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# Himalayan Catastrophe that Engulfed North Bihar

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**Abstract:** The recent Kosi megaflood, caused by a breach in the Kosi embankment in Nepal on August 18, 2008 and a sudden change in the course of the Kosi River, was one of the most significant and damaging flood events ever to hit Bihar. The Kosi disaster also ranks as one of the greatest disasters in India. This preliminary note briefly discusses some of the available details of the megaflood, the past great floods on the river, the special hydro-geomorphic characteristics of the basin, and the probable reasons for the failure of structural measures designed to mitigate the flooding problems on this Himalayan river with unique behavioural characteristics.

**Keywords:** Kosi River, Hydrogeomorphic characteristics, Catastropic floods, North Bihar.

## INTRODUCTION

The Kosi River has a history of devastating floods and capricious behaviour, and is aptly called the *river of sorrow*. On August 18, 2008 the river suddenly tore apart its eastern embankment at Kusaha in Nepal and reoccupied one of its former courses (Fig. 1), causing the worst flood in last five decades. The flood overwhelmed the life and the landscape of Bihar. In terms of the quantum of destruction, this extraordinary event is comparable to the super-cyclone of October 29, 1999 and the tsunami of December 26, 2004. This megaflood uprooted over three million people, swamped hundreds of villages and caused serious damage to infrastructure. This brief note attempts to understand the nature of the problem of this unique river by asking some very fundamental questions.

### How Unusual was the August 2008 Flood Event?

Hydrological records for the Kosi River are not long (>100 years) and continuous to satisfactorily answer questions, such as – (a) just how unusual was this flood event? (b) have similar or more extreme events occurred in the past? and (c) whether the frequency of such events has increased in recent decades? This is because, extreme events with a recurrence interval of 100 years or more are not represented in the short instrumental records (<50 years).

Annual peak discharge data available for the Sunakhambhi Khola/ Barahkshetra (*see* Fig.4 for location) gauging stations in Nepal indicate that, within the 20th century, high discharges in the range of 24000-26000 $m^3s^{-1}$ were recorded on three occasions i.e. in 1924, 1954 and 1968 (UNESCO, 1976; Galgali, 1986; Rakhecha, 2002; Sinha et al. in press). In terms of flood size, the 1968 flood was the highest, although in terms of the quantum of devastation the 1954 flood event was the worst. The peak discharge estimated for the 1968 event was ~2.6 times higher than the average annual peak discharge at Barahkshetra (Fig.2). Before 1924, there are reports of large floods in 1879, 1886, 1890, 1898, 1899 and 1922 in Bihar.

In the absence of long (>100 years) discharge records, hydrologists generally use meteorological records to estimate the recurrence interval of extreme hydrological events. However, as most of the catchment area of the Kosi River falls within the territory of Nepal and Tibet, for a greater part of the basin area historical rainfall records are not available with the India Meteorological Department (IMD) to inform on the number of flood-producing heavy rainfall events during the last 100 to 150 years. What is more surprising is that no serious efforts have been made to obtain and use rainfall data from neighboring countries to reconstruct the long-term rainfall series for this transboundary river (as well as other rivers) in spite of the fact that post-1947 data are available with the Nepal Department of Hydrology and Meteorology for the Kosi River (Sharma, et al., 2000). In a recent study, Ranade et al. (2007) have reconstructed rainfall series for the period prior to 1901 (sometimes going back to 1813) with lesser observations for a number of river basins of India, including Kosi. However, the reconstructed series (1870-2005) for the Kosi River is based on the data from one station located on the Bihar Plains and not upstream. Needless to say the

