Kosi Embankment Breach in Nepal: Need for a Paradigm Shift in Responding to Floods

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The breach of the Kosi embankment in Nepal in August 2008 marked the failure of conventional ways of controlling floods. After discussing the physical characteristics of the Kosi River and the Kosi barrage project, this paper suggests that the high sediment content of the Kosi River implies a major risk to the proposed Kosi high dam and its ability to control floods in Bihar. It concludes by proposing the need for a paradigm shift in dealing with the risks of floods.

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On 18 August 2008, a flood control embankment along the Kosi River in Nepal terai breached and most of its monsoon discharge and sediment load began flowing over an area once kept flood-secure by the eastern Kosi embankment. Soon a disaster had unfolded in Sunsari district of Nepal terai and in six districts of north-east Bihar of India: Supaul, Madhepura, Saharsa, Arariya, Purniya and Khagariya. About 50,000 Nepalis and a staggering 3.5 million Indians (people of Bihar) were affected. A few died but the exact death toll is not known. The extent of the adverse effects of the widespread inundation on the dependent social and economic systems is only gradually becoming evident.

Cloudbursts, landslides, mass movements, mud flows and flash floods are common in the mountains during the monsoon. In the plains of southern Nepal, northern Uttar Pradesh, Bihar, West Bengal and Bangladesh, rivers augmented by monsoon rains overflow their banks. Sediment eroded from the upper mountains is transported to the lower reaches and deposited on valleys and on the plains. As they make their way from the mountains to the plains, rivers cut their banks, shift laterally and meander. This natural process can create problems when rivers erode lands, wash away crops and undermine the basis of local livelihoods. In particular, while fine sediment brought by floods increases the productivity of land, the deposition of large particles by sandcasting harms agriculture.

The Kosi embankment failed when the river discharge at Chatara was lower than its long-term average for August, 4,729 m^3/s (DHM 2008). The breach and the ensuing inundation was not the result of monsoon-induced floods and cannot be attributed to climatic causes. In fact, rainfall in the hills was below normal during the first half of August. If the discharge of the river on that eventful day had been anywhere close to the peaks historically observed in the Kosi River, the scale of the disaster would have been more devastating. The maximum flood peak recorded in August 1968 was 25,878 m^3/s (GOI 1981), almost six times higher than the discharge when the breach occurred.

After the Kosi embankment breached, the river's waters began flowing through its older abandoned channels, seeking the path of least resistance and filling enclosed basins, low-lying lands and ponds. As this article is being written, the river continues to scour and transform the lower stretches of the plains into flow channels, while sand and sediment is being deposited on fields, irrigation channels and drainage ditches. The preliminary estimates of losses incurred in Nepal and Bihar are summarised in Table 1 (p 71).

Before the August breach the region had enjoyed protection from recurrent flooding for about 50 years. After the embankments were completed in 1959, the area to the east of the river was built up with roads, irrigation channels, railways and other developments, many of which have blocked the natural drainage of old river courses and divided the region into a series of enclosed basins. The barrage was built as a river gradient control measure and after its completion has led to sediment deposition in the upstream reaches and the Kosi in the upper stretch has begun to flow in a braided pattern. Before we explore what caused the breach it will be useful to discuss the Kosi River system and the conceptualisation and development of the Kosi barrage project.

Table 1: Losses Due to Breach

	Districts	Affected Population	Affected Family	Death	Missing	Loss of Agriculture Land	Road km
Nepal	Sunsari	50,000	7,102	22	21	5,592	0
Bihar	Saharsa, Supaul, Araria, Madhepura, Khagaria and Purnia	3.5 million	30,000	76	NA	35,000	NA

Source: Agencies.

River System

The Sapta Kosi River, which means "seven rivers", is the biggest in Nepal. It drains the eastern part of the country, particularly the region east of Gosainsthan (north of Kathmandu) and west of Kanchenjungha, a region known as the Kosi basin. Altogether the river drains an area of 71,500 km² in Tibet, Nepal and north Bihar and has seven major tributaries, the Sun Kosi, the Indrawati, the Dudh Kosi, the Tama Kosi, the Likhu, the Arun and the Tamor of which the Sun Kosi, the Arun and the Tamor are the main ones.

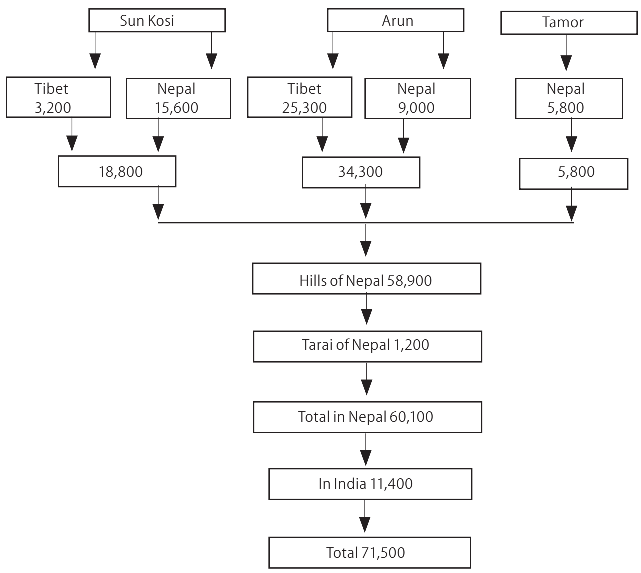
The much enlarged Sapta Kosi turns south and flows through the Barahkshetra gorge for about 15 kms before reaching Chatara in the terai. Downstream of Chatara, the Trijuga River, which drains the southern Mahabharat range in Nepal, flows from the west into the Kosi. After flowing through the Nepal terai enclosed in embankments, the river flows over the Kosi barrage and enters north Bihar. The breakdown in area of Kosi catchment is shown in Figure 1.

