

Effect of the barrage and embankments on flooding and channel avulsion case study Koshi River, Nepal

Lochan Devkota¹, Alessandra Crosato², Sanjay Giri³

¹*Mott MacDonald Singapore Pte Ltd*

Grange Road, #07-01, Orchard Building, Singapore 239693

lochan.devkota@mottmac.com

²*UNESCO-IHE, Institute for Water Education*

P.O.Box 3015, 2601 DA Delft, The Netherlands

a.crosato@unesco-ihe.org

³*Department of River Dynamics, Morphology and Water Transport, Deltares*

Rotterdamseweg185, 2629 HD Delft, The Netherlands

Sanjay.Giri@deltares.nl

Abstract— Humans have utilized water resources for millennia by modifying natural river courses and such interventions have greatly influenced not only river flows and sediment fluxes, but also the overall river morphology.

Situated in the Nepal's eastern Ganges region, the braided Koshi River is unique among the other rivers, because of the high frequency of channel avulsion and other morphological changes, such as: channel migration, channel width adjustment. This study examines effect of the Koshi barrage and related embankments on flooding and channel avulsion in Koshi River. In particular, it tries to explain the avulsion that occurred in 2008, studying the role of the Koshi barrage, and related embankments, constructed near the border between Nepal and India in 1963. Series of satellite images and historical maps show overall sedimentation, especially in the western side of the river channel, which lead to the shifting of the Koshi River towards the east (almost 6 km) during around 40 years period, since the construction of the barrage, although before, shifting toward the west. The barrage was constructed at eastern side of the river channel within two embankments, leading to sedimentation in western side, since river is flowing short courses. Sediment deposition upstream of the barrage brought to the conditions that lead to dike breaching in 2008. During the 2008 flooding event, huge amounts of previously deposited sediment were eroded from the river bed upstream of the barrage. The resulting bed lowering means a gain of time to prevent a similar event in the future, since new space for sediment inside the embankments system has been created. So, this time, estimated in 40-50 years, can be used to take proper river engineering measures.

Keywords— Aggradation, Avulsion, Barrage, Flooding, Koshi River, Morphology

I. INTRODUCTION

The Koshi River, also called as Sapta-Koshi, is a trans-boundary river originating from the Himalaya and flowing through the eastern part of Nepal and the flat plain of India. It is the largest tributary of the Ganges, causing soil erosion equivalent to nearly 50% of total sediment load and accounting for about 25% of Nepal's total river runoff [7]. The

average monthly discharge of the river varies from 500 to 6,000 m³/s with a mean annual flood discharge of around 7,000 m³/s [12]. The river brings about 120 million cubic meters of sediment load every year at Chatara derived from landslide and mass wasting to the Ganges and approximately 90% of this load is transported during monsoon period (June - October) [2], [7]. The Koshi River is also known as the "Sorrow of Bihar"; through flooding and very frequent changes in course it has caused widespread human suffering [14].

The Koshi River is one of the largest braided streams of the world [4], [2]. It forms a huge alluvial fan when it enters in the flat plain of Nepal and India. The alluvial fan of the river downstream of Chatara is built by large sediment fluxes, which is also the primary factor causing the shifting of the Koshi River and extensive flooding [1]. The dynamic nature of the river has attracted attention for over a century and a variety of mechanisms have been suggested to explain its avulsions ranging from "tectonic tilting" and "nodal avulsion".

II. KOSHI FLOODING

Flood event is common in the Koshi River since its historical time. In 18 August 2008, dike breach of Koshi River took place at Kusaha around 12 km (Chainage from the barrage 12.1 km to 12.9 km) upstream from the barrage and the river made an eastward jump of several kilometres. Sinha [13], describe that unlike the previous westward avulsions, the 2008 avulsion of the Koshi recorded an eastward jump of ~120 km which is an order of magnitude higher than any single abusive shift recorded in historical times. The avulsion was triggered by a breached in the eastern embankment and 80 – 85% flow of the river was diverted into the new course. Since, the new course had a much lower carrying capacity, the water flowed like a sheet, 15–20 km wide and 150 km long with a velocity of 1 m/s at the time of breach. Interestingly in some part, the new course did not join back the Koshi nor did this find through-drainage into the Ganga, as a result of which a very large area remained inundated/waterlogged for more

than four months after the breach. After nine months, the river was diverted back into the pre-2008 channel. The resulting flood left nearly 527 lives inundated, 116 thousands Hacter of land and left 234 thousand people homeless [9]. About 1,500 square kilometre of farmland was left useless, covered under a thick layer of infertile, dry sand.