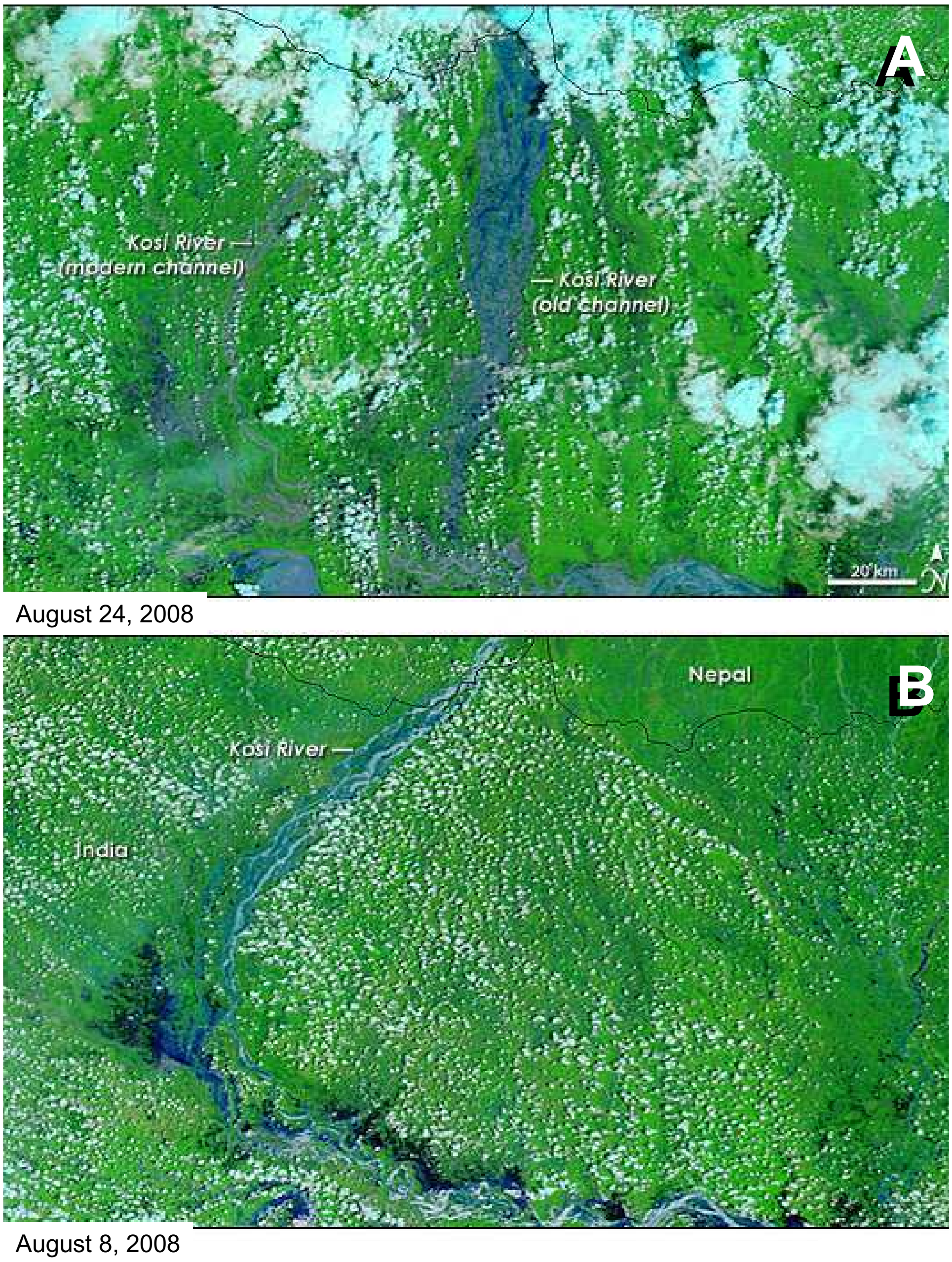


**Fig.1.** Satellite pictures of August 24, 2008 (**A**) showing the post-flood channel and of August 8, 2008 (**B**) illustrating the pre-flood channel. Note that the new channel is much wider than the former course because of flood. The images were acquired by Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite Source: NASA's Earth Observatory.

developed long rainfall series would have provided vital information about extreme events and their periodicity if the series would have had incorporated all the available data from Nepal and Tibet as well.

Notwithstanding these limitations, it is reasonable to infer that the August 2008 flood was a catastrophic event, because the flood was one of the most widespread, long duration and damaging natural disasters ever to hit Bihar. The increased population density translated this into an unprecedented human misery.