The Kosi catchment has unique features. As the crow flies, about 150 kms from north to south the catchment covers six geological and climatic belts varying in altitude from above 8,000 m to just 95 msl (mean sea level): the Tibetan plateau, the high Himalaya, the midland hills, the Mahabharat Lekh (range), the Chure (Siwalik range) and the Terai. The Chure merges with the Mahabharat Lekh east of Sapta Kosi River. Eight peaks over 8,000 m including Sagarmatha, are in the Kosi catchment as are 36 glaciers and 296 glacier lakes (Bajracharya et al 2007). This unique landscape is the result of the interaction between the formations of the Himalaya region and Kosi River and its major tributaries (Zollinger 1979). The Sun Kosi, Arun and Tamor flowed into the Tethys sea before the Himalayan range emerged about 70 million years ago. As the Himalayas were pushed up, the rivers cut through the valleys, deepening them rapidly while at the same time the range lifted making deep gorges between the peaks. The Arun and Tamor rivers, for example, flow in deep gorges between Kanchenjungha (8,586m) and Sagarmatha (8,848m) peaks (Figure 2, p 72). Though less dramatic than the gorge formed by the Kali Gandaki River between Annapurna and Dhaulagiri range in central Nepal, they are nonetheless striking. The Mahabharat created a barrier to south-flowing rivers, forcing them to flow parallel to the Lekh until they were able to flow through it. The Sun Kosi and the Tamor, for example, respectively flow east and west along the northern side of the range until Tribeni where they join the Arun coming from the north. The Sapta Kosi then cuts through a gorge to reach the Terai in the south. The change in altitude cuts deep channels formed of coarse materials in the mountainous landscape (Simons et al, undated).

Rainfall, Hydrology and Sedimentation

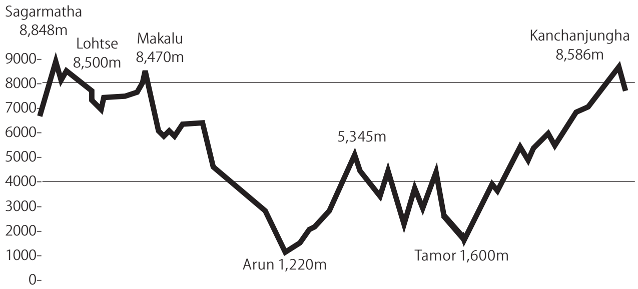
The Kosi catchment falls under the influence of the monsoon, which lasts from June to September and is marked by large regional and temporal variations in rainfall. The rainfall is generally sharp and intense though the date of onset, and the magnitude, duration and intensity of rainfall varies at macro-, meso- and micro-scales. In the rain-shadow regions of the Tibetan plateau, conditions are dry and desert-like. In a large area of the catchment, orographic effects cause large local variations even within a valley. Sudden cloudbursts, which can generate almost 500 mm of rainfall in a single day, are common. In fact, this phenomenon is one of the causes of the unique behaviour of the Sapta Kosi River in the plains.

Figure 1: The Kosi River Catchment Area



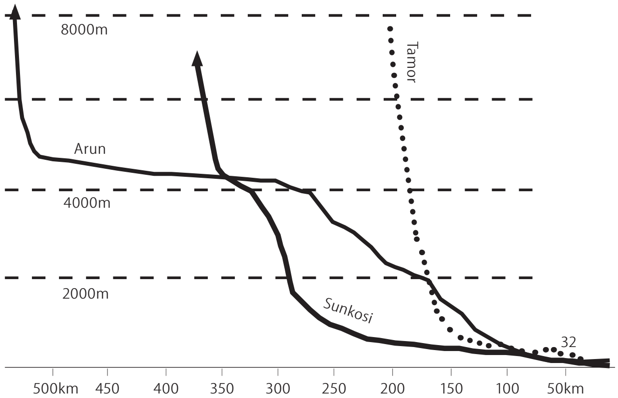
The Sapta Kosi exhibits seasonal variations in flow and sediment charge. The fluctuation in its flow in the gorge can be sudden and great; a rise of 20 to 30 feet in 24 hours is not uncommon. Incessant rain in the catchment also leads to flooding. The second highest flood in the Kosi, which occurred in 1954 was the result of long-lasting rainfall. The record of 1968, in contrast, was caused when the impact of a tropical storm in the Bay of Bengal extended to eastern Nepal and the Darjeeling hills. In the smaller tributaries of the Kosi the impact of flooding is localised, but it can become widespread if the magnitude, extent and duration of the accompanying rainfall in great enough. At the end of the monsoon, when the land is saturated, the contribution of cloudbursts to overland flow is almost 100% and can lead to devastating effects.

Figure 2: Arun and Tamor Gorges in the Kosi Basin



Source: Zollinger (1979).

Figure 3: Slopes of Sunkosi, Arun and Tamor Rivers



Source: Zollinger (1979).

Cloudbursts trigger debris flow resulting from mass wasting and landslides; such debris is often released into river channels, temporarily damming them. When a dam is breached a peak flood of short duration results: these *bishyari* (landslide induced flood) as they are known locally, cause heavy damage along river bank for several kilometres downstream of the point of origin until it is attenuated when the flood wave reaches wider river reaches. In the Kosi catchment the occurrence of bishyari is common but random; their development is too rapid to allow sufficient warning time. It is a major source of sediment load of the Kosi River.

In the high Himalayas, glacial lake outburst floods (GLOF) are a regular phenomenon. The rapid retreat of glaciers in the last half of the 20th century has often formed ice-core moraine-flanked lakes of melt water. Occasionally, a moraine dam breaches and a lake empties in a very short time. The result is floods of great magnitude in downstream river reaches. The water carries with it sediment from the moraine dam as well as earth from the riverbed and banks gouged out by the flow. The combined action of sudden flooding and debris movement washes away riparian farmland, settlements, infrastructure and many unsuspecting individuals in its wake. Like the bishyari GLOF is also a major source of sediment load.

