# FLOOD AND SEDIMENT MANAGEMENT IN KOSI RIVER

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## 1.0 INTRODUCTION

Bihar is one of the poorest states in India. It has long suffered from dire poverty and stagnant economic growth, although it has shown some signs of improvement in recent years. Recurrent floods are devastating to Bihar's economy and undermine poverty alleviation efforts. Floods are an especially major problem along the Ganges and its Himalayan tributaries. Floods not only affect lives, livelihoods, productivity and security of existing investments, but are also a disincentive for additional investments in Bihar.

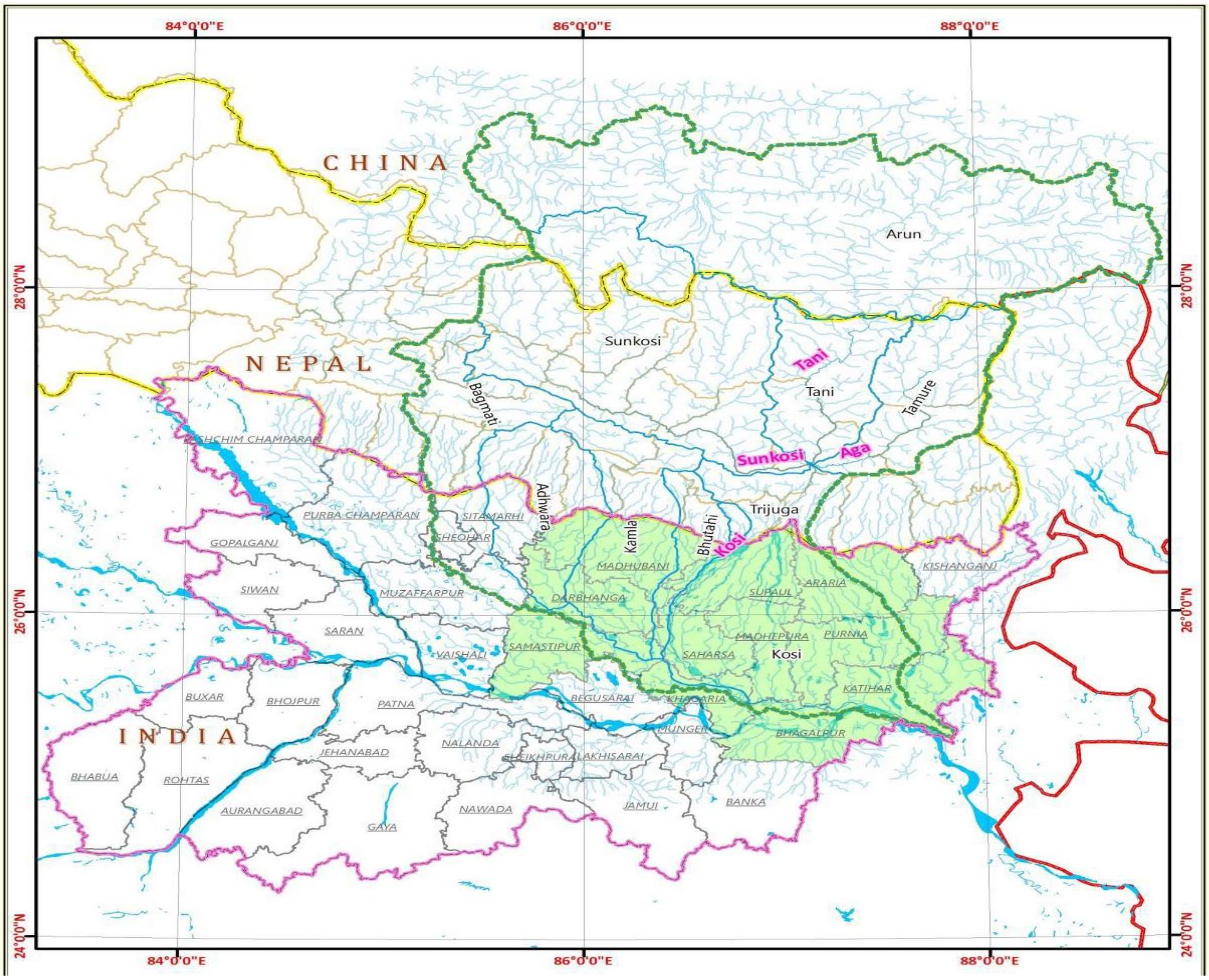


***Fig. 1 Kosi River Watershed***

Kosi River is one of the biggest tributary of River Ganga originating from Tibet and joins the Ganges in Bihar state (India) via Nepal. Total drainage area of the Kosi River is 95156 km2. Majority of the area comes from Tibet and Nepal (80%), and only 20% drainage area is in Indian Territory. The upper catchment (80% drainage) area is responsible for the morphological activities in the downstream reaches as it receives an average rainfall of 1,456 mm. It carries huge amount of sediment with its flow every year causing change in morphological behavior of the river. The problem of the flooding is implicitly governed by river sedimentation. River sedimentation has gradually reduced the capacity of the river to carry extreme flows which cause flooding in the plains along the banks.

Bihar accounts for about 17% of the flood-prone area and 22% of the flood-prone population in India. As much as three-fourths of Bihar's area is flood-prone and three-fourths of north Bihar's population is under the threat of recurrent floods. Bihar's vulnerability to floods is due to its very flat topography just downstream of the steep Himalayas, intense Monsoonal rains (more than 2,500mm/yr in the upstream areas and about 1,200 mm/yr in the State, 80% during the months of June-September), high sediment loads, high population density (880 per sq.km), low-socio-economic development, inadequate water infrastructure to regulate flow (e.g. storage upstream in Nepal or designated detention areas), and a history of weak governance.

The rivers that cause much of the flooding include the Ganges and its tributaries (Burhi Gandak, Gandak, Adhwara Group, Kamla, and Kosi from the Himalayas on its left bank and the lower reaches of the Sone and Punpun rivers on its right bank). However the Kosi River that flows from Nepal to India was known as the " Sorrow of Bihar". It was named "River of Sorrow" because it had caused widespread human sufferings in the past. Kosi River has once again lived up to the epithet it had acquired over the years. This young river, which has the history of frequently changing its course, leashed the fury on the people of Bihar.

## 2.1 Kosi Basin Characteristics

### 2.1.1 Origin of River Kosi

The River Kosi originates at an altitude of over 7000 m above MSL in the Himalayas. It lies between 85° and 89°E Longitude and 25° 20′ & 29′ N latitude. In the north, the river is bound by the ridge separating it from the Tsangpo (Brahamputra) River, while the River Ganga forms its southern boundary. The eastern and western boundaries are the ridge lines, separating it from the Mahananda and the Gandak/Burhi Gandak catchments respectively. The highest peaks in the world, the Mount Everest and the Kanchenjunga are also in the Kosi catchments. The upper catchment of the river system lies in Nepal and Tibet. It enters the Indian Territory near Hanuman Nagar in Nepal. It joins the Ganga River near Kursela in Katihar district.

### 2.1.2 Tributaries of River Kosi

In Nepal, this river is known as 'Saptakoshi' It is formed by the confluence of seven smaller streams, namely, the Sun Kosi, the Bhotia Kosi, the Tama Kosi, the Dudh Kosi, the Barun Kosi, the Arun Kosi and the Tamar Kosi, meeting above Tribeni, about 10 km. upstream of Chatra. But for all practical purposes, the confluence at Tribeni in Nepal is considered to be formed by the three major tributaries out of the seven, the Arun Kosi from North, the Sun Kosi from West and the Tamur Kosi from East.The Arun, the longest of the three tributaries passes through Tibet, named there as Phung-chu, drains the highest peak of the world i.e. the Mount Everest (8878 meter above MSL). The Tamur Kosi drains the second highest peak, the Kanchanjunga and the Sun Kosi drains the eastern Kathmandu valley in Nepal.

