as order increases. After Himalayan course (upper reaches), Kosi enters plain areain North Indian plain. There is sudden decrease in 3'rd and 4'th order of streams due to this sudden canges of slope characteristics.

Bifurcation ratio(Rb) considered an important parameter which denotes the flood potentiality of any basin. It also gives inference of drainage network characteristics and geological condition of the basin. The bifurcation ratio for different order of streams in Kosi basin is 2.17 for 1'st to 2'nd, 1.83 for 2'nd to 3'rd, 1.74 for 3'rd to 4'th, 1.39 for 4'th to 6'th, 7.76 for 5'th to 6'th, 0.71 for 6'th to 7'th respectively (Table 2). This 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 representlarge amount of water collectivity and higher stream waterflow. This high amount of water collected in upper reaches drained through the lower order streams of plain areas. But in Kosi basin, very less numberof 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.

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 Ratioo (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 (Km2)
	Form Factor (Ff)	Ff= A/L^2; Where, A= Area of the basin (Km2), L = Basin length (Km).
	Circularity Ratio (Rc)	Rc = 4πA / P^2; Where, A = Area of the basin (Km2), P = Outer boundary of a drainage basin (Km).
	Elongation Ratio (Re)	Re = P / πL; 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 (Km2), P = Basin perimeter (Km).
	Constant of channel maintenence (CCM)	CCM = 1/Dd; Where, Dd = Drainage density
	Stream Frequency (Sf)	Sf = ∑Nu/A; Where, Nu = Total no of streams of a given basin, A = Total area of basin (Km2)
	Drainage Density (Dd)	Dd = ∑Lu/Au; where, Lu= length of streams (Km), Au=Basin area (km2).
	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.