The sediment load from these various sources and from the large catchment areas of the Kosi is brought to the terai plains at Chatara. Here the river begins to deposit its coarse sediment load on the "inland deltas" thereby causing the river to move laterally. Studies suggest that the Kosi transports about 120 million cubic metres (cm) of sediment every year, 95% of it during the monsoon months. As a result, the Kosi has an extremely high flux density and is, hydrologically speaking, a very violent river.

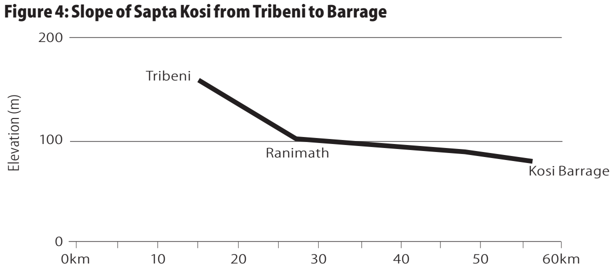
The behaviour of the Sapta Kosi River is the outcome of the combination of factors discussed. These factors render the river particularly active during the monsoon months. The fact that three of its tributaries, each with very different characteristics including area, slope, run-off response, and sediment yield, meet at Tribeni (Table 2) and immediately turn south through the gorge before reaching Chatara adds to the unpredictability of the river. In the stretch of 15 km from Tribeni to Chatara the river's altitude reduces from 160 msl to 100 msl and then to 95 msl at the barrage (Figure 4).

Much of the sediment load brought by the Kosi is deposited in a fan as the river debouches from the mountains onto the terai plains. This exceptionally large amount of sediment is brought down to Chatara in the terai and is dumped on the river bed as the slope of the river levels off. Over time, as its main channel has aggraded, the Kosi River has shifted course. Indeed, in the last 220 years the Sapta Kosi River had moved about 115 kms (Gole and Chitale 1966) (Figure 5, p 73) before it was jacketed between the two embankments in 1959 to prevent flood water from inundating the surrounding lands. Colonel Rennel's map of the eastern Ganga plain shows the dynamic nature of not just the Sapta Kosi but also that of Tista, Brahmaputra and Meghna (Figure 6, p 75).

Technological Choice

In many developing countries, embankments continue to dominate as the preferred strategy to mitigate the impacts of floods.[1] An embankment is a continuous earth bund on one or both sides of a river constructed at a sufficient distance to create in the river channel a passage capable of conveying floodwaters and thereby protect areas outside it. The alignment, spacing and height of embankments depend on the areas to which protection is to be provided, the magnitude of the peak flood discharge expected and the availability of resources (material: sand, soil, clay; finances; human resources) for construction. Availability of land and local politics, to a large degree, also matter, particularly when private land has to be acquired.[2] To protect important areas, embankments are designed to contain floods with 100-500-year return periods but in other cases substantially shorter return period of 25 or 50 years may be used.

Figure 4: Slope of Sapta Kosi from Tribeni to Barrage

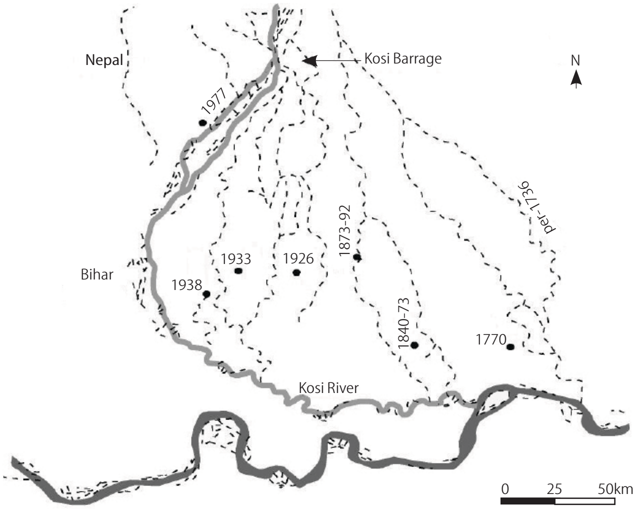


Source: Based on Topo Map, Gon.

Table 2: Characteristics of the Tributary Rivers

River	Catchment Area Km^2	Mean Flow m^3/s	Specific Flow m^3/s/km^3	Annual Sediment Load m^3/sX 10^6	Specific Sediment load (Suspended) m^3/s/km^2	Average Gradient%
Sunkosi	18.800	471	0.025	54.2	2,818	0.0062
Arun	34,300	451	0.01	34.6	947	0.0134
Tamor	5,800	347	0.06	29.6	5,016	0,0276
	58,900			118.4	1,920	

Figure 5: Westward Movement of Kosi



Source: Gole and Chitale (1966).

A flood of a known return period is routed through the river channel and floodwater levels (called stages) in various sections of the channel determined. The level of the top of an embankment in any place is fixed by providing a free board of one to two metres. A huge quantity of earthwork is involved in the construction of embankments, which involves compacting layers of earth with optimum moisture content. Once built, all embankments need regular maintenance. For embankments taller than five metres, it is common practice to provide a berm of adequate width at an intermediate elevation (Figure 7, p 75).

In many cases around the world, embankment heights have often been raised to adapt to the higher river stages because of the occurrence of a flood higher than the ones the embankments are designed to contain. But basics of engineering suggest that because the cost increases with height, embankments taller than about 10 m are uneconomical (Garde and Ranga Raju 1978). An embankment should follow the general curvature of the stream so that the river current does not attack it and is built in conjunction with spurs providing some protection against river currents. According to Garde and Raju (1978) "(Embankment) breaches, especially in the upper reaches, can result in flooding of the entire area which depends on levees for protection". That is exactly what happened in west Kusaha in the Sunsari district of Nepal in the recent embankment breach: an upstream breach devastated downstream regions protected by the embankment. River engineering texts emphasise that a fire-fighting-type maintenance is needed to keep embankments safe. In their book *Water Resources Engineering* Linsley et al (1992) write:

> Levees should undergo regular inspection with the aim of looking for evidence of bank caving, weak spots created by animals or vegetation, foundation settlement, bank sloughing, erosion around the outlets of sewers or other pipes passing through the levees and other possible sources of danger. Any alarming condition should be corrected promptly. During flood a continuous patrol of the levees should be maintained. Patrols should have arrangement for immediate communication with flood-fighting forces and equipment for immediate repair of minor danger spots.