### 2.1.3 River Kosi in Plains

Below the confluence at Tribeni, the Kosi flows in a narrow gorge for a length of about 10 km., till it debouches into plains, near Chatra in Nepal. Further down, the river runs in relatively flat plains of Nepal terai consisting of sandy soil. The river flows through Nepal for 50 kms below Chatra to Hanuman Nagar, before it enters the Indian Territory. From Chatra to Galpaharia, the river flows in a south-west direction in this reach, the westward swing of the river is restricted by the the Mahabharat range. In the portion below Chatra, the river divides itself into several channels spread over a width of 6 to 16 km. Below Hanuman Nagar, the river Kosi runs about 100 kms in a sandy tract and finds its way southward through a number of channels. After that, the the river takes an eastward direction and has a single defined channel. The main channel joins the river Ganga near Kursela in Katihar district. In plains of Bihar, the river has two important right bank tributaries; these are the Bagmati and the Kamla Balan. The other tributaries worth mentioning on the right bank are the Trijuga and the Bhutahi Balan.

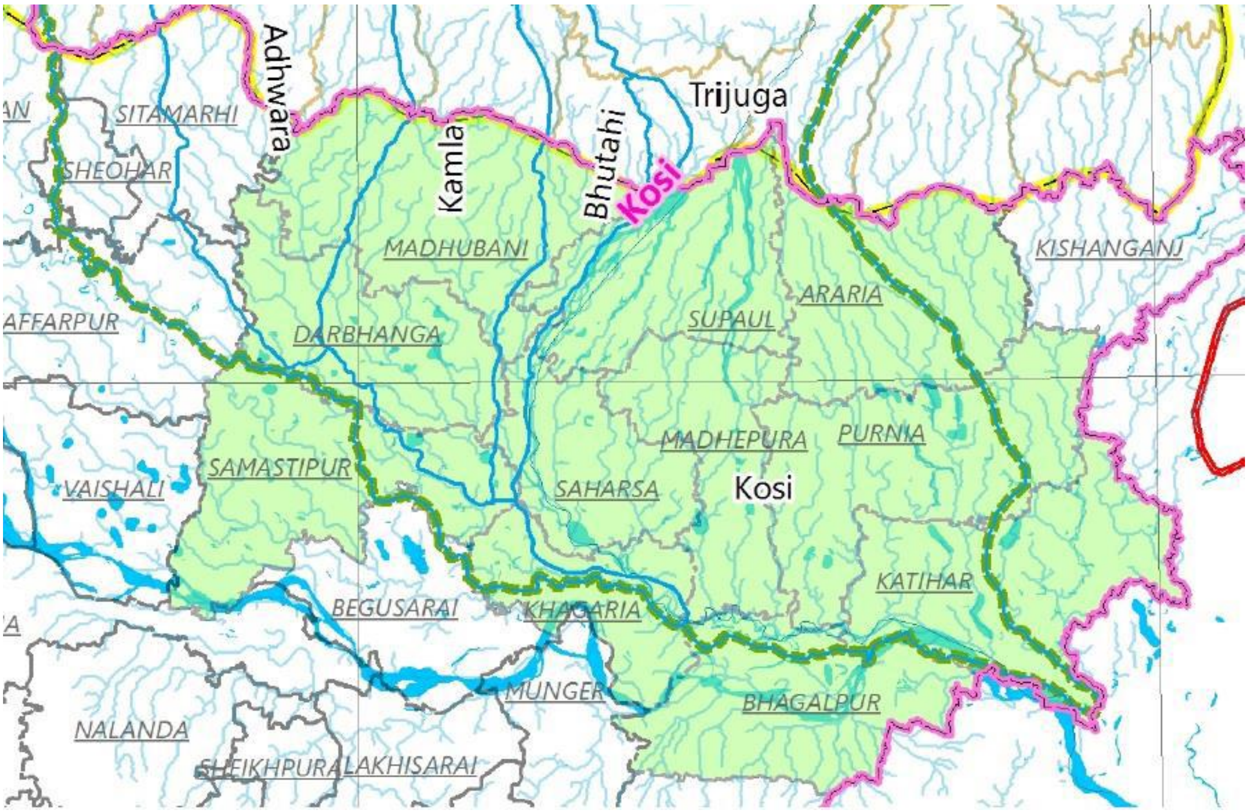


Fig. 2 Kosi Basin in Bihar

### 2.1.4 Catchment

#### 2.1.4.1 Catchment Area

There are three main rivers in the hilly catchment, Tamor, Arun and Sun Kosi, in the hilly catchment above Chatra and lower flood plain catchments, as show in Figure 1. The entire catchment could be divided into two parts, i.e., hilly catchment above Chatra and Flood plain below Chatra

The river Kosi drains a total catchments area of 95456 Sq.Km in India and other countries. Out of the total catchments area of the Kosi, only 31726 Sq.Km lies in India and the rest 63730 Sq.Km lies in Tibet and Nepal.

**Table 1 Salient Features of the Kosi Basin**

| | | |
|---|---|---|
| 1. | Total Drainage Area | 95156 Sq. Km |
| 2. | Drainage Area in India | 31726Sq. Km |
| 3. | Population in Bihar | 66.55 Lakh |
| 4. | Water resources (Surface water) | 52219 MCM |
| 5. | Average annual rainfall | 1456 mm |
| 6. | Total length of main river in Bihar | 260 Km |
| 7. | Cropped area in Bihar | 8694 Sq.Km |
| 8. | Tributaries: Bagmati(R), Kamla Balan(R), Bhuthi Balan(R), Trijuga(R), Fariani dhar(L), Dhemama dhar(L) | |

**Table 2 Kosi Basin Area**

| Kosi catchment area distribution | | |
|---|---|---|
| Kosi catchment | | Area ($km^2$) |
| Above Triveni (Nepal& Tibet) | Sun Kosi | 19000 |
| | Arun | 34650 |
| | Tamor | 5900 |
| | Total | 59550 |
| Kosi lower basin in India | | 11070 |
| Between Triveni & Indo-Nepal border (Nepal) | | 3880 |
| Kamala | | 5445 |
| Trijuga | | 706 |
| Bhutahi Balan | | 1105 |
| Bagmati | | 13400 |
| Total Kosi Catchment area | | 95156 |

### **2.1.5.2** Slope

The slopes of the three hilly rivers, Tamor, Arun and Sun Kosi in the upper catchment are shown in Figure 2-5. It is clear that Tamor is smallest and steepest river whereas Arun Kosi is longest and relatively less steep.