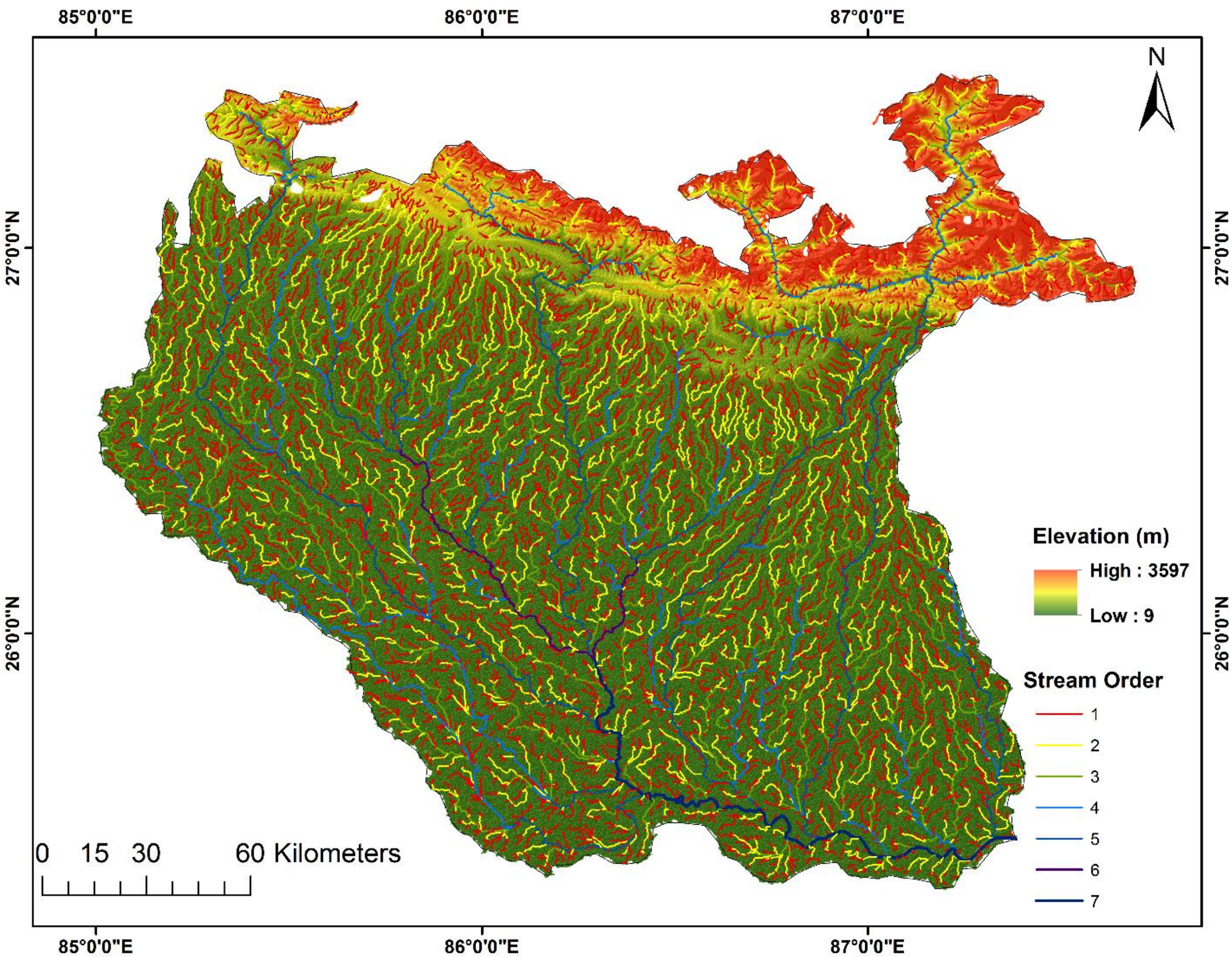


Figure 3: Stream characteristics of Kosi basin

Stream length (Lu) is indicative of successive stages of development of stream segments. The stream length for different orders of the present basin is 1'st (12396 Km), 2'nd (6595 Km), 3'rd (3463 Km), 4'th (1756 Km), 5'th (1327 Km), 6'th (162 Km), and 7'thorder (216 Km) (Table 2). In general situation the stream length should decrease with increasing stream order. But in Kosi basin stream length of 7'th order is greater than 6'th order which brings into assumption that the basin is susceptible to flooding during high rainfall season. This also infers that the basin has variation in topography and lithology as well as highly susceptible to erosion.

Mean stream length (Lum) is an important property of drainage network components. Longer streams noticed in higher order. The mean stream length of Kosi basin is 1'st (2.33 Km), 2'nd (2.69 Km), 3'rd (2.59 Km), 4'th (2.29 Km), 5'th (2.41 Km), 6'th (2.28 Km), and for 7'th order (2.18 Km) (Table 2). The mean stream length of Kosi basin denotes youth stage of geomorphic development of streams in the basin. The anomaliessuggesting slope changes and changes in geological setup, which in turn denotes abrupt changes. This has also bearing discrepancies of surface flow discharge and sedimentation.

Stream length ratio (Rl) is an important indicator of surface flow, erosional stage, and discharge characteristics of the basin. The stream length ratio of Kosi basin starts with 0.86 for 1'st to 2'nd order, 1.04 for 2'nd to 3'rd order, 1.13 for 3'rd to 4'th order, 0.95 for 4'th to 5'th order, 1.06 for 5'th to 6'th order, and 1.04 for 6'th to 7'th order (Table 2). The changes in stream length ratio denotes that the area is inearly stage of geomorphic development and the area have highpotentiality of frequent changes in future.

Stream frequency (Sf) provides drainage basin response to runoff processes. Stream frequency ultimately depends on the underlying geology, rock structure, lithology, vegetation cover, overland flow etc. of the basin. Stream frequency of the Kosi basin is 0.27 (no. /Km2) which can be categorized as a moderate stream frequency (Table 2). As most of the study area of basin is under plain areas that's why the frequency is so low. The area is highly flooded susceptible because less number streams present to drain out the excess water in monsoonal season.