In a similar vein Garde and Raju (1978) suggest that very careful supervision especially during floods will be necessary so that any breach can be plugged almost on a war-footing. Needless to say, both suggestions are unachievable goals, even in a developed country. In many regions of the developing world such as in Nepal and Bihar, regular maintenance of embankments is just not part of the social and political ethos.

Historically, many countries worldwide have built embankments to prevent water from affecting fields and habitation. In China, the Hwang Ho and Yangtze Rivers were embanked in the seventh century. The Nile in Egypt was embanked in the 12th century and the Mississippi River in the 19th century. Embankments were also built along the Gandak River in India and rivers in Orissa in the 18th and early 19th centuries (Mishra 1997). The pace of embankment building in south Asia, especially in India, began to gain momentum after 1940. In the last 50 years, the government of India (GOI henceforth) has constructed a total of 33,630 km of embankments.[3] Of the total, about 3,454 km were built in Bihar, 2,681 km in Uttar Pradesh and 10,350 km in West Bengal. Bangladesh has built about 8,300 km of embankments since 1959. In Nepal, only a few hundred kilometres have been constructed.

In India, the drive to build embankments gained momentum after the floods of 1953, when the government of India constituted the National Programme of Flood Management in 1954. After this, successive governments of India (both central and state) began building embankments to control floods (Sinha and Jain 1998).[4] The process had actually started much earlier, in the 1940s. Prior to 1940, British engineers had argued that embankments constrained flood in an unproductive manner and did not build them. Then, in 1942, an advisory committee constituted by GOI made the construction of embankment the sine qua non for solving flood problems in the delta region of Orissa. According to some analysts, this turnabout may have received a push from a combination of the exigencies of war, a revenue surplus and the anti-slump investment programme of the government (Roy 1999).[5] The Kosi barrage project and the embankments finally agreed by government of Nepal (GON hereafter) and GOI in 1954 constitute one element of this paradigm. The long and tortuous history of controlling the Kosi is dealt with extensively by Mishra (1997) and is not repeated here. The embankments were completed in 1959 while Kosi barrage was completed in 1964. The barrage began to add to the rate of sediment deposition, changed the morphology introducing one of the several factors that led to the 2008 breach.

Embankment and Breach

Because embankments are built of earth, usually that is available locally, they are susceptible to breaches. According to Linsley et al (1992) "foundation condition, and building material for levees (embankments) are rarely fully satisfactory, and thus, even with best construction techniques there is a hazard of failure". In developing countries where the quality of construction leaves much to be desired, the risk is augmented. Design approaches mention the inherent limitation of embankments and their susceptibility to breaches. Some of the limitations common to all embankments are as follows:[6]

(1) Because of floodwaters flowing over the embankment body, erosion can result in instability. If the flood stage exceeds the top of the embankment the result is an immediate breach. This

happens when the design flood stage is exceeded and the embankment is overtopped.
(2) The shear property and stratification of soil layers within the embankment are critical from the point of view of safety. The permeability of the embankment determines the velocity at which water percolates through it and consequently affects its stability.
(3) High pore pressure on the water side of the embankment is sometimes responsible for base failure and uplift.
(4) The velocity of flood flow and how it is directed at the river face of an embankment may also lead to failure.
(5) Nearby human activities such as agriculture, traffic and the constructions of buildings or pipelines in or beneath an embankment can affect its safety. Damage to the grass cover of an embankment can result in erosion and contribute to failure.
(6) Since an embankment is part of the local landscape and influenced by biological processes, they can be weakened due to digging by burrow animals, rodents and the spread of plant roots.

The breach of the Kosi embankment and the disaster was not caused by overtopping. Instead, preliminary investigations indicate that the disaster was the collusion of other factors discussed above. In addition, the breach was a result of the larger context within which the embankment was conceptualised, built and maintained. These factors are as follows.

Reliance on a Structural Solution (Embankments) Promoted a False Sense of Security: The fundamental lapse was the mistaken belief that the Kosi embankment had made the region of east Bihar flood secure. Hierarchically-organised agencies usually pursue strategies of control, like embankments, to minimise risks. The structure seduced people living in the region into believing that they were safe from floods. As a result, local resilience was externalised to outside agencies (state or irrigation departments) which for their part kept themselves insulated from the realities of the field and from critical voices that challenged assumptions about total flood control. Some of the most vociferous critiques of embankment technology came from social movements in Bihar such as Barh Mukti Abhiyan (Gyawali 2000).

Inappropriate Technology in a Sediment Charged River: Since the barrage functioned as a gradient control structure, the amount of sediment deposition in the river section upstream of the barrage began to increase rapidly. The embankment had changed the morphology of the river. The breach has reinforced earlier arguments that it was, and is, an inappropriate technological choice to contain the Kosi's floods.

Poor Management of Infrastructure (Embankments): The prevailing engineering and technical practices did not mandate regular maintenance; nor were relevant procedures and guidelines drawn. If the maintenance needs demanded by the engineering ethics discussed above are used as a yardstick, then the institutional handling of the task gets less than one on a scale of one to 10 for its performance.

The Lack of a Warning Mechanism and No Preparedness: Because of the false sense of security there was no warning mechanism or preparedness whatsoever. As a result, the message that the embankment had breached in upstream Nepal was not communicated to people downstream and those likely to be affected could not be evacuated in time resulting in a massive man-made calamity. In a region made flood-secure by embankment warning measures are a contradiction and pose legitimacy problem to the hierarchies due to technological lock.