### Why does the Kosi River Spill Over its Banks and Inundates Large Areas Frequently?

Flooding is a natural feature of the monsoon-fed streams and rivers. Virtually all the rivers of the Indian sub-continent have long histories of floods. Most commonly floods occur

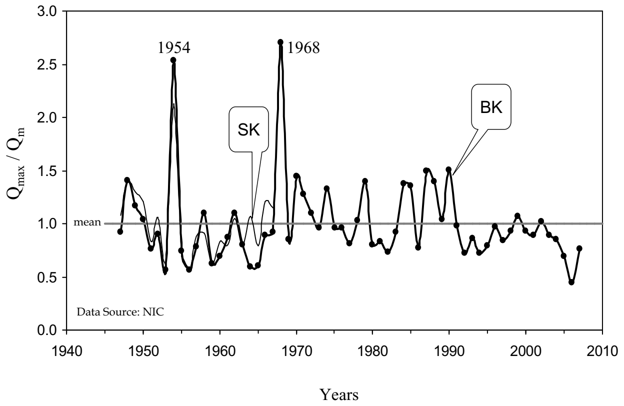


**Fig.2.** Time series plot of $Q_{max}/Q_m$ ratio. $Q_{max}$ = annual peak discharge and $Q_m$ = long-term average peak discharge. SK = Sunakhambhi Khola gauging station data; BK = Barahkshetra gauging station data. See text for source of data.

from heavy monsoon precipitation when natural watercourses do not have the capacity to accommodate and carry excess water. Floods on the Kosi River are an annual feature. The question that follows is – why the Kosi catchment produces excess runoff which the river finds itself unable to handle?

Runoff in a catchment depends on the interaction of a number of factors, such as terrain and basin characteristics, intensity and duration of precipitation; forest cover, antecedent conditions, etc. A basic understanding of the topographical and synoptic characteristics of the basin can, therefore, provide some explanation to this simple yet profound question.

***Drainage Basin and Relief Morphology***

With an area of about 75,000 km$^2$, the Kosi is one of largest Himalayan tributaries of the Ganga River. The river rises over the Tibetan Plateau at an elevation of more than five km above sea level (ASL) and flows through Tibet, Nepal and India. Mt. Everest (8848 m ASL), the highest peak in the world, and Kanchanjangha (8598 m ASL) are located within the Kosi catchment. The river is comparable to the Kaveri River in length and basin area. However, what is peculiar about this modest-sized river is that nearly 84% of the catchment area is characterized by highlands and only 1/5$^{th}$ of the basin area constitutes the plains (Fig.3). Thus, the upland-to-plain area ratio is 5.25, one of the highest for a river of this size (Sinha and Friend, 1994). Digital Elevation Model (DEM) analysis, based on Shuttle Radar Topography Mission (SRTM) data, reveals that approximately 50% of the basin area is above 4000 m ASL and the area below 120 m ASL is only 16% (Fig. 4). This in simple words means that there is not enough space on the plains to accommodate the enormous runoff (52 x 10$^9$m$^3$) generated by 84% of the catchment area.

On account of very high basin relief (highest in the world), the Kosi River in Himalay has an unusually steep channel gradient. Consequently, the Sapta Kosi and its tributaries (Sun Kosi, Tamur and Arun) cascade through steep, narrow and deep gorges, carrying enormous sediment load on the way. When the river finally exits the mountainous terrain and emerges onto the Bihar Plains the channel bed profile abruptly flattens, forcing the river to dump most of its sediment load within the channel and over the adjacent flood plain. The Kosi channel, downstream of the exit-point is very wide, shallow and highly braided. The channel morphology and pattern are manifestations of the inability of the river to carry all the sediments imposed from upstream. High width-depth ratio and low channel gradient implies that the specific stream power, or the ability to do work, is remarkablely low below the exit-point. Rough estimates indicate that the unit stream power in the braided reach is less than 10 Wm$^{-2}$.

Over thousands of years, the river has brought and deposited huge quantities of sediments in this manner and has formed a gigantic alluvial fan in the foothills, popularly known as the *Kosi Megafan*. With the passage of time, the active channel of the river is silted up and the river is forced to abandon the course and shift by avulsion, in the process impacting newer areas. During the past two and half centuries the river has been wandering across the gently-sloping fan surface and reworking all the land in between (Gole and Chitale, 1966). The lobe-like feature at the downstream end of the Kosi River (Fig.4) is characterized by very wide and flat land. The shaded contour map of the megafan given in Fig.5 clearly shows that contour lines, although not smooth, broadly comprise arcs of