As early as 1966, scientific concerns were shown that the flood embankments could not prevent the shifting tendency of the Koshi Course [5]. Although, it prevented major flood in Bihar for about 50 years, the project was disputed. Many scientists continued to caution that the Koshi barrage was on verge of breach, worries had been expressed that a disaster was inevitable, the 2008 flood rectified their concerns, it took. Inadequacy of proper communication has been demonstrated by some field research scientists in relation to failure of dike [11].

The extreme flow in the Koshi River at Chatara station was 25,879 m³/s in 1968 followed by 24,241 m³/s in 1954 and then about the 24,000 m³/s in 1980 [2]. But, the flood flow in August 2008 at Chatara was only about 4,250 m³/s, which was less than the mean annual flood flow so poor maintenance is direct cause of the breach. Study carried out by Devkota et. al. concluded that geomorphology of the river is poorly understood and as the world's second largest silt carrying river, the role of silt in bank erosion needs further study.

Regmi [9] claims that, at least three points indicates the 2008 Koshi flood as manmade; failure to address the sedimentation problem upstream of the barrage with effective counter measures, no regular repair and maintenance work of the upstream embankments and due to delay in opening the barrage gates.

Following the flood in 2008, Sinha [12] and Reddy et al. [8] examined aspect of the Koshi River as cited by Chakraborty et al. [1], the megafan and flood management efforts in this area. Sinha [12] clearly mention that, to date most of the flood prevention efforts were with a notion of "river control" rather than "river management". He pointed out that unlike the progressive shift of the Koshi toward west; during the last flood it has shifted a long distance to the east. He emphasized that the August 2008 event was flooding due to avulsion rather than flooding by overtopping of the river banks. He further claims, confinement of the Koshi within the embankments further worsened the situation and has caused significant aggradations within the channel belt and ultimately river was possibly flowing at a higher elevation than the surrounding areas outside the embankment. Critical issues raised by Chakraborty et al [1], during the flood of August 2008, the Koshi avulsed to the east, why did it stop moving further west [as predicted by Shillingfield, 1983 quoted by Gole and Chitale [5]. Furthermore, Reddy et al. [7] suggested that the river should be allowed to flow through its post-2008-flood course and that a detailed topographical survey and age determination should be carried out for future flood prediction.



Figure 1: Koshi River before (left) and after (right) dike breach in 2008.

III. CHANNEL AVULSION

The tendency to change course in rivers depends upon a wide range of geomorphic contexts and is triggered by an extreme event or by human intervention on the river. In the Koshi River, both situations are present. Probabilities of occurrence of high discharge from upstream are same as before the construction of the Koshi barrage, but construction of barrage and embankments change water and bed levels and in particular lead to increase in sedimentation, increasing the tendency to erode banks and ultimately channel avulsion. So, damming the Koshi River is a recipe for disaster, because upstream sedimentation was inevitably leads to overtopping and breaching of the dikes.

IV. DATA ANALYSIS

Koshi catchment receives 80 to 85% of the total rainfall from the southerly monsoons which break towards the end of May and continue until October. The average annual rainfall in the drainage basin is increase from 1780 mm in the foothills to 3560 mm in the southern slopes of the Himalayan. Koshi exhibits a highly variable discharge. Average monthly discharge of the Koshi River varies from 500 to 6,000 m³/s. The peak flow normally recorded from July to October following heavy rain falls in the catchment areas and may around ten times as large as the mean discharge in a single year. The mean annual flood discharge of the Koshi is around 7,000 m³/s. During 67% of the time flow is less than mean annual discharge of 1525 m³/s near Chatara as shown in Figure 2.