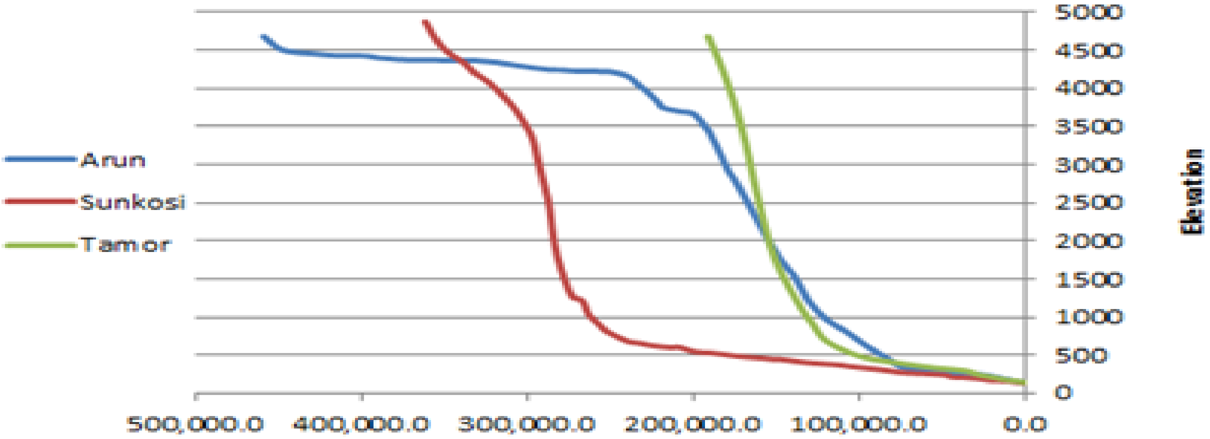


**Fig. 3 Slopes of Hilly Rivers, Sun Kosi, Arun and Tamor**

## Longitudinal Profile

**Table 2 Average Bed Slope of Kosi River from**

**Chatra to outfall point in Ganga near Kursela In Different Reaches**

| Sl.No. | Reach | Average Bed Slope | Remarks |
|---|---|---|---|
| 1 | 0 Km. to 42 Km. | 1:714,(1.4 m/Km.) | Chatra to Barrage |
| 2 | 42 km. to 68 Km. | 1:1396,(0.716m/Km) | Barrage to Dagmara |
| 3 | 68 Km.to 134 Km. | 1:2222,(0.45 m/Km.) | Dagmara to near Mahesi |
| 4 | 134 Km. to 310 Km. | 1:9090,(0.11m/Km.) | Upto outfall in Ganga near Kursela |

The entire lower catchment is nearly a level country which is split into numerous “dhars” in the old beds of Kosi River. There are undulations and innumerable depressions called “Chaurs”, where water remains accumulated for most part of the year.

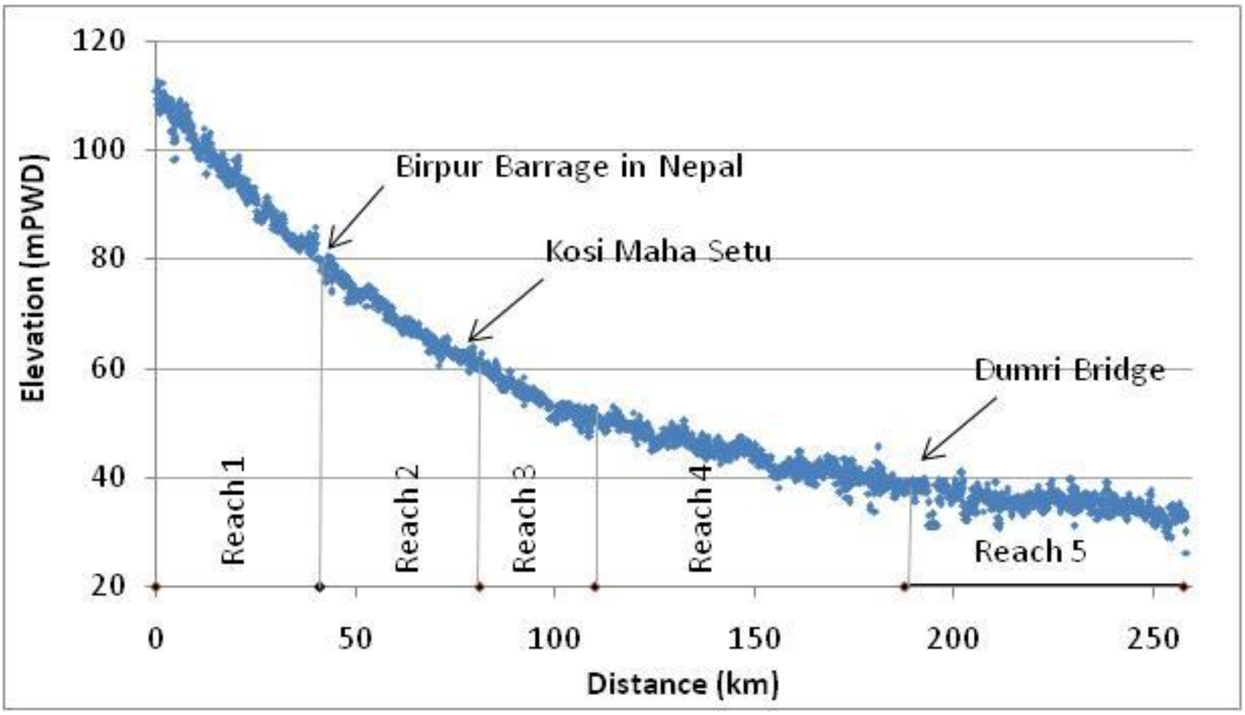


**Fig. 4 Bed Slope of Kosi River from Chatra to outfall point in Ganga near Kursela In Different Reaches**

### 2.1.4 Hydrology

The River kosi can be broadly divided into two parts from hydrology and hydrometeological point of view. The upper catchment, which lies in Tibet and Nepal, comprises of about 80% of the total basin area, has quite different characteristics with respect to the lower basin area ( i.e. 20% of the total area) falling in Bihar. The upper catchment is mainly responsible for the hydrological behavior of the river; where as lower catchment has little contribution to it.

### 2.1.5. Geology

The geology of the Kosi catchment, by and large, is unstable in nature and susceptible to heavy wear and tear which ultimately increase sediment load in the flow of the river.

The drainage basin of the Kosi on the basis of soil characteristics can be divided into three zones:

(i) Upper catchment Zone- The upper catchment of the Kosi Basin lies totally in mountainous region. The soils of this region are usually of three types, namely, (a) Mountain Meadow soil (b) Sub-mountain soil and (c) Brown Hill soil

(ii) Mid area Zone- The mid area zone comprises the area between the mountainous and plain portion of the catchment at the foothills of the Himalaya, also known as terai region, which basically lies in Nepal. These terai regions have excessive growth of vegetation and weeds on account of excessive moisture content.

(iii) Lower reach zone- Lower reach zone of the kosi basin in the basin in the plains comprises large inland delta formed by the huge sandy deposit of the Kosi River. On account of heavy siltation of the order of 25 million cubic metre of sand/silt per year and thereby in the process of building up the delta.

### 2.1.6. Morphology of the Kosi River

The Kosi River carries huge amount of sediment. The reason for that is that the river cuts across the Himalaya and the Shiwalik ranges and high rainfall (mean1456 mm/yr) leads to extensive soil erosion and landslides in its upper catchment. The silt load of the river is one of the highest in the Indian sub-continent, about 95 MCM/yr. On reaching the plains, high aggradations of river bed and sediment bed load offer enough resistance to the water, forcing the river to find alternate paths, resulting in lateral shift of the river course. The river in the plain flows in several channels in a width varying from 6 to 16 Km.The River before training used to move several km. in a year causing excessive damage to life and property. Records show that between year 1736 and 1953 the river moved through a distance of about 112 Km. westward till its course was confined through jacketing by constructing embankments and series of spurs on both the banks. Though shifting of a river is part of its natural evolution process, other factors inducing this phenomenon could be earthquakes, landslides and neotectonic activity. The Kosi River is responsible for many floods in Bihar. Afflux bundhs were constructed U/S of the Kosi barrage in a length of 12 km in the west and along 32 km in the east to control the shifting and streaming the river towards the barrage. As far as the afflux embankments are concerned, they are tied up at the two ends of the barrage and diverge upstream primarily to hold the pool of water impounded behind the barrage and to contain the extent of submergence on both sides of the river upstream of the barrage, both due to impoundment as well as due to backwater effect of impoundment on the incoming flows. The afflux embankments get away from river currents or velocities. To channelize the river flow in the downstream side, 125 km long eastern embankment and a 101 km long western embankment were constructed on the basis of 25 years return period using local earth as a construction material with top width- 6.1m and side slope varying from 2:1 to 3:1. Numerous spurs were constructed with embankments to keep the river flow centrally by providing top width- 4.0.m and side slope- 2:1. The building up of embankments on either side of the river confined the river channel to some extent. The Kosi River has an average discharge of 55,000 cusec (1557 cumecs), which increases 18 to 20 times during peak floods. The highest flood recorded in recent history of the river is reported to be 9, 13,000 cusec (25854 cumecs) on 5th October, 1968. The Kosi barrage has been designed for a peak flood discharge of ≈ 9, 50,000 cusecs (26901 cumecs).