Drainage density (Dd) denotes the available stream length in any definite area. It is a key factor of draining in any area. The capability of any area 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/Km2) which is very low (Table 2). 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

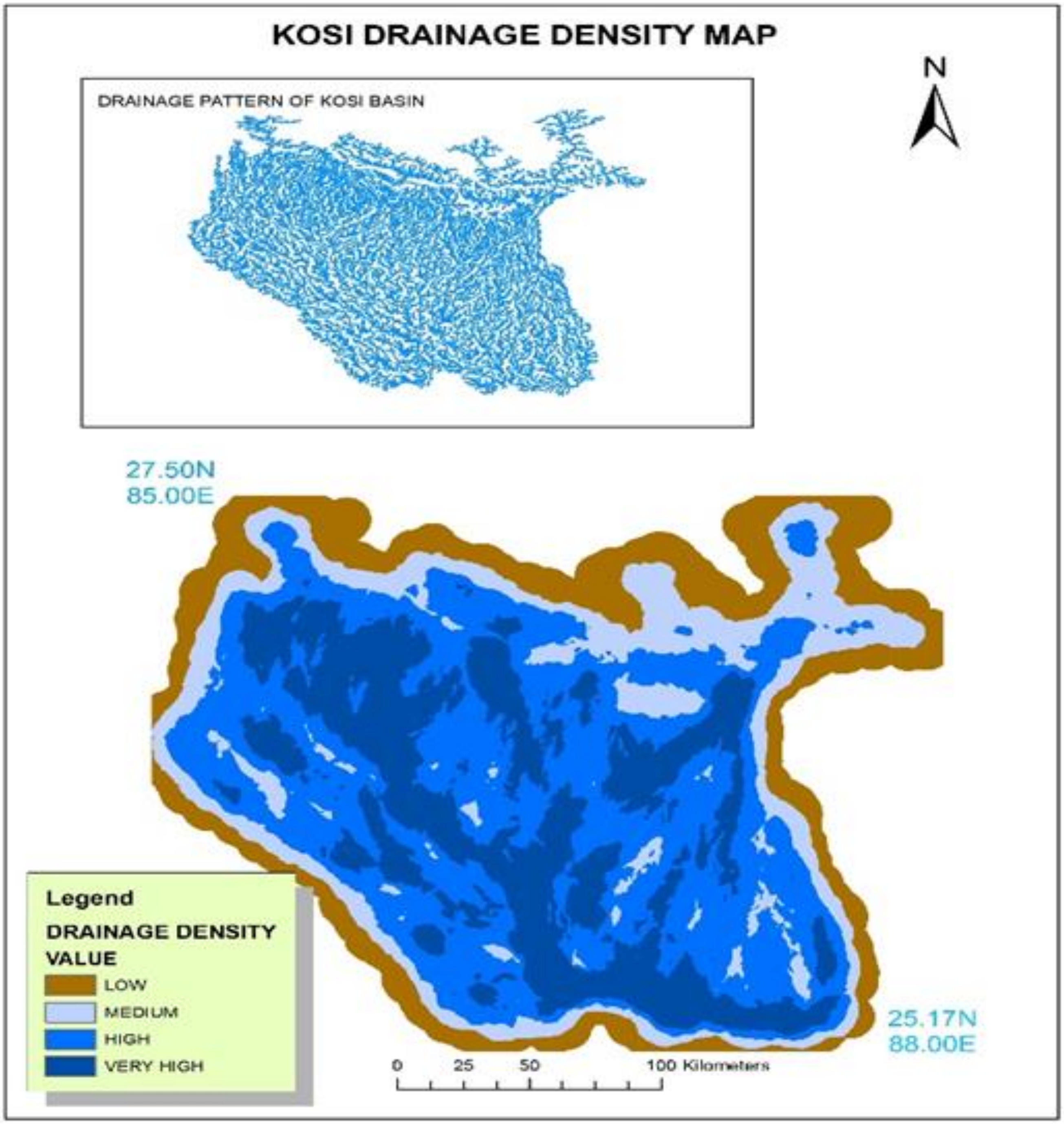


Figure 4: Drainage density of Kosi basin

Texture ratio (Rt) is also an important fluvial parameter which denotes the relative spacing of drainage network of any basin. Collectively drainage density and drainage frequency can be called drainage texture. It depends upon number of geological and geomorphological factors. The drainage texture of present basin is 7.60 which indicates coarse drainage texture (Table 2). Indirectly it denotes lower capacity of the region to drain out of the excess rainfall in basin area.