Furthermore, analysis carried out by Devkota [3] shows that 2008 event was occurred at normal hydrological year as shown in Figure 3. So, flood discharge during 2008 is not an extreme discharge to trigger the dike breach comparing to other years.

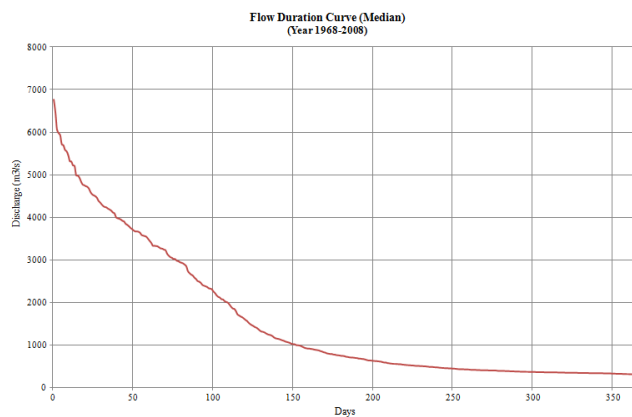


Figure 2: Flow duration curve of Koshi River near Chatara, 1967-2008.

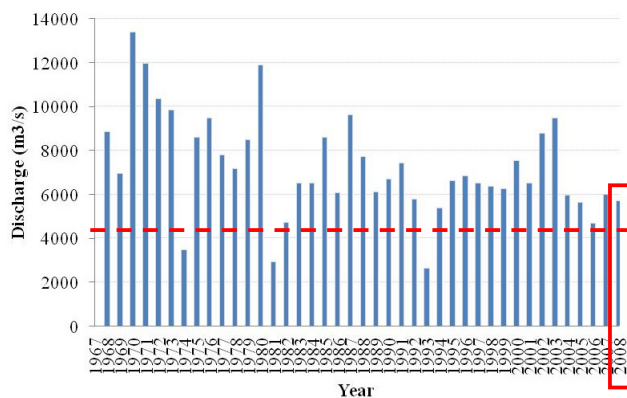


Figure 3: Annual maximum discharge of the Koshi River near Chatara, 1968-2008.

Construction of the Koshi Barrage lead to high aggradations upstream of the barrage, but the area just downstream of barrage has been marked by a small degradations [10], [4]. After the Koshi project was finalized, river showed important morphological changes. Bed aggradations and degradations of the Koshi River were studied by Sanyal [10] for different reaches, for period of 1955-1974. The river bed levels were observed to mostly aggrade in two reaches (upstream of the barrage) after construction period of the Koshi Project as shown in Table 1:

Table 1: Koshi River bed level changes as studies [1].

River Reach	Length of Reach (km)		Bed level variation (mm/yr)		Volume changed in river bed (million m ³ /yr)	
	From	To	1955-62	1963-74	1955-62	1963-74
Chatara	Jalpapur	27	(-) 17.6	(+) 123.4	(-) 4.04	(+) 28.30
Jalpapur	Koshi Barrage	15	-165.6	+107	-16	+10.43

Based on Table 1, one can concluded that the majority of sediment load became trapped, leading to a phenomenal rise of the riverbed, 10 to 20 cm per year in many places. This made the embanked channel significantly more destructive because of the bed and water level than it had been previously. Such an elevated river is very channeling to keep stable.

V. MAP ANALYSIS

Available satellite image of November 2010 and Historical map from 1970's was considered as main sources of information including aerial photographs and Google images for map analysis. Topography 1970 shows that, river was wide up to 10 km (around 14 km upstream from the barrage) as shown in Figure 4. Initially, river was flowing through the whole embankments with three main channels. But, topography 2010 shows that, river is confined within less than 4.5 km and flow is concentrated towards the east. There are presences of few permanent islands with series of migrating and non migrating bars. So, almost in 40 years period, Koshi River significantly changes its course within its two embankments and barrage. Many changes in channel patterns, flow distribution and position of islands were observed as shown in Figure 4. There was huge sedimentation occurred over short period of time on the western side and river flow concentrate toward the east. Permanent islands presence in the topography 1970 on western side becomes permanent bank and flow concentrated towards the east. When these islands become permanent bank, other islands were also changed/modified their shape and position due to modified flow distribution and dominating channels pattern. Comparing to topography 1970 with topography 2010 one can notice that the number of islands is also reduced over time.