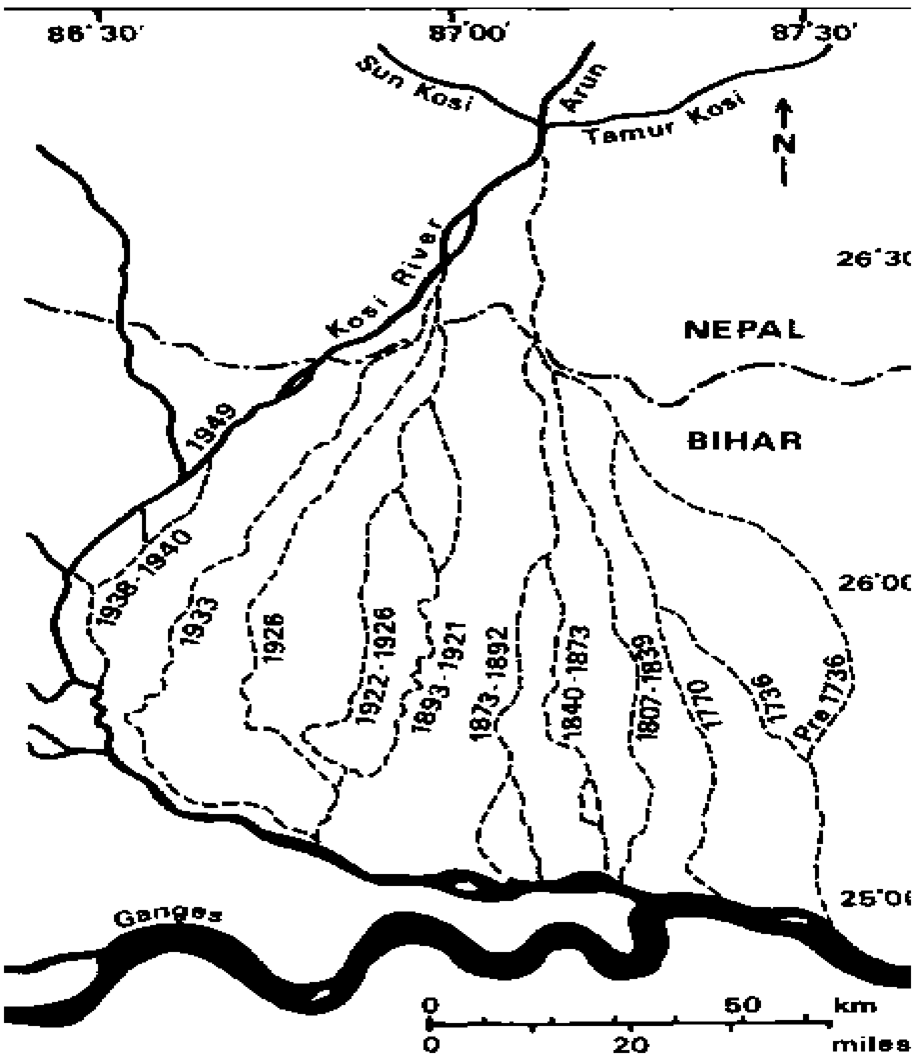


**Fig.4 Showing Kosi River Course**

which ultimately results into overtopping and breaches of banks and flooding in the basin area. Breaches have occurred in seven of the years from 1963 to 2011 and result from: (i) high discharge exceeding the carrying capacity of the embankment, and (ii) intentional cuts along the jacketed portions of the rivers by villagers. Outside of the mainstream of rivers, floods occur even when there is no breaching, due to floods coming from tributaries, heavy rainfall in the local area and drainage congestion.

## 3.0 Problems of the Kosi river

Kosi river basin downstream of Chatra suffers from four major problems owing to flood and sediment are as given below

Problems of the Kosi river basin can be categorised as :-

a. Problem of river shifting.

b. Problem of heavy sediment load.

c. Problem of flooding

d.Problem of water logging and drainage congestion.

## 3.1 Problem of River shifting

Kosi river has an exceptionally high sediment yield of 0.43 million tonnes/year/km2 which is accommodated in a very narrow alluvial plains almost one-fifth of the upland

area. This has resulted in predominantly aggrading channels of the Kosi and building up of a very large positive topography called ‘Megafan’. Most analysts agree that the confinement of the Kosi within the embankment further worsened the situation and has caused significant aggradation within the channel belt. Kosi River shows a large braided network of streams of various orders of magnitudes. Its (i) large dimension, (ii) multi-threads morphology, (iii) sandy bed, and (iv) avulsive behaviour make it very important to understand the sediment dynamics and propose a management strategy.
Kosi River shifts laterally over the Himalaya foreland plain by continual minor cut-offs, bank cutting and by episodic major shifts across watersheds. Migration is unidirectional because after a channel is filled to instability, floodwater will drain preferentially into a new adjacent low area rather than across it to the next watershed or back to the last abandoned channel. Records show that between year 1736 and 1953 the river moved through a distance of about 112 Km. westward till its course was confined through jacketing by constructing embankments on both the banks. The historic shift is shown above.

As already described earlier, the river had been taking sudden jumps from one course to another and is known to have shifted by 20 kms to the west in the course of single year. Through such movement, from the year 1736 to 1950, about 7,770 sq.km. of land in Bihar and approximately 1295 sq.km. land in Nepal has been laid waste as a result of sand deposition. In the course of shifting, many towns and villages were wiped out and heavy losses of property, live stock and even human lives were inflicted. The whole area which was once very fertile, containing lush green crops, got transformed into barren, undulating and full of sand dunes, left behind by the river, along with a chain of marshes and lakes, which served as breeding ground for mosquitos. Diseases like Malaria and Kalazar etc. were rampant. The entire population of the Kosi region in the lower valley had undergone acute hardships on all counts, mental physical and financial.

### 3.2 Problem of heavy sediment load

The shifting tendency of river is attributed to the heavy silt load carried by the river in the upper reaches, where slope is very steep. It is often cited as the root cause of all troubles in the Kosi river basin. In 1941 Mr. C.C. Inglis in his report on " Factors affecting the Westerly movement of the Kosi river " summed as hereunder.
" The cause of the movement is the building up of the steep sub montane delta due to an excess charge of sand. This sand is stated to be, to a considerable extent due to land slides and erosion, which occur as a result of removal of forest trees and undergrowth from the steep hill sides, in order to secure short term cultivation".
There are several reasons for the heavy contribution of silt in the Kosi river. These are :-

i. Geologically the river is very old while the mountain through which it is passing is very young. The uplift and the gradual building of the Himalayas continued for a very long period. During the process of uplift, folding and faulting, the river altogether, maintaining its original course flowed with increased gradient, causing side and bed erosion all along the course.
ii. As a result of this deep cutting the sides have become steep causing frequent land slides.
iii. Frequent seismic disturbances caused further loosening and disintegration of the already shattered rock in the region.
iv. Due to absence of any flat valley in the upper catchment of the Kosi river, upstream of the gorge, the entire sediment load is carried down.
v. When the river debauches in the plain, the bed slope of the river becomes as flat as 0.4 metre/km to 0.2 m per km. The considerable fall in the bed slope of

the river causes fall of velocity and ultimate reduction in silt carrying capacity of the river.