Poor Capacity to Respond to the Humanitarian Crisis: The delayed response to the humanitarian crisis in Bihar was manifestation of the overconfidence of the state structure. The bureaucracy had deluded itself into thinking that everything was under control and seized by a paralysis.

Institutional Dysfunction and Governance Deficit: The calamity can also be attributed to dysfunction of institutions and the lack of good governance and absence of accountability. Because the government operates so poorly, improprieties in the conduct of technical and engineering practice are rife. Bharati (1991) highlights a dramatic account:

> [S]uch is the racket of breaches that out of the 2.5 to 3 billion rupees spent annually by the Bihar government on construction and repair works, as much as 60% used to be pocketed by the politician-contractors-engineers nexus. There is a perfect system of percentages in which there is a share for everyone who matters, right from the minister to the junior engineer. The actual expenditure never exceeds 30% of the budgeted cost and after doling out the fixed percentages, the contractors are able to pocket as much as 25% of the sanctioned amount. A part of this they use to finance the political activities of their pet politicians and to get further projects sanctioned. Thus the cycle goes on. [The result is that...] the contractor's bills are paid without verifying them. The same lot for boulders and craters are shown as freshly purchased year after year and the government exchequer is duped of tens of millions. Many of the desiltation and repair and maintenance works shown to have been completed are never done at all and yet payments are made... So much is the income of the engineers from the percentages that the engineers do not bother to collect their salaries.[7]

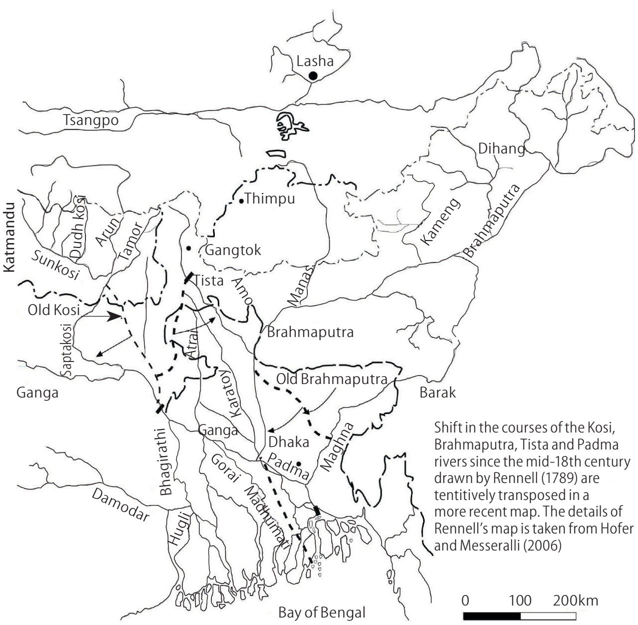
The Trans-Boundary Dimension of the River and Nepal-India Treaty: The fact that Kosi River and the Kosi project crosses national boundaries also contributed to the disaster. The revised Kosi Treaty of 1966 entrusts the responsibility of maintaining the project and its appurtenance with India (GOI and the Bihar government). Only article 10 (iii) of the 17 sections of the revised treaty mentions maintenance:

> HMG [His Majesty's Government] agrees to permit, on the same terms as for other uses, the use of all roads, waterways, and other avenues of transport and communication in Nepal for bona fide purposes of the construction and *maintenance of barrage and other connected works* (emphasis added).

The treaty is vague about the need to maintain the barrage and embankments regularly. It does not accord any responsibility to the upstream stakeholder Nepal in the operation and management.

The Political Transition in Nepal: The ongoing political transition in Nepal added a layer of stress. Fundamental changes including an accord between Nepal's mainstream political parties and the Maoists, elections to a Constituent Assembly and the abolition

Figure 6: Dynamic River System of Eastern Ganga Plain



Source: Hofer and Meseralli (2006).

of monarchy have resulted in continuation of a volatile body politics in Nepal. Street protests and disruptions are common and regular. The Nepal terai is witnessing a surge in violence perpetrated by armed groups more criminal than political. The blockage of transport routes due to strikes is frequent and vehicular traffic can cease for days and in extreme cases, even weeks. Lawoti (2007) characterises street protests in Nepal as follows:

> [Protest] is more apparent with actions and events, rather than any specific group of actors. Bandhs (shutdowns), strikes, chakka-jams (traffic blockades), masal juluses (torch-lit processions) and dharnas (sit-ins) have been used by various groups, ranging from the parliamentary political parties to the Maoists, identity movements, political interest groups, economic associations, students' groups affiliated to political parties, teachers' associations, bus-owners' associations, social-justice movements, and even spontaneous collectivities (such as when the locals bring the traffic to a halt along the highways, often after fatal vehicle accidents).

The first two weeks of August 2008 saw a similar closure in eastern terai, a condition which exacerbated the existing weakness.

The breach and the devastation caused by the Kosi flowing in its old courses should be a clarion call to identify and pursue approaches that build local resilience against the risks associated with floods. The need for a reflective enquiry was even more necessary because the Kosi project did not deliver the benefits it promised. It did provide irrigation but to a grossly reduced area. It never delivered as much power as it was designed for because high sediment concentration in canal water spelled the plant's doom. The credentials of the Kosi project's flood control are in tatters as large areas outside of the embankment are susceptible to flooding, the very same areas the embankment was supposed to protect. The 2008 breach is one more nail in the coffin.

The seven breaches in the past 50 years (Table 3) should have prompted those in pursuit of hierarchic science to learn and put in place new ways of doing business, but a certain learning disability meant that no lessons were and are internalised. Instead, the status quo continued. The communiqué issued following the meeting of a high-level Nepal-India committee on water resources in October 2008 is a reflection of the tradition[8] and yet another shift in attention to implementing the Sapta Kosi high dam protect to control flooding in Bihar. Indeed the communiqué did not even mention the need to look afresh at the breach and the resultant inundation disaster, a clear cut consequence of a failed paradigm.