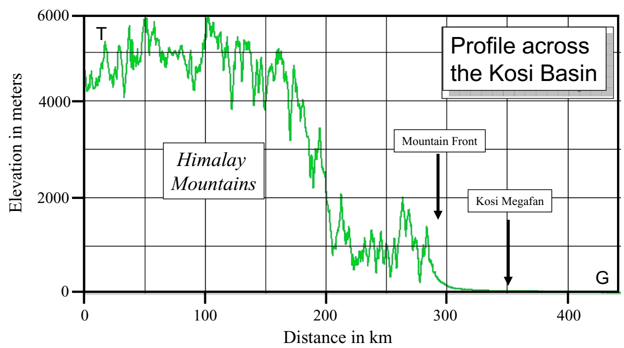


**Fig.3.** Transverse profile across the Kosi Basin. T = Tibet, G = Ganga River.

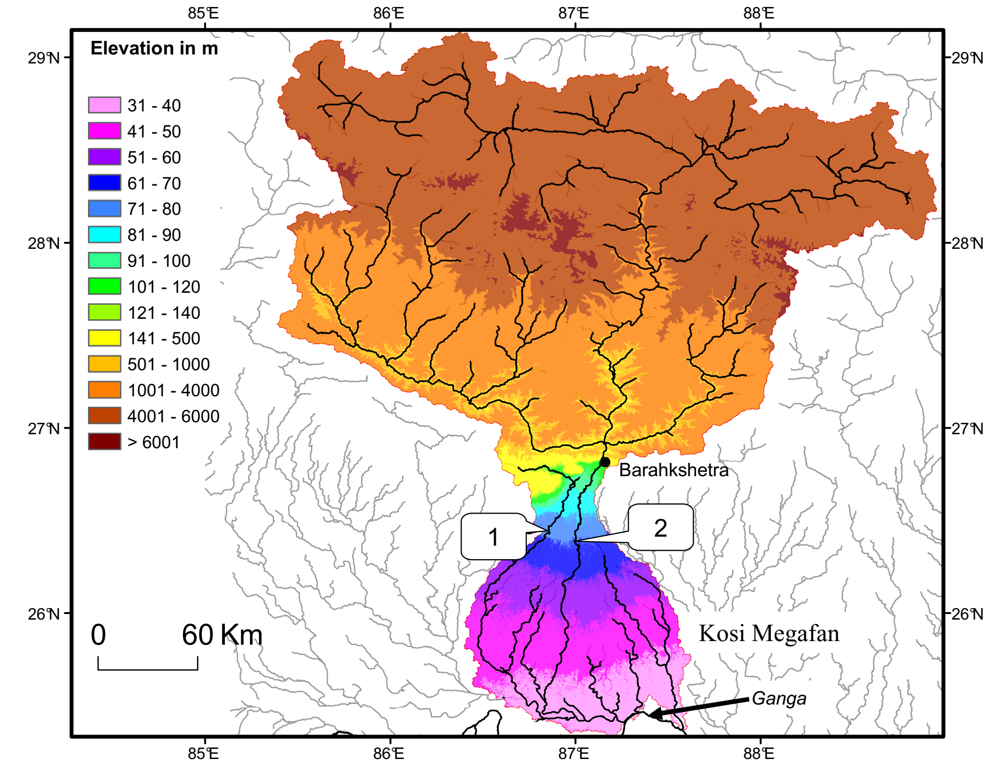


**Fig.4.** Classified colour-coded elevation image of the Kosi Basin. The image was generated from SRTM-DEM data. The image shows the fan area and the upstream area in Himalay. 1 = pre-flood course; 2 = post-flood course. Note the straight course of the Kosi River over the fan surface derived from SRTM data in ArcGIS.