Closer view in Figure 4, near the dike breached area during 2008 (indicated by arrow) reveals that, there was huge sedimentation near the western bank and river section narrowed from around 10 km to 4 km. Analyzing these maps, one can conclude that the flow was concentrated toward east after construction of barrage and embankments, although historical map analysis of Chakraborty et. al. [1] study shows that Koshi River continuously migrated >113 km westward across the surface of the megafan over the last two centuries (1760 to 1960) before construction of barrage. So, significant influence of the embankments and barrage were observed during 40 year period for channel avulsion and upstream aggradation especially near the western embankment.

In addition to this, Figure 4 also reveals that barrage was not constructed in the middle of two embankments. Due to closer in eastward position of the barrage, all flow is concentrated towards the east following the shorter course where high slope occurred and leading sedimentation to westward. So, position of barrage gate also plays a significant role to shift the river towards the east.

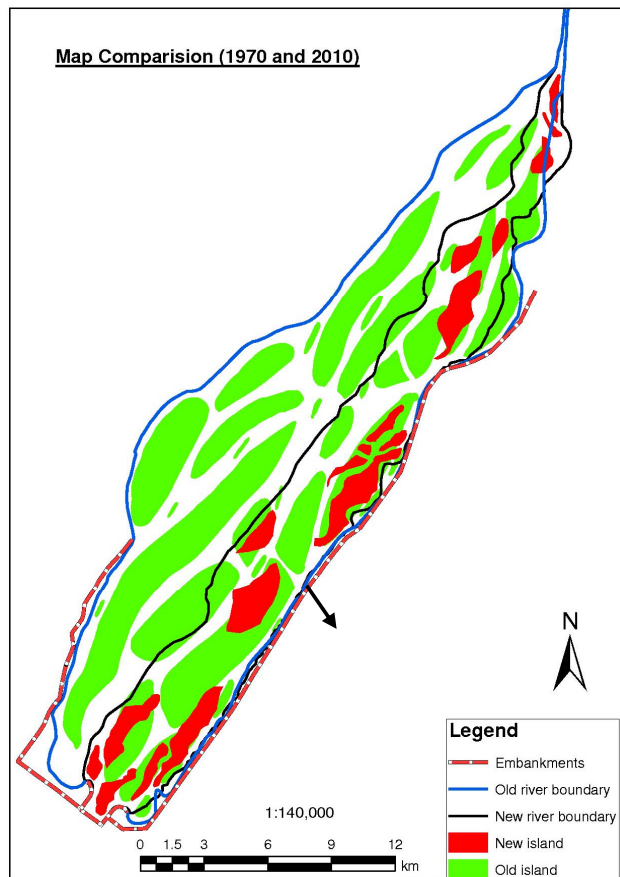


Figure 4: Comparison of two maps (1970 and 2010) with fixed embankments.

VI. SEDIMENT VOLUME ANALYSIS

Sediment volume is critical parameter to analyze the morphodynamics changes. Since, there were no measurement of the exact bed level before and after the 2008 event, one can't give the conclusive answer of the bed level development of the Koshi River [3]. But, based on previous study, analysis and findings, simplified sediment volume analysis for past and future are carried out based on the available data, considering that the 2008 event occurred during an ordinary hydrological year. Detail sediment balances after construction of barrage at 1963 to dike breach 2008 are illustrated in Table 2.

Table 2: Sediment Balance from 1963 to 2008.