Form factor (Ff) indicates the flow characteristics of a basin. The value of form factor of present basin is 0.45 which indicates the basin is near circular to circular (Table 2). It also indicates higher peak flow in limited times. Due to circularity nature of the basin, it receives high amount of water from large areas of basin. Kosi have exceptionally high sediment yield (0.43 million tines/ year/km2). Thisis draining through a narrow alluvial plain which is almost one-fifth of its upper coarse. All amount of water will ultimately drain out through single outlet causes flood potentiality. And also the flood management of circular basin is costlier than elongated basin.

Elongation ratio (Re) is also a significant index of basin shape. It helps to give the idea about hydrological character of a drainage basin. Values around 1 are indicative of circularity and less than 1 is elongated characteristics. The Re value of the Kosi basin is 1.52 which denotes perfect circular characteristics of the basin (Table 2). Circular basin has the greater potentiality of flood due to its large catchment area and low draining capacity. The Re characteristics of Kosi basin reflects its flood potentiality.

Circularity ratio (Rc) is another important basin form characteristics. 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 circularity value of the Kosi basin (0.25) denotes high peak flood runoff in monsoon season (Table 2).

Compactness constant (Cc) denotes the relationship of circular basin with that of its hydrological characteristics. It gives the value equal to unity if watershed would near to circular. The Cc value of the present basin is 2.00 which denotes the flooding potentiality (Table 2).

The *Constant of channel maintenance (CCM)* is the required minimum area for the maintenance and development of a channel. It denotes the basin area amount needed for a linear length of channel. The CCM of the Kosi basin is 1.49 (Table 2). 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

Basin relief (R, H) is important factor for understanding the drainage network and its evaluation stage. Basin relief is ultimately the product of geology, acting drainage system, pedology, climate and vegetation characteristics of the region. The highest relief of Kosi basin is 3597 m. nearHimalayan peak. Lowest relief is 9 m. where it merges with Ganga (Table 2). So, the Relative relief is 3588 m. which seems very high for erosional activity.

Relief ratio (Rr) denotes the overall steepness of basin and is an important indicator of the erosional process. The relief ratio of Kosi basin is 12.41 which indicates low relief (Table 2). In Kosi basin, very high slope found in upper Himalayan reaches. But in lower reaches it hasvery low slope which causes flood situation (Fig 4).

Dissection index (Di) indicates the vertical erosion and dissected characteristics of a basin. It also indicates the stages of landform development of any basin or physiographic region. As dissection index is the ratio between Relative reliefs to the highest relief of the region, value ranges from '0' (absence of vertical dissection) to '1' (Vertical areas). The Dissection index value of present basin (0.9) indicating that Kosi merges with Ganga in perfect plain areas (Table 2).

Ruggedness index (Ri) indicates the stages of landform development as well as instability of the region or basin. 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 of Kosi basin indicates its youthful stage of landform development (Table 2).

Channel gradient is another important geomorphic indicator which indicates the channel surface altitude. In mountain-alluvial settings the greatest decline of 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. For present river basin it is almost vertical from source region up to Himalayan foothill areas (Fig. 5). 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.

Table 2: Drainage morphometric values of Kosi basin

	Parameters	Calculated Value
Linear Aspect	Stream No. (Nu)	I (5315), II (2449), III (1338), IV (768), V(551), VI (71), VII (99)
	Bifurcation Ratio (Rb)	I/II (2.17), II/III (1.83), III/IV (1.74), IV/V (1.39), V/VI (7.76), VI/VII (0.71)
	Mean Bifurcation Ratio (Rbm)	2.60
	Stream Length (Lu) (Km)	I (12396), II (6595), III (3463), IV(1756), V (1327), VI (162), VII (216)
	Mean Stream Length (Lum)	I (2.33), II (2.69), III (2.59), IV (2.29), V (2.41), VI (2.28), VII (2.18)
	Stream Length Ratio (Rl)	I/II (0.86), II/III (1.04), III/IV (1.13), IV/V (0.95), V/VI (1.06), VI/VII (1.04)
Areal Aspect	Basin Perimeter (P)	1392
	Basin Area (A)	38689
	Form Factor (Ff)	0.45
	Circularity Ratio (Rc)	0.26
	Elongation Ratio (Re)	1.52
	Compactness constant (Cc)	2.001392
	Constant of channel maintenence (CCM)	1.49
	Stream Frequency (Sf)	0.27
	Drainage Density (Dd)	0.67
	Texture ratio (Rt)	7.60
Relief Aspect	Absolute Relief (R)	3597
	Relative Relief (H)	3588
	Relief Ratio (Rr)	12.41
	Dissection Index (Di)	0.990
	Ruggedness Index (Ri)	2.40