Exacerbated Risks

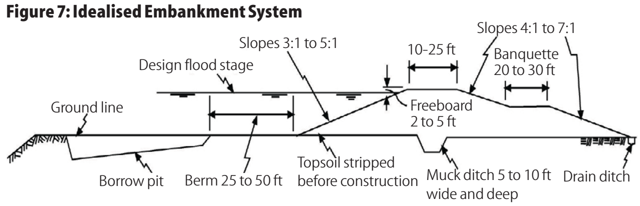
Nepal and India have been discussing the Sapta Kosi multipurpose project with flood control, irrigation, hydropower and navigation benefits for a long time. The site of the proposed dam is located midway between Tribeni and Chatara in the gorge at *Barahkshetra*. A feasibility report was completed in 1953, but due to its high cost, the proposal was dropped and instead a barrage at Hanuman Nagar in Nepal and embankments along both river banks were built. In 1981, the GOI completed a second feasibility study, which suggested that the dam height be kept at 269 m. The proposed project was investigated a third time in 1984 when with the help of the Japanese while the GON prepared the Kosi basin master plan.

A joint communiqué issued in 1991 during Nepali prime minister Girija Prasad Koirala's visit to India, made the following statement about the proposed project:

> Joint studies/investigations that are necessary to finalise the parameters of the Sapta Kosi High Dam Multipurpose Project will be carried out expeditiously. For this purpose, a joint team of experts shall be constituted to finalise the modalities of the investigations and the methods of benefit assessment. Thereafter, the two sides will start the investigations of the project, with the view to preparing a detailed project report.

Six years later, in 1997, a meeting of Nepali and Indian government experts was held in Kathmandu. It was agreed to begin a joint study of the Kosi high dam and the Sun Kosi Kamala diversion project and a memorandum of understanding was signed[9] to study both proposals a few months after India and Bangladesh signed a treaty to share the Ganga water at Farakka. The then Bihar government had objected to the provision of the treaty arguing that Bihar's share of the Ganga waters was compromised. Subsequently, Janeswar Mishra, the union minister for water resources, had assured Bihar during his visit to

Figure 7: Idealised Embankment System



Source: Linsley et al (1992).

Table 3: Summary of Past Breaches

Year	Breached Places
1963	West embankment, Dalwa Nepal
1968	West embankment, Jamalpur Darabanga Bihar (breached at five places)
1971	Near east embankment Matniyabandha, Bihar
1980	Near east embankment Baharawa Bihar
1984	East embankment, Hempur, Navahatta Block, Bihar
1987	Gandaul and Samani, Bihar
1991	West embankment, Joginiyan Nepal
2008	East embankment, West Kushaha Nepal

Source: Mishra (2006).

Patna on 13 December 1996 that by building the Kosi high dam its share of the water would be assured (Gyawali and Dixit 2000).

The high dam was seen as the preferred method for controlling the flooding of the Kosi while embankments were seen just as a temporary measure. As early as 1967 Inglis (1967) wrote that unless the deposition of sand between the Kosi embankments was reduced, breaches in the embankments was inevitable. He suggested constructing storage reservoirs in the Himalayan reach designed to trap sediment and practising soil conservation measures in the catchment area. Excessive sedimentation, some argue, is due to the misuse and mismanagement of catchments; the belief is that implementing soil conservation measures will reduce the inflow of sediment to reservoirs.[10] While soil conservation and watershed management are necessary to maintain the in situ integrity of an ecosystem, the bulk of the sediment load in the Kosi basin is derived from natural causes andsuch activities will have little impact as a similar case of Mangla dam in Pakistan bears testimony. Here, watershed management had no evident impact on the sediment load entering the reservoir.[11]

Chitale (2000) suggested that Kosi embankments provide only a temporary palliative and that a permanent solution needs to be devised. Achieving permanency, as we will discuss, is an unachievable goal and even a very high risk approach. Sedimentation and flood caused by in basin rainfall or non-point catchment sources are the two major risks. The state government of Bihar, however, has framed long-term solutions to the problem of flooding in terms of the viability and vitality of structural measures such as the construction of dams in Nepal: its short-term measures focus primarily on building embankments along the rivers in Bihar.[12] The government's Tenth Five-Year Plan (2002-07) made the following observations:

> The long-term solution of flood problem in Bihar lies in the provision of reservoirs in the upper reach of main rivers and their tributaries. Unfortunately, most of these rivers originate in Nepal and flow through it for the considerable length before entering Bihar. All suitable dam sites fall in that country. Only with the sincere cooperation of the HMG Nepal and Central Government, construction of dams in Nepal territory is possible. Sites on the tributaries of Kosi River have been investigated and a high dam at Barahkshetra is proposed which would moderate the maximum probable flood of 42,475 cumecs (15 lakh cusecs) to a flood of 14,000 cumecs (5 lakh cusecs) at Barahkshetra. It will also trap the bulk of coarse and medium silt carried by the river which in turn helps stabilise the river and reduce the meandering/braiding tendency of the river.

This plan as well as the 2008 Nepal-India communiqué, shows that despite the failure of structural measures to control floods, government authorities continue to rely on them as their primary strategy. They ignore the unavoidable risk sedimentation poses to proposed reservoirs including the Sapta Kosi as well as social, environmental externalities that can lead to conflict and risk due to earth tremors that adds significantly to the cost of project development. These issues and risks were intensely debated in India in the 1980s in the case of the Tehri dam in the Garhwal Himalayas and the Sardar Sarovar project on the Narmada. The debate over the costs, benefits and risks of the proposed Kosi high dam and other large-scale storage projects proposed in Nepal will now also involve India's northern neighbour in a time period (post-2000) in the institutional, social and political interregnum as the country is shifting from a kingdom to a federal republic. How the debates will proceed in the trans-boundary context of Nepal and India remains to be seen. Unlike the Sapta Kosi and other large-scale projects in Nepal, the Tehri dam did not have a trans-boundary dimension though the Sardar Sarovar project did involve upstream-downstream element (Madhya Pradesh and Gujarat) within the Indian Union. In our quest to find a new paradigm, these issues need much deeper discussion than the scope of this paper allows.