The silt carrying capacity of the river drops suddenly as soon as the river comes into the plains. This causes silt deposition in the bed inducing vagrant tendency in the river.

**3.2.1 The average annual sediment load of the river at Barhakshetra**

The average annual sediment load of the Kosi at Barahkshetra has been assessed at 95 million cu. meter The break up of the same is as under :-

| | | |
|---|---|---|
| i. | Coarse sediment | 18.0 Million cu meter |
| ii. | Medium sediment | 23.85 Million cu meter |
| iii. | Fine sediment | 53.14 Million cu meter |

## 3.3 Problem of Flooding

### 3.3.1 Causes of flooding

The Lower catchment of river Kosi and its tributaries are affected badly by severe floods almost every year. As the river with its tributaries like Kamla Balan, Bagmati and Adhawara group emerge from the hills and enter into plains of Nepal Terai and Bihar, their velocity of flow is dropped. This results into increase in the depth of flow and reduction of silt carrying capacity. Due to reduction in silt carrying capacity, silts are deposited into beds, resulting into rise of river bed and bank erosion. The mouth of the channels also gets choked too often causing shift in courses, bringing new areas under the grip of flood. This phenomenon is further attributed to the rise in the water level, which ultimately results into overtopping and breaches of banks and floodings in the basin area.

### 3.3.2 Water logging and drainage congestion

#### 3.3.2.1 Reasons of water logging and drainage congestion

The reasons of water logging and drainage congestions have been identified as given below:-

i. In the lower Kosi basin ( i.e North Bihar), the river, in the process of shifting from east to west, has left large tracts of low land and undulating sandy tracts.

## 4.0 To counter these problems, following major structural measures were constructed in the past

1 Birpur barrage

2 Jacketing the river with embankments

3 River training works

### 4.1 Birpur Barrage

Birpur barrage at Bhimnagar was the first structural measure undertaken to manage Flood issues in Kosi River. The salient features the Birpur barrage is given in Table

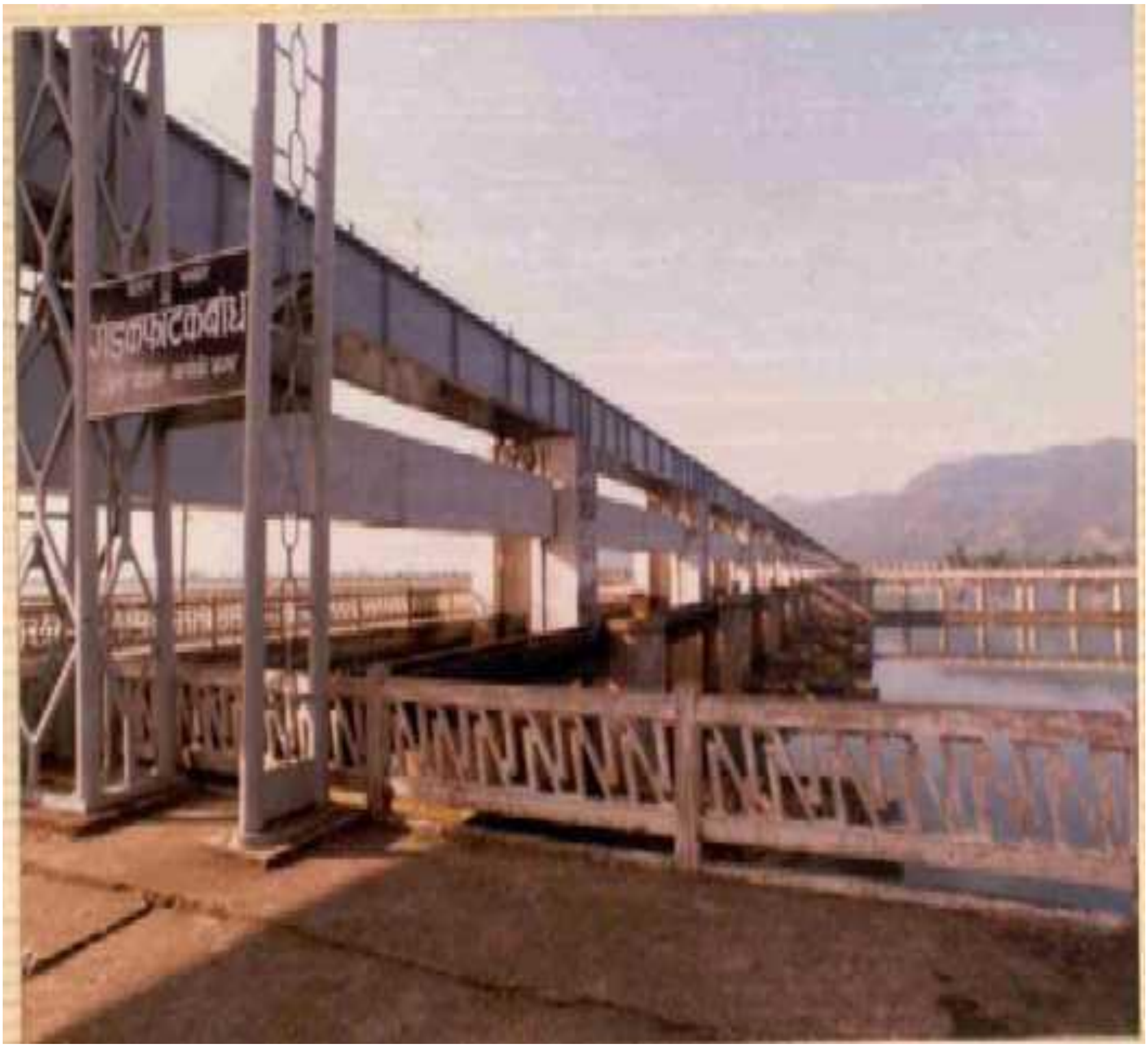

**Fig. 5 Birpur Barrage**

**Table 3** Salient features the Birpur barrage

| S.NO | PARTICULARS | UNIT | |
|---|---|---|---|
| 1 | Catchment area (up to Barakshetra) | 22,988 Sq. miles | 58,849 Sq.km |
| 2 | Distance of Barrage from Barakshetra | 33 Mile | 53 km |
| 3 | Designed discharge | 950 Lac cusecs | 26900 cumecs |
| 4 | Length of Barrage | 3770 feet | 1149 metre |
| 5 | Looseness factor of Barrage | 1.45 | 1.45 |
| 6 | Silt factor | 1.3 | 1.3 |
| 7 | Number of sluices | 56 | 56 |
| | (i) Left under sluice | 6 nos. each 60'00" | 6 nos. each 18.288 M |
| | (ii)Spill way | 46 nos. each 60'00" | 46 nos. each 18.288M |
| | (iii) Right under sluice | 4 nos. each 60'00" | 4 nos. each 18.288M |
| 8 | Length of Stilling Basin with friction block | 89'6" | 27.28 M |
| 9 | Lacey's scour depth | | |
| | (i)Spill way | 38.60' | 11.77 M |
| | (ii) Under sluice | 41.20' | 12.56 M |
| 10 | Intensity of discharge | | |
| | (i) Under sluice | 397 cusecs | 11.24 cumecs |
| | (ii) Spill way | 358 cusecs | 10.14 cumecs |
| 11 | Present pond level | 245'0" | 74.69 M |
| 12 | Future pond level | 255'0" | 77.74 M |
| 13 | Crest level | | |
| | (i) Under sluice | 230'0" | 70.12 M |
| | (ii) Spill way | 235'0" | 71.64 M |
| 14 | Size of gates | | |
| | (i) Under sluice | 60' x 26' | 18.288 x 7.92 M |
| | (ii) Spill way | 60' x 21' | 18.288 x 6.40 M |
| 15 | Piers width | | |
| | (i) Main pier | 70'0" | 2.134 M |
| | (ii) Double pier | 10'0" | 3.048 M |
| | (iii) Dummy pier | 6'0" | 1.829 M |
| 16 | Guide bunch | 6000'0" | 1830 M |
| | Left | 6000'0" | 1830 M |
| | Right | | |
| 17 | (A) Eastern Kosi main canal | | |
| | (i) Discharge | 15000 cusecs | 424.80 cumecs |
| | (ii) C.C.A | 15.13 Lac Acres | 16.13 Lac H.A |
| | (B) Western Kosi main canal | | |
| | (i) Discharge | 8500 cusecs | 240.72 cumecs |
| | (ii) C.C.A | 8.03 Lac Acres | 3.25 Lac H.A |
| 18 | Kosi river embankments | | |
| | (i) Western afflux bund | 7.25 Mile | 12.00 km |
| | (ii)Eastern afflux bund | 20.00 Mile | 32.00 km |
| | (iii) Eastern embankment | 78.13 Mile | 125.00 km |
| | (iv) Western embankment | 63.013 Mile | 101.00 (47+54) |