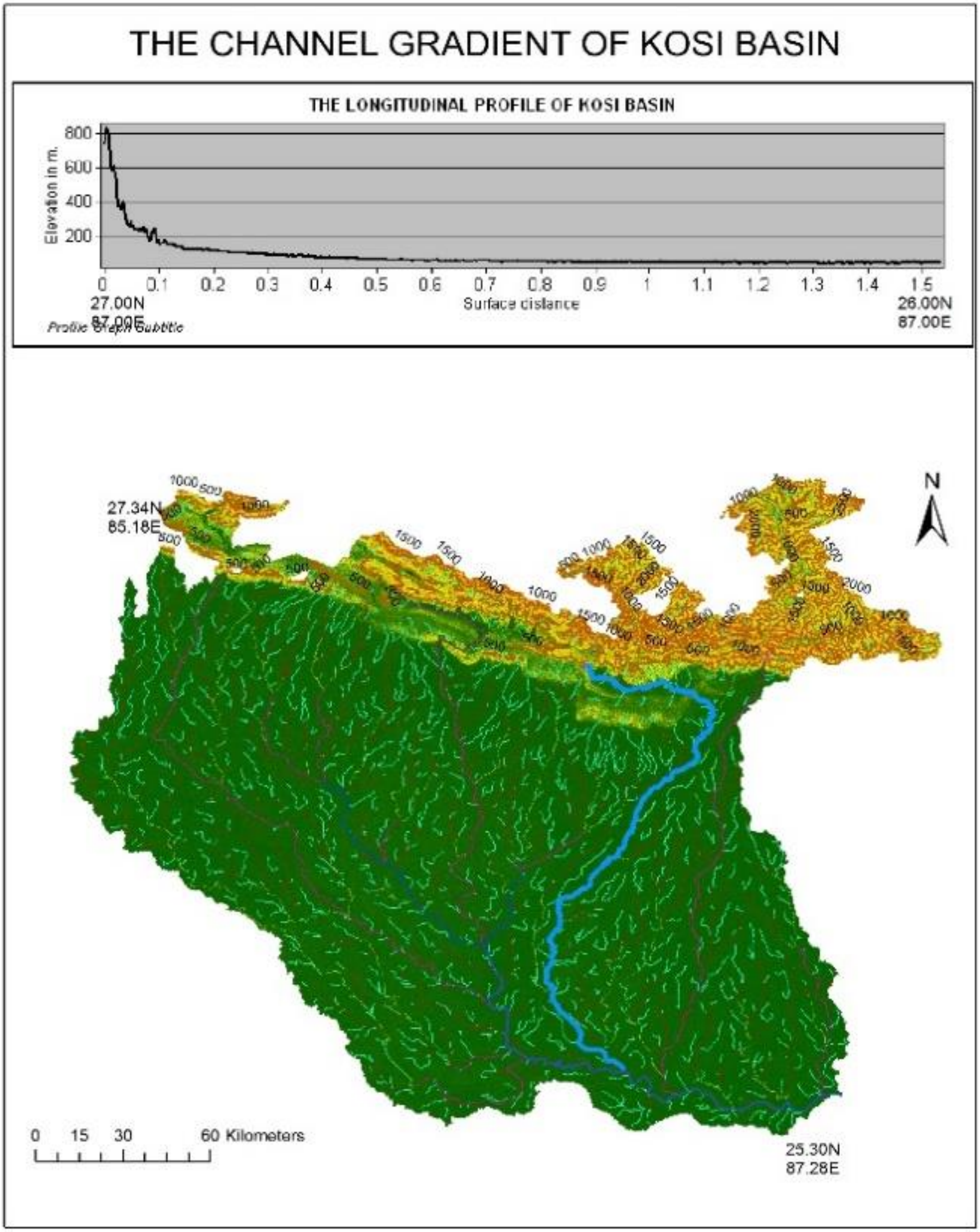


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Figure 5: Channel gradient of Kosi basin