Building Resilience

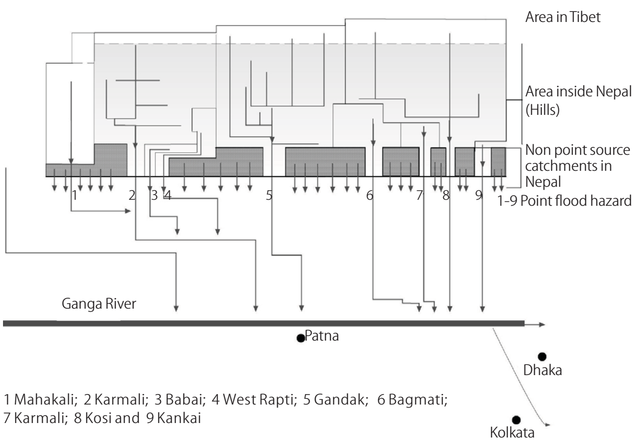
With regard to controlling flooding, the proposed Kosi high dam has three limitations. It is unlikely to control or obviate flood disaster in the immediate term because even if the bulldozers needed to build the project begin moving now it would take a minimum of 20 to 25 years to complete the project if the process proceeds as designed without any interruption. This would happen only when Nepal and India reach an agreement on sharing of cost and benefits, complete designs, do financial closure, put in place environmental impact mitigation plan and resources, and complete social, economic and cultural rehabilitation of the involuntary displaced populations. In most of the water projects in the past, these later activities have been taken pari passu along with the construction and consequences were that those facing major risk were further marginalised and impoverished. In the intervening period, other ways of responding to floods are still needed. In the long-term, storage depletion due to sedimentation implies that the much-needed space to accommodate the floodwater and sediment will not be available and downstream flooding will continue to remain a major risk.

The 4.08 billion cm dead storage of the proposed reservoir with a gross storage of 8.5 billion cm will be filled with sediment in 35 to 40 years (assuming trap efficiency of 90-98% and an annual sediment inflow of 120 million cm). In any case the Kosi high dam has been conceptualised to function as a sediment trap. Will building a multi-billion dollar sediment trap make economic sense? Yet another question is, whether the Kosi high dam would control floods in Bihar as is anticipated in the political and policy circles in the intermediate term? The geographical and hydrological characteristics of the region show that it will not. Downstream of the proposed high dam, Nepal's terai region, crisscrossed by many streams, extends for about 40 km. This area is drained by the Chure River and can be conceived as a non-point flood source (Figure 8, p 77)[13] as opposed to rivers that carry monsoon run-off from mountainous catchments, which function as point sources of flood hazards. In Nepal, the number of such outlets is nine. As these rivers progress southward, their floods add to the inundation of the middle and the lower Terai with an intensity depending upon whether or not their discharges synchronise with run-off from Chure rivers.

Mishra (2003) has pointed out that rainfall in the catchments south of the proposed dams in the mountains can produce substantial floods and that the catchment area of the Kosi River below the proposed Sapta Kosi dam site up to the river's confluence with Ganga is about 13,676 square km – almost the same as the catchment of the Bagmati River which itself is capable of producing high floods. The two events of 1998 and 2008 in Nepal's

Terai region show that these regions do generate high floods. In 1998 eastern Uttar Pradesh was flooded by exceptionally high floods. The trigger was a very wet monsoon which brought down 3,000 mm of rainfall against the normal 1,500 mm. Similarly inundation of Nepal Terai and north Uttar Pradesh in late September 2008 was caused by exceptionally high rainfall. The impact was further compounded by drainage congestion. In-basin rainfall is a major cause of flooding of the Gangetic plain which means that we need to re-conceptualise ways of managing floods. In fact, there are no sites in the non-point source catchment where dams can be built and embankments do have limitations.

Figure 8: Schematic Diagram of Point and Non-point Sources of Floods in Nepal's Terai and Northern Ganga Plain



Given the hydro-ecological context, both embankments and high dams are methods of flood control with severe limitations and major risks. An embankment can provide relatively high levels of flood protection immediately following construction though its disadvantages include water-logging and mosquito infestation. Its ability to provide protection from flooding declines over time depending on rates of sedimentation and, to a lesser extent, on how well it is constructed and maintained. In the case of the Kosi River, the riverbed aggraded rapidly, thus rendering the surrounding land vulnerable to flooding. A study of the contour of the land shows that the river bed within the embankment was about four metres higher than the elevation of adjoining land: in other words, the bed rose approximately one metre per decade after the embankments were built.

Unless some way of addressing the massive amount of sediment deposition can be found the embankments will inevitably breach and the river will flow across lands that have been settled for decades. In fact, breaches are an inherent feature of any flood control embankment system and the August 2008 event was actually the eighth major breach since the embankments were completed in 1959. Many smaller breaches have occurred in embankments in Uttar Pradesh. Major breaches have also occurred in the Mississippi, river Tay in Scotland (Gilvear and Black 1999), Sacramento and New Orleans regions in the United States. All breaches cause human misery as lives, assets and properties are lost. No matter how well embankments are maintained, a breach may occur during either a high or, a normal flow. With regard to performance of embankments globally, it can be said that embankment are of two types: those that have breached and those that will breach. The Kosi embankment breach in west Kusaha in Nepal is in fact a manifestation of the first type and a failed paradigm.