## 4.2 Embankments system

Kosi River is confined to flow within embankments. Embankments on both sides downstream of the barrage for a length of about 387 km have been constructed to check the westward movement of the river. The embankments on both sides of the river are kept at about 12 to 16 km. Construction of embankments on either side of the river confined the river channel to some extent as sediment which previously spilled over flood plains is now confined within the river. The eastern and the western embankments between the Chatra to Kursela is shown in Figure 6.

**Table 4: List of Embankments and its detail**

| Sl. No. | Name of the Embankment | River | Length |
|---|---|---|---|
| 1 | Eastern afflux embankment (EAB) at u/s of Kosi Barrage | Kosi | 32 km |
| 2 | Western afflux embankment (WAB) at u/s of Kosi Barrage | Kosi | 12 km |
| 3 | New Nepal Embankment (Above EAB) | Kosi | 15 km |
| 4 | Eastern Kosi embankment (EE) | Kosi | 125 km |
| 5 | Western Kosi embankment (WE) | Kosi | 47 km |
| 6 | Ghoghrdiha Ghoghepur Embankment (GGE) | Kosi | 54 km |
| 7 | Sikrahatta – Majhari Low Embankment (SMLE) | Kosi | 18 km |
| 8 | Extended Sikrahatta – Majhari Low Embankment (ESMLE) | Kosi | 12 km |
| 9 | Khando/Tiljuga left and right Embankment | Tiljuga | 25 km |
| 10 | Bhutahi Balan left and right Embankment | Bhutahi Balan | 30 km |
| 11 | Badlaghat – Magarpara Embankment (BME) | Kosi | 32 km |
| 12 | Magarpara – Narayanpur Embankment (MNE) | Kosi | 31 km |
| 13 | Tirmuhani – Kursela Enbankment (TKE) | Kosi | 28 km |
| 14 | Kamala Balan Left Bank Embankment from Indo Nepal Border (Jainagar) to Kothram (leaving gap from 12.5 km to 22.5) – (KBLBE) | Kamala Balan | 92 km |
| 15 | Kamala Balan Right Bank Embankment from Indo Nepal Border (Jainagar) to Kothram – (KBRBE) | Kamala Balan | 95.5 km |
| | | Total | 648.5km |

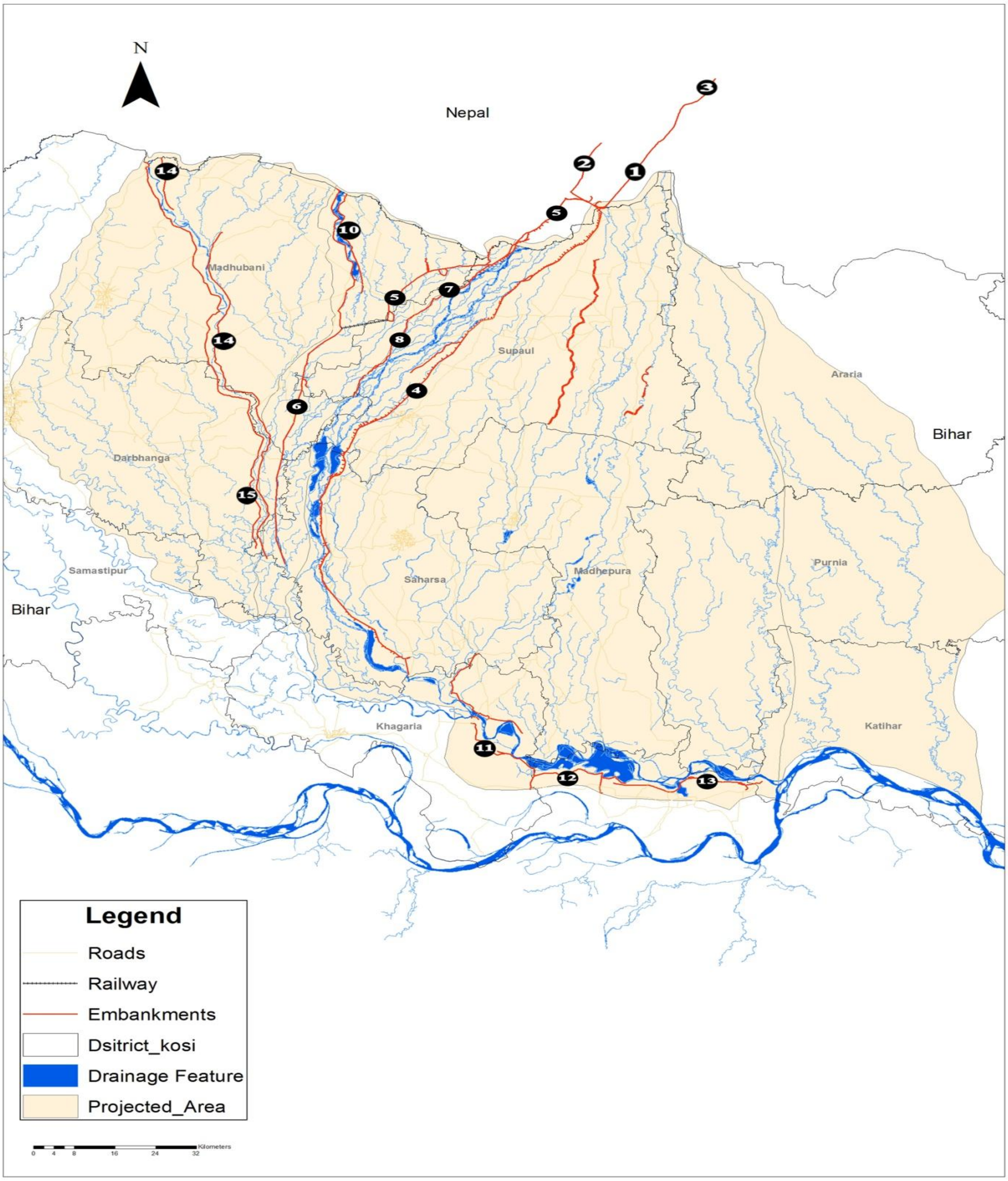


**Fig. 6 The eastern and the western embankments**

### 4.2.1 Historical breaches

Kosi embankments have seen a number of breaches at various locations/stretches due to unprecedented high discharge. Breaches could also be attributed to other reasons like shifting of river channels. Also, it is reported that sometimes habitation inside the embankments tends to breach the embankment to save them. Some of the most significant and noted breaches are given below.

**1963**: The first breach was on the western embankment in Nepal in 1963 near village Dalwa.

**1968**: Breach of 1968 was at five places in Jamalpur. This was caused due to highest flow of 913,000 cu ft. /s (25,900 m3/s) ever recorded in the river.