IV. Conclusions

From the present study it can be inferred that the Kosi basin has dendritic near circular stream pattern facilitating concentrated runoff near the watershed's outlet. This increases the potentiality of flooding and related embankment failure. Kosi basin 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 because of less time available for infiltration of overland flow. Anomaly in bifurcation ratio between 6'th and 7'th order streams brings strong assumption that Kosi hashigh potentiality of flooding and current topographic development. The irregular changes of stream length of Kosi River indicate changes in topography which in turn indicates the younger stage of Kosi basin development. The calculated value of low drainage density (0.67 km/km2), low stream frequency (0.27), 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 high overland flow with low velocity giving rise to 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.

The values of relative relief (3588 m.), dissection index (0.999), and ruggedness index (2.40) of Kosi basin indicating the basin is in primary stages of geomorphic development and geomorphic and hydrological instability will more common in future. It can be concluded that morphometric analysis derived values indicate Kosi basin is susceptible to extreme flooding and related embankment failure instead of its large catchment area.

From time series analysis of remote sensing data it has been ascertaining that the land cover changes were taking place in the proximity of river course (Ghosh, 2009).

Instead of high dams and embankment non-structural measures should be favoured for river management in Kosi particular and northern Bihar in general. Use of diversion channel for drain out of excess water in monsoon season is another possibility of management. Paleo channel identification of Kosi river and channel network development is another possibility for flood management. The sediment supply characteristics in upper courses of Kosi is also necessary for flood management. There is necessity to develop basin-scale risk map with high-resolution remote sensing and GIS data.

References

[1] Agarwal, R.P. and Bhoj, R. 1992. Evolution of Kosi fan, India: Structural implications and geomorphic significance. Int. J. Remote Sensing, 13: 1891-1901.

[2]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.

[3] Arogyaswamy, R.N.P. 1971. Some geological factors influencing the behavior of the Kosi. Records of Geological Survey of India, 96: 42-52.

[4]Castillo, V. Diazsegovia, A. and Alonso, S.G. 1988. Quantitative Study of Fluvial Landscapes, Case Study in Madrid, Spain. Landscape and Urban Planrung, 16: 201-217.

[5]Chandran, R.V. Ramakrishnan, D. Chowdary, V.M. 2006. Flood mapping and analysis using air-borne synthetic aperture radar: A case study of July 2004 flood in Baghmati river basin, Bihar. Current Science, 90: 249-256.

[6]Ghosh, A.K. Bose, N. and Sinha, R.K. 2004. Study of Spatio-Temporal changes in the wetlands of north Bihar through Remote Sensing. Paper presented at the Conserving Soil and Water for Society: Sharing Solutions, USA.

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

[8]Jain, V. Sinha, R. Jain, V. and Sinha, R. 2008. Geomorphological Manifestations of the Flood Hazard : A Remote Sensing Based Approach.Geocarto International,18: 1752–762.

[9]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.

[10] Magesh, N.S. and Chandrasekar, N. 2014. GIS model-based morphometric evaluation of Tamiraparani subbasin, Tirunelveli district, Tamil Nadu, India. Arab J Geosci, 7: 131 – 141.

[**11]**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 Neotectonic Activity. J Indian Soc Remote Sens, 41(4): 895 – 904.

[12] 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.

[13] Singh, H. Parkash, B. and Gohain, K. 1993. Facies analysis of the Kosi megafan deposits. Sedimentary Geology,85: 87–113.

[14] Sinha, R. 2009. Dynamics of a River System – the Case of the Kosi River in North Bihar. Earth Science India, 2: 33–45.

[15] Sinha, R. Bapalu, G.V. and Singh, L.K. 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.

[16]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.

[17] Wells, N.A. and Dorr, J.A. 1987. Shifting of Kosi River, northern India. Geology, 15: 204-207.