Given the natural and social contexts of flood disasters-wet monsoons, frequent cloudbursts and social vulnerability – there needs a shift in the paradigm underlying flood mitigation approaches. The focus must shift away from total control of flooding to maintaining unhindered drainage. In the 1930s, British engineers argued against controlling floods and instead emphasised providing drainage facilities, cushioning floodwaters in ponds and depressions, and promoting inland fishery. In response to floods on the Mahanadi delta in Orissa, British engineers argued that floodwaters should be allowed to flow into the sea as soon as possible. The 1928 flood report had this to say:

> [T]he problem which has arisen in Orissa is due, in the main, to the efforts which have been made towards its protection. Every square mile of country from which spill water is excluded means intensification of floods elsewhere, every embankment means the heading up of water on someone else's land…. The problem in Orissa is not how to prevent floods but how to pass them as quickly as possible to sea. And the solution lies in removing all obstacles, which militates against this result…. To continue as at present is merely to pile up debt which will have to be paid, in distress and calamity.[14]

By arguing that floodwaters must be allowed to pass as quickly as possible out to the sea, the British engineers recognised the importance of providing unimpeded drainage to floodwaters Along with facilitating drainage, policies must incorporate the objectives of minimising vulnerability and building local resilience. During a flood, settlements and villages become isolated as tracks and paths are submerged. People cannot commute to work or travel to markets; they cannot even go to health posts to access basic health services. Roads are important but improperly built roads impede drainage. Local governments, in collaboration with central government agencies, need to improve accessibility in general and during floods in particular. They must revisit the conventional approach to designing roads, culverts and bridges and give attention to the nature of regional drainage patterns. Their objective should be to design and locate roads so that while they improve accessibility during floods and not impede drainage. At the same time, timely maintenance and upgrading are vital too. Unfortunately, the agencies responsible for maintaining infrastructure often disappear from the scene during floods. By strengthening the capacity of local governing bodies to design appropriate infrastructure and maintain them, solutions will be sensitive to local contexts. Augmenting capacity necessitates making new and sustained investments, which may be justified by long-term benefits in reducing losses and vulnerability.

The ability to reduce vulnerability to disasters in general including floods is strongly related to the robustness of the following systems (Moench and Dixit 2004):

(1) Communications (including the presence of diversified media and accessibility to information about weather in general and hazards in particular); (2) Transportation (including during extreme events); (3) Finance (including access to banking, credit and insurance products for risk spreading before, during and following extreme events); (4) Economic diversification (access to a range of economic and livelihood options); (5) Education (the

basic language and other skills necessary to understand risks, shift livelihood strategies as necessary, etc); (6) Organisation and representation (the rights to organise and to have access and voice concerns through diverse public, private and civil society organisations); and (7) Knowledge generation, planning and learning (the social and scientific basis to learn from experience, proactively identify hazards, analyse risk and develop response strategies that are tailored to local conditions).

Investments in implementing flood control measures such as embankments, flow modification structures, and bank stabilisation have been considerable but structural approaches have not helped minimise the impacts of flood disasters. In fact, they have exacerbated them. Evidently the goal of controlling flooding completely is unattainable. In fact, the 2008 Kosi breach points to a major flaw in the conventional approach pursued in that the river flow was lower than the historical average monsoon flow in August. The minimisation of flood-related risks also needs to focus on the provision of livelihood diversification options.

Dixit et al (2007) suggest that approaches to flood mitigation that combine flood-adapted structural elements (improving drainage, houses on stilts, raising the plinths of houses, etc) with other (transport, financial, communication, etc) systems that contribute toward building social resiliency could be an effective alternative to historical approaches. Overall, the practice of creating closed basins and sub-basins needs be shifted to that of providing an open basin system that can adapt to flooding in a future likely to be more uncertain due to climate change. Improving access to core services such as drinking water supply, reliable energy, health services and empowering women contribute to social resilience and could serve as the cornerstone of the shift.

NOTES

1 Embankments are also referred to as levees or dikes. In this article we will use the term embankment.

2 Politics comes to the centre stage when a project is implemented. This became evident while building the Kosi embankments. See Mishra (2001) for a discussion.

3 Details are available at (http/wrmin.nic.in/publication/ar2000/arooch/5.html).

4 The flood policy announced on 3 September 1954, outlined the need to build control and protection measures (Seth 1998).

5 D'souza (1999) provides a detailed discussion of floods in Orissa.

6 E Niederleithinger et al also mention some of these as the causes that can lead to failure.

7 See Bharati (1991).

8 According to the minutes, (a) the JCWR reviewed the proposals under consideration in the Standing Committee on Inundation Problems for construction of embankments along the Mechi River. The JCWR directed that the flood protection works required along river Mechi in West Bengal and Bihar in India and in Nepal for expeditious execution may be examined by the proposed Joint Standing Technical Committee, taking into account the need for embankments along the Mechi River in its entirety, (b) the Nepalese side requested for early closure of the breach as the local population is still not able to return to their homes due to flooding. The Indian side informed that all efforts are being made by the project engineers to plug the breach, and (c) the tenure of Sapta Kosi high dam multipurpose project including Sun Kosi storage cum diversion scheme was extended by one year.

9 The opening of the Kosi project head, divisional and field offices was also discussed. In 2004, a team from the Central Water Commission of government of India visited Nepal and the office of the Joint Project Office-Sapta Kosi and Sun Kosi Investigation (JPO-SKSKI) was established in Biratnagar. The office invited contractors to submit sealed tenders by 17 January 2005, for conducting geo-technical investigations of the two proposed projects in different locations. See Gyawali and Dixit (2000).

10 Watershed management and catchment treatment are recommended measures to reduce sedimentation rates in rivers. But the question is whether sediment load will significantly reduce by watershed management in a region where cloudbursts and other natural events are common and where only a small fraction of the total load is contributed by sheet and rill and gully erosion while mass movement, due to natural causes contributes the rest. Experience indicates that soil conservation and watershed management activities are important at local level to improve livelihood rather than to minimise regional sedimentation. Also see Tejwani (1987).

11 See, Mahmood (1987).

12 See Moench and Dixit (2004).

13 Mishra (2003) argues that flood from diffused catchments are serious.

14 Quoted in Roy (1999).

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