**1971**: The Bhatania Approach Bundh that was constructed in 1968-69, collapsed between 10th to 19th kilometer below Bhimnagar in 1971 and many villages were washed away. No breach was observed in eastern embankment.

**1980**: On the eastern embankment near Bahuarawa in Salkhua block of Saharsa district at 121st kilometer below Bhimnagar. The river eroded the embankment in about 2 kilometers reach.

**1984**: On the eastern embankment near Hempur village in the Navhatta block of Saharsa district, 75 kilometers below the Bhimnagar barrage.

**1991**: In the western embankment near Joginia in Nepal. This was a repeat performance of Bahuarawa breach where the river had receded after eroding the embankment.

**2008 Kusaha breach**: The most devastating shifting of Kosi through the breach of afflux bundh at Kusaha upstream of Kosi Barrage. It is evident that breaches have taken place upstream and downstream of Birpur barrage (Kushaha, Dalwa, Joginiya etc.) and in the middle reach near Mahesi/ Nauhata and downstream , where the river turns towards eastern side.

The 18 August 2008 avulsion of the Kosi River recorded an eastward movement of 120 km which is an order of magnitude higher than any single avulsive shift recorded in historical times. The avulsion was triggered by a breach in the eastern afflux bund of the Kosi at Kusaha, 12 km upstream of the Kosi barrage as detailed in Figure 7. This avulsed channel 'reoccupied' one of the palaeo channels of the Kosi and 80–85% flow of the river was diverted into the new course. Therefore, presumably, if the breach had not been repaired, the Kosi would have taken up a new course or the revival of an old course to the Ganga


**Fig. 7 Breach in the eastern afflux bund**

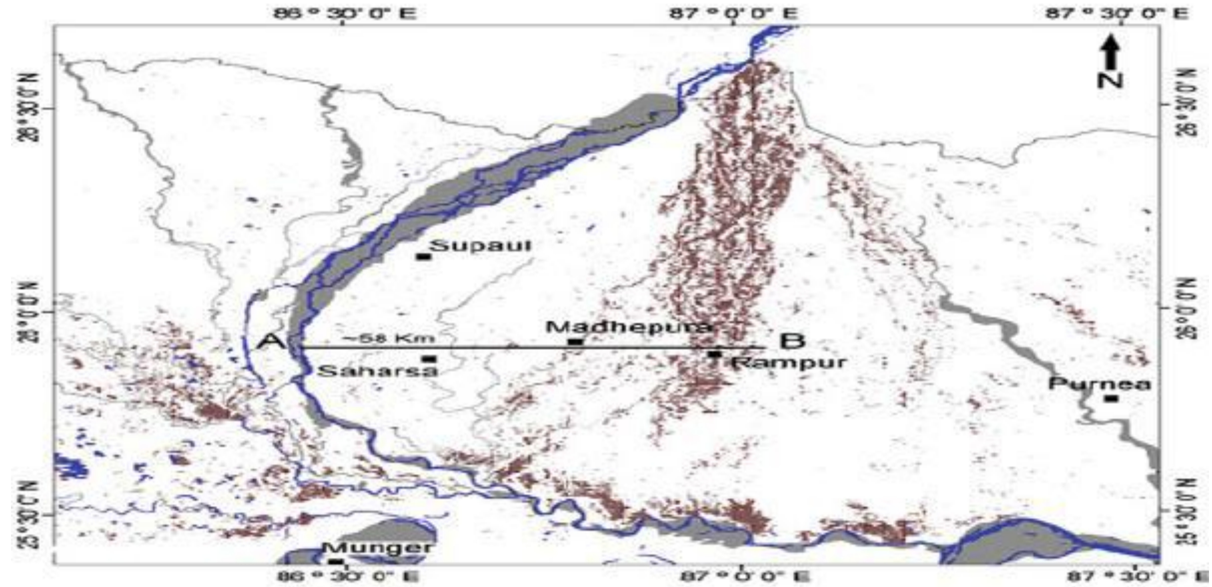


**Fig 8 Inundation map due to kusaha Breach Year 2008**

## 4.3. Current approach to embankment maintenance/strengthening and planning new works

The Government of Bihar (GoB) thus far has focused on structural interventions, such as constructing, raising, and strengthening of embankments (levees), river training, and river bank and town/village protection measures. More than 3500 kms of embankments have been constructed over the years, which remain a major and important component of the flood risk management system in the State. It is thus necessary to continuously monitor the status and safety of embankments to rationally assess the need and nature of embankment maintenance, anti-erosion works or flood fighting works to protect the embankment and the downstream habitations.

Maintenance and strengthening of existing embankments and planning new embankments continues to be a field-driven programme, in which just after flood, field engineers prepare schemes for repair/maintenance of the embankments in particular reaches, strengthening specific river training works and river banks, and submit to visiting Anti-Erosion Committee (AEC) constituted by the WRD to inspect the existing embankments and flood management structures. A high level Technical Advisory Committee (TAC) reviews the schemes submitted by the field engineers, and makes suitable suggestions. The field engineers prepare working estimates as per recommendation by Technical Advisory Committee (TAC). These selected proposals are placed for approval by the Department to a Departmental Committee known as Scheme Review Committee (SRC). SRC provides sanction after reviewing the available resources and economical viability of such schemes. The Flood Control Board then approves the schemes sanctioned by the SRC. These approved schemes are then taken up for implementation before the onset of next monsoon.

### 4.3.1 Review of kosi embankment managemet

The management of Embankment for Kosi basin is done as per directions from nodal agencies like GFCC, WRD, Flood monitoring cells etc. A standard SOP (Standard operating procedure) has been published by Water Resources Department, Bihar that provides the guidelines for planning and approval processes for maintenance and management of flood and flood structures.The present practice of maintenance of the embankment by Government of Bihar is governed by embankment manual of CWC.

The maintenance is carried out in-flood and post-flood period based on the inspection report of the engineers of Kosi Project &Chief Engineer concerned and recommendation of Kosi High Level Committee & TAC of Govt. of Bihar. All the flood control works must be properly maintained to provide protection for which they were designed. Broadly the process of maintenance is as per the guide lines of the WRD Govt. of Bihar and maintenance manual of CWE.

## 5.0 Model Development

### 5.1 Schematization of river network

The HD model domain for the Kosi River extends from Chatra in Nepal to Kursela in Bihar, India. In Nepal territory, from Chatra to Kosi barrage the length of the river reach included in Hydrodynamic (HD) model is 53 km (Chainage 0 at Chatra to 53 km at Kosi Barrage). In this reach, river comprises a total of 53 cross-sections at 1000 m interval. In India, length of the Kosi River reach is 220 km (Chainage 53 km at Kosi barrage to 273 km at Kursela). From Kosi barrage to Basua the reach is jacketed with embankment and towards the downstream of Basua there is contribution from Bagmati River and associated catchments. The MIKE 11 model domain is presented in Figure 9.