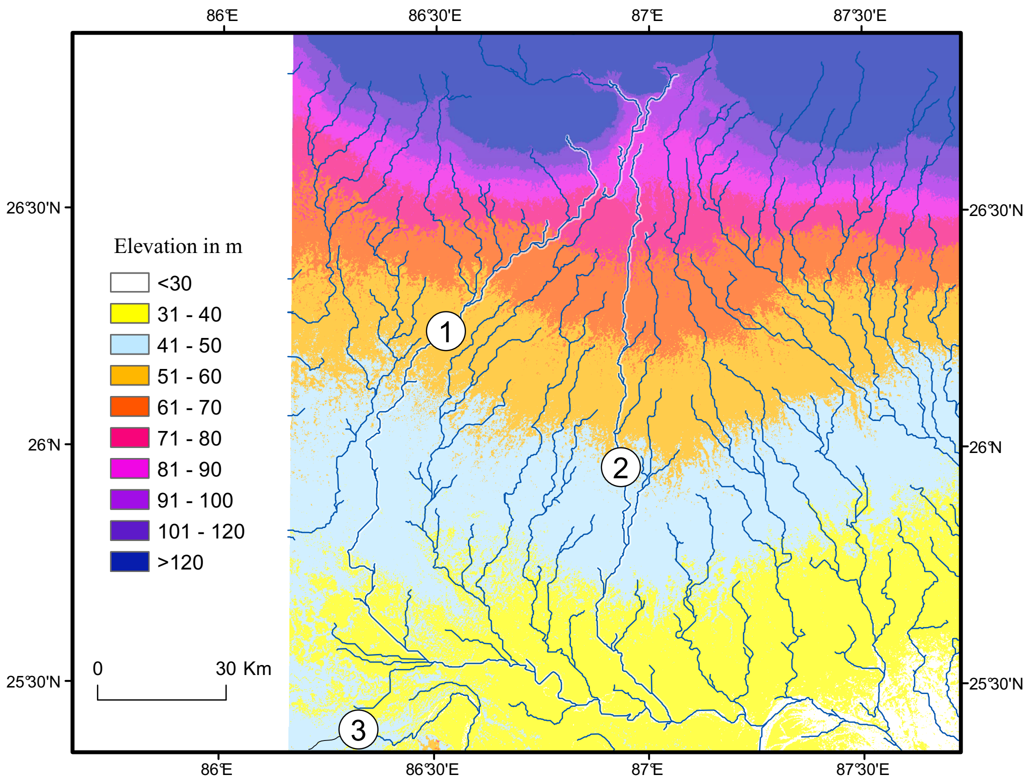


**Fig.5.** Classified colour-coded elevation image of the Kosi Megafan, showing elevation classes and drainage network extracted from the SRTM-DEM data. 1 = pre-flood course; 2 = post-flood course; 3 = Ganga.

concentric circles. The fan area is ~ 100 x 150 km. The elevation difference ranges from 80 to 100 m, giving a fan surface gradient of about 0.55 x $10^{-3}$. Geomorphologically, such lands will experience frequent flooding.

***Catchment Hydro-climatic Conditions***

In a study of megafans, Leier et al. (2005) noted that the Kosi-type fluvial megafans are associated with particular climatic conditions. Such megafans are produced by rivers characterized by highly seasonal rainfall and river regime conditions. Large fluctuations in discharge promote channel instability and avulsion. The FFMI (flash flood magnitude index) for the Kosi River is 0.31, which is higher than the world average (0.28).

A factor that has significantly contributed to the large variation in the discharge is the occurrence of heavy rain-producing synoptic weather conditions in the catchment during 'monsoon breaks', a unique meteorological phenomenon of the Indian monsoon. Monsoon breaks occur when the axis of the monsoon trough shifts northwards from its normal position and lies over the sub-Himalayan and the foothill regions. This shift in the axis results in torrential rains over the northeastern and central Himalaya and their adjoining plains, and drought conditions over rest of the country. The Weekly Weather Reports published by IMD mention a temporary northward shift of the western end of the monsoon trough during 16th and 20th August 2008. The reports also state that the eastern end of the trough was situated over the northern parts of Bihar on 28th and 29th August 2008. It is, therefore, likely that very heavy to extremely heavy rains (12.5 - 25 cm) must have occurred during this period in the upper catchment of the Kosi River in Nepal. About 151 mm rainfall was record at Dharan (26°48'37" N and 87°16'12" E), near Barahkshetra, on August 29, 2008 (source: Meteorological Forecasting Division, Government of Nepal). According to Ramaswamy (1985), marked break-situations were also observed in July and August 1954, when a catastrophic flood occurred. Thus, it appears that monsoon-break situations are one of the highly favourable synoptic conditions for the occurrence of heavy rainfall, apart from active monsoon conditions. The orographic effect of Himalay, also significantly contributes to the rainfall variability.