S N	Descriptions	Quantity	Unit	Reference
1	Average annual sediment ¹ (wash + bed material) input of the Koshi River	120	Million m ³	[4]
2	Total sedimentation Volume outside the river ² (event + afterward)	315 - 420	Million m ³	[6]
3	Difference between sedimentation volume - Sediment input	195 - 300	Million m ³	
Deposited volume inside river channel (last 12 km) 1963-2008				
4	1963 averaged bed level	79.1	amsl	
	Average aggradation rate	0.12	m/yr	[10]
	2008 averaged bed level ³	84.5	amsl	
	2009 averaged bed level	80.0	amsl	2009 Survey
	Bed level changed during 2008 event	-4.5	m	Scoured
Eroded volume of bed material during 2008				
5	Average channel width	2,200	m	Google and satellite map
	Scoured length	25,000	m	
	Bed level changed	-4.5	m	
	Total sediment scoured from the river bed	~248	Million m ³	

¹Derived from landslide and mass wasting to the Ganges, thus including fine sediment

²Area outside the Koshi River in which sediment deposited in 2008

³Estimated before 2008 breach event

Above average annual sediment load consist of both suspended as well as bed material load the Koshi River. The result shows that, sediment deficit during 2008 was scoured from the river bed (upstream of the breach) which is almost equal. This scouring depth is also supported by Hooning [6] study which illustrated that, after 15 days of the dike breach, groynes, located on 30 km upstream of the breach were collapsed because the river bed had dropped. One explanation of this collapse is that while the breach was open, retrogressive erosion in the river caused enormous quantities of sediment was flushed from the river bed upstream of the breached area.

VII. SEDIMENTATION TRENDS

A degradation of the riverbed between the embankments, due to the flood of 2008, means a gain of time since new space for sediment inside the embanked system is created. This "Time" can be used to determine how many years are available before the next event occurs to take proper measures. Unfortunately, precise data and information about the river bed is not available, but some calculations are made based on the available data.

After the construction of barrage and embankments, aggradation rate of the Koshi River was around 0.12 m/yr. But due to sedimentation in the western side, the river width has decreased, which led to the higher velocity in the river channels. So, due to this higher velocity one can expect less deposition than in the past. Let's assume, new deposition rate 0.10 m/yr after 2008, of course this assumption needs proper check based on the field data.

Table 3: Filling time calculation of sediment after 2008.

Descriptions	Quantities	Unit	Remarks
New deposition rate	0.1	m/yr	
Expected bed level change (scoured) for next event	4.5	m	
Required filling time for new space	40 - 50	yrs	

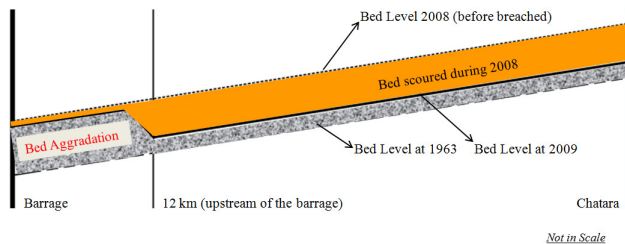


Figure 5: Sketch, bed level development in Koshi River after the Koshi Project.

Since, the future sedimentation rates are likely to be less than 0.10 m/yr; one can presume new flooding under ordinary hydrological conditions will occur after 40-50 years. However, if an extreme hydrological event occurs, this period will be much shorter. So, this gain "Time" can be used to take possible measures to prevent another flooding event.

VIII. CONCLUSIONS

Series of satellite images and historical maps show eastward shifting of the Koshi River after the construction of the barrage and embankments, although before, the river was shifting toward the west. Barrage was constructed at eastern side of the river channel, leading to sedimentation in the western side. Barrage and embankments play significant role for channel avulsion and upstream aggradation. Barrage imposes a nodal point in which channels converge and diverge-based on the bar formation upstream of the barrage, one or the other channel downstream silts up.

Sediment volume analysis, during 2008 events reveals that sediment deposited in inundated areas originates from erosion of sediment deposited from 12 - 42 km upstream of the barrage. 2008 event re-set the entire system which appears again subjected to sedimentation in the area upstream of the barrage. The resulting bed lowering in 2008 means a gain of time to prevent a similar event in the future. So, in 40 - 50 years, another flooding event will occur in the Koshi River even under normal hydrological condition if effective measures are not taken. If an extreme hydrological event occurs, this period will be much shorter.

So, ultimately key factor in the flooding problem approaches are the strategic to deal with sedimentation in the Koshi River.

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