Such heavy precipitation in the mountainous catchment area is too much for the Kosi River to handle, causing water to overflow and inundate large areas in the low-gradient reach of the river over the Kosi Megafan.

More or less, similar hydro-geomorphic conditions also exist in some of the other Himalayan rivers. But only the Kosi River, unfortunately, seems to have the right combination of basin relief, basin size, upland-to-plain area ratio, intensity and duration of rainfall over the catchment and the downstream rate of change in the channel gradient to frequently produce flood havocs over the Bihar Plains.

**What are the Reasons for the Episodic Shift in the Course of the Kosi River?**

The classic paper by Gole and Chitale (1966), for the first time, brought to the notice of the world the unique behavioral characteristics of the Kosi River. Their study revealed that during the past few hundred years, the Kosi River has episodically shifted by over 100 km westward across its gigantic fan by successive avulsions. Wells and Dorr (1987) investigated the possible causes of the frequent shifting of the Kosi channel and concluded that the shifts were stochastic and autocyclic, and not related with any type of catastrophic events, such as high-magnitude floods or severe earthquakes.

From the historical records it is apparent that the Kosi River channel in its lower reaches is inherently unstable and dynamic. Logically, this appears primarily due to the excess sediment load that the river carries every year, and which the river is unable to carry once it exits the mountains. Galgali (1986) reports the average sediment concentration (mass of sediment in water per unit volume of water) at Barahkshetra (Fig. 4) to be ~ 0.16% and the annual sediment load of the Kosi as 82 x $10^6$ $m^3$. This translates to ca. 1100 $m^3$ of sediments per $km^2$. Exceptionally high sediment concentration (0.47%) was observed during the megaflood of August 1954 (Galgali, 1986). The excessive sediment load brought by the river is deposited within the channel which reduces the channel capacity and raises the bed level. The natural response of the river is either to over spill its banks or to altogether abandon its channel and to move to areas of lower elevation (Wells and Dorr, 1987).

Therefore, a change in the position was overdue after the channel occupied its course in mid-1950s. There are reports of breaching of the Kosi western embankment during the last few decades, suggesting that the Kosi River was trying to break the man-made barriers and move further west. Apparently, the Kosi channel was unable to shift because of levees. The anticipated event finally occurred on August 18, 2008 when the Kosi was able to breach the eastern (not the western) embankment in Nepal at Kushah and revert to its old abandoned channel that it had formed in the early part of the 20th century.

That such an event was waiting to happen was foreseen by many experts familiar with the behaviour of the Kosi River. In an article in Nepali Times about five years ago

(8-14 August 2003 #157) Mr. Navin Singh Khadka wrote: *"At the point where the river flows out of the mountains in Chatara, the Kosi is riding higher and experts fear it could easily flow back to its original course … …the threats of a Kosi breach at Chatara or a flood bypass of the barrage are clear and present dangers. It could happen 10 years from now, or it could happen next week. But it will happen. And when it does it will make this year's floods …… look like a picnic"*. This prediction came true five years later.

Gole and Chitale (1966) opined that the river in its natural course would eventually find a stable course that would roughly run straight south from Chatra (near Barahkshetra). On August 18, 2008 the Kosi took this shortest route to the Ganga River (Fig.1). That this course is most suitable for the river under the given topographic conditions, has been clearly brought out by SRTM-DEM analysis. It is interesting to note that the drainage network automatically extracted from DEM (Fig.4) shows that the path of the Kosi River (marked 2 in Fig.4) does not coincide with the ca.1954 course, but with the post-August 18, 2008 path.

Should the river be diverted back to its original course? To answer this question it may be necessary to undertake systematic investigations of the possible consequences for the local population as well as the river. It is not unlikely that the river may stabilize for a while if it is left undisturbed at this point of time, or it may choose to go back to its original course. However, what will be the recovery time, remains uncertain.

**Is There a Sustainable Solution to the Problem?**

Hydro-climatic and relief conditions of the river basin suggest that large-magnitude floods will occur in future also and are inevitable.

The long-term solution suggested by hydraulic engineers to resolve the problem of frequent flooding has been the construction of flood embankments and high dams. Not surprisingly, attempts were made to tame the erratic Kosi by constructing flood embankments at the Indo-Nepalese boarder to confine the spills and by constructing the Bhimnagar Barrage to regulate the river flow and trap sediment, after the devastating floods of August 1954. The barrage was completed in 1963. A high dam at Barahkshetra in Nepal was also proposed in 1946, but this proposal was shelved due to economic and other reasons.

Serious doubts were expressed on the effectiveness of the engineering structures after the great flood of 1993 on the Mississippi River. Reports indicate that over 80% (i.e. over 1000) of the levees in upper Mississippi were either overtopped or failed. This and other failure-stories indicate that physical structures are not viable solutions to the chronic flooding, especially for a river like Kosi that carries enormous amounts of silt and is inherently unstable. The August 2008 extreme event was a clear demonstration. Flood embankments or levees are only short-term measures and large dams can only control common moderate-magnitude floods, but not the extreme ones. In the case of flood embankments and levees, regular maintenance and constant vigilance are a pre-requisite for preventing breaching of the embankments (Galgali, 1986). Structural measures often create a false sense of security and encourage more and more people to settle in the flood sensitive areas. Failure of dams and embankments then result in misery of an amplified scale.

A problem that needs a special consideration while formulating an effective as well as safer flood defense system is the enormous amounts of sediment (>80 x $10^6$ $m^3$) the river brings down from the Himalay every year. Any structure across the river traps more sediments and puts enormous pressure on the structure and also affects the river regime. Sediment accretion reduces the storage capacity and increases the chances of overbank flows and bigger floods. Studies indicate that after the construction of the Bhimnagar Barrage across the river in 1963, extensive deposition of coarse sand occurred in the reservoir area extending up to 10 km upstream (Galgali, 1986). Considering the fact that about 80 million cubic meters of sediments pass through this reach every year, regular dredging of the river bed or building durable and higher embankments does not seem to be a viable and river-friendly proposition. Further, in view of the large area (over $10^4$ $km^2$) and population ($10^6$ to $10^7$) under constant threat, other measures normally adopted for flood control, such as relocating villages or raising the level of the adjacent land, etc. also do not seem to be logical, economical and sustainable solutions.

Flood forecasting and warning, and dissemination of this information to concerned authorities is one of the most recommended non-structural measures to save lives and minimize damages. Unlike earthquakes and landslides, which occur with little or no warning, floods on large rivers generally develop over a period of days. The heavy rain-producing synoptic weather conditions, such as monsoon breaks, could also be easily monitored and flood warnings could be issued well in time. Use of more sophisticated mathematical models for the purpose of flood forecasting could significantly contribute in disaster mitigation.

Upland reforestation and afforestation could also be an important step because only about 25% of the basin area in Nepal and Tibet was under forest cover in 1970 (Sharma et al. 2000). A substantial increase in the forest cover in the upland (excluding the dryland area of Tibet) could have a remarkable impact on the production of annual runoff and sediment load. However this requires regional cooperation among the co-riparian nations.

Reserving lands in the highly flood-prone areas to accommodate flood waters during extreme floods could considerably reduce economic damages and loss of human life. Another potentially promising solution that could lessen the severity of great floods is to transfer or divert the excess water from the active channel at the apex of the fan to the multiple palaeo-channels during peak flows. This of course requires an innovative design from hydraulic engineers (something on the lines of sea dykes of Netherlands) and support from the local population.

Systematic flood-risk zone mapping for the entire megafan area is the need of the hour. Previous studies have covered only some parts of the fan area (Rao et al. 1998). In addition, since channel migration poses considerable threat to the population, there is a need to undertake avulsion hazard zone mapping to identify areas with high avulsion hazard potential. The mapping and identification of *hotspots* can be achieved by combining high resolution topographic data and hydraulic models for this very flat terrain. Cartosat or Airborne Laser Swath Mapping technology (ALSM) or LiDAR (Light Detection And Ranging) offer high-quality and high-resolution topographical data that could be used in such models.

Recent IPCC (Intergovernmental Panel on Climate Change) Assessment Reports project an increase in Asian summer monsoon variability and changes in monsoon strength. Although there are no distinct trends in peak floods on Kosi, the risk of flooding is likely to increase as a result of increased variability in the monsoon precipitation. Empirical, statistical or physically based models could be used to determine how and to what degree changing climate can impact floods on this Himalayan river, with unique behavioural characteristics.

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