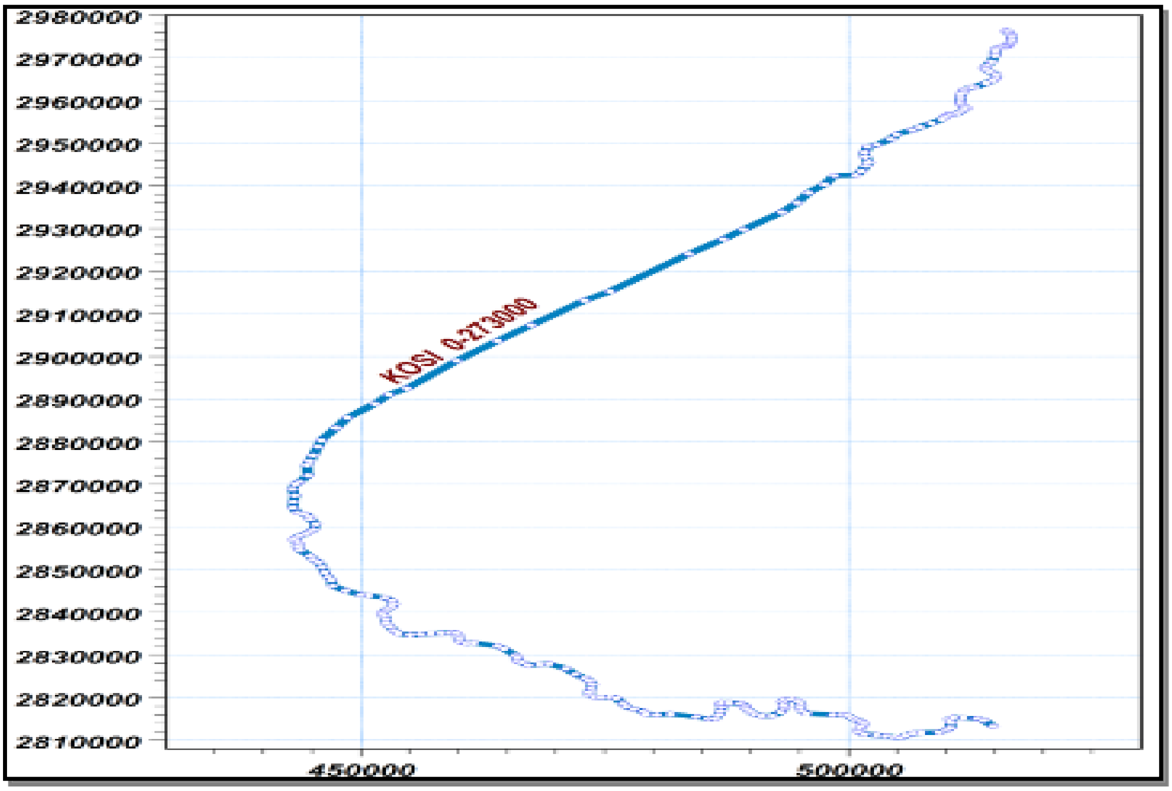


**Figure 9: Schematic River Network of the 1 dimensional Hydrodynamic Model**

### 5.2 Simulated longitudinal profiles of water level

The simulated water level profiles for the entire reach for discharges of different return periods, viz. 5, 10, 25, 50 and 100 years are shown in Figure 8-55, Figure 8-56, Figure 8-57, Figure 8-58 and Figure 8-59 respectively.

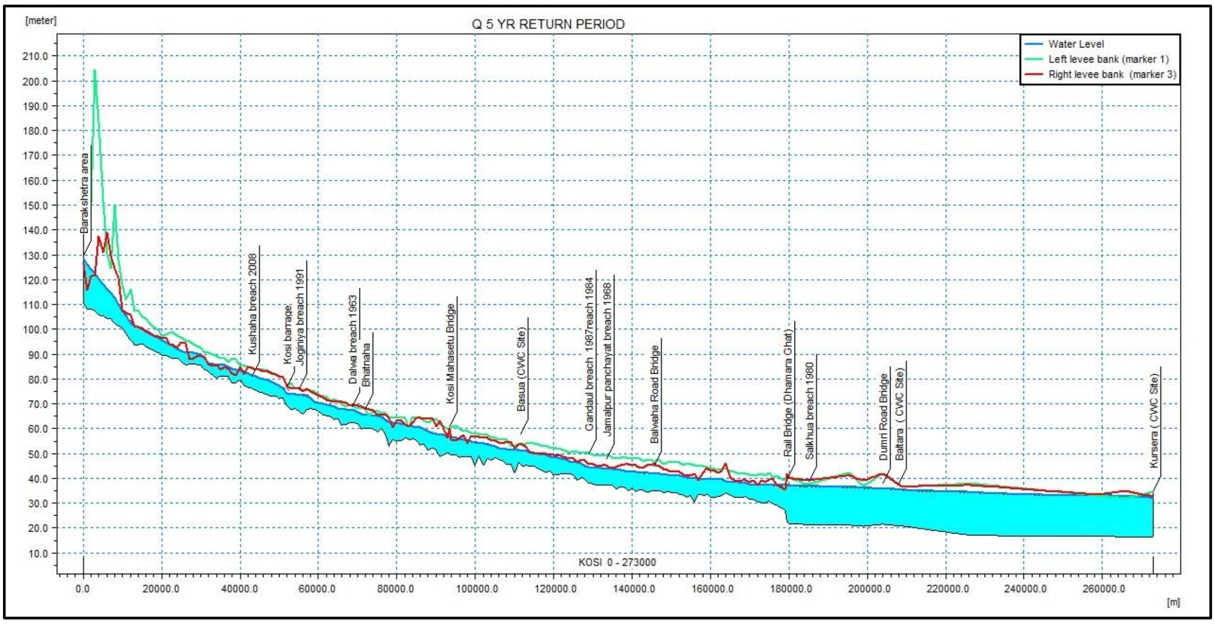


**Figure 10: Simulated water level for discharge of 5 year return period**

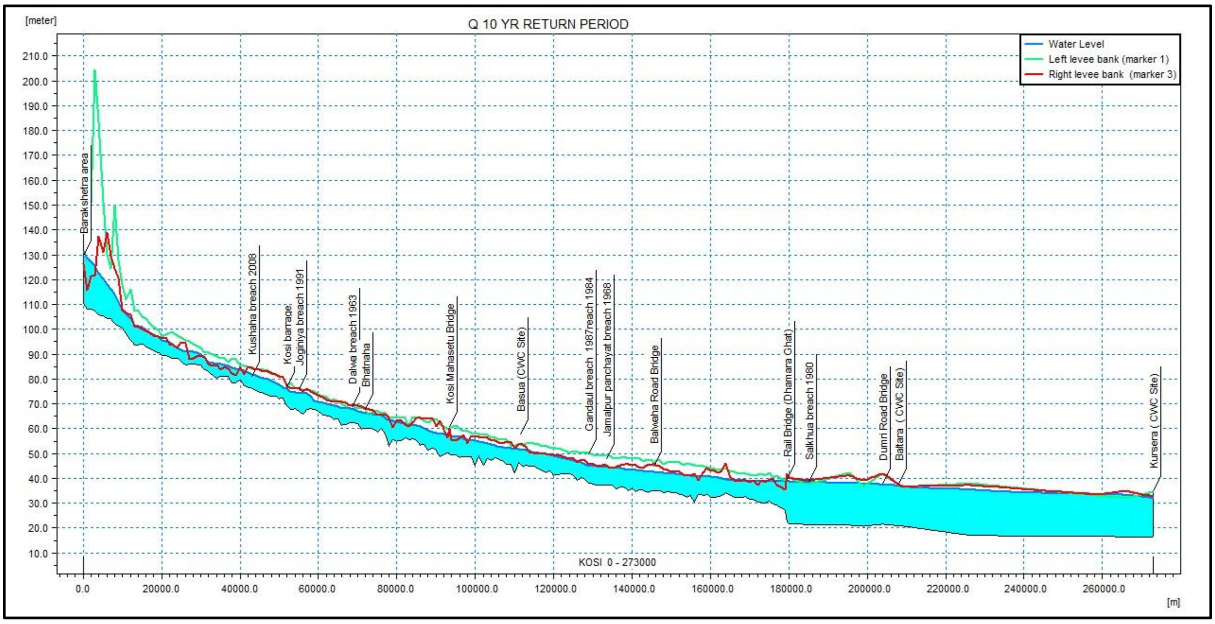


**Figure 11: Simulated water level for discharge of 10 year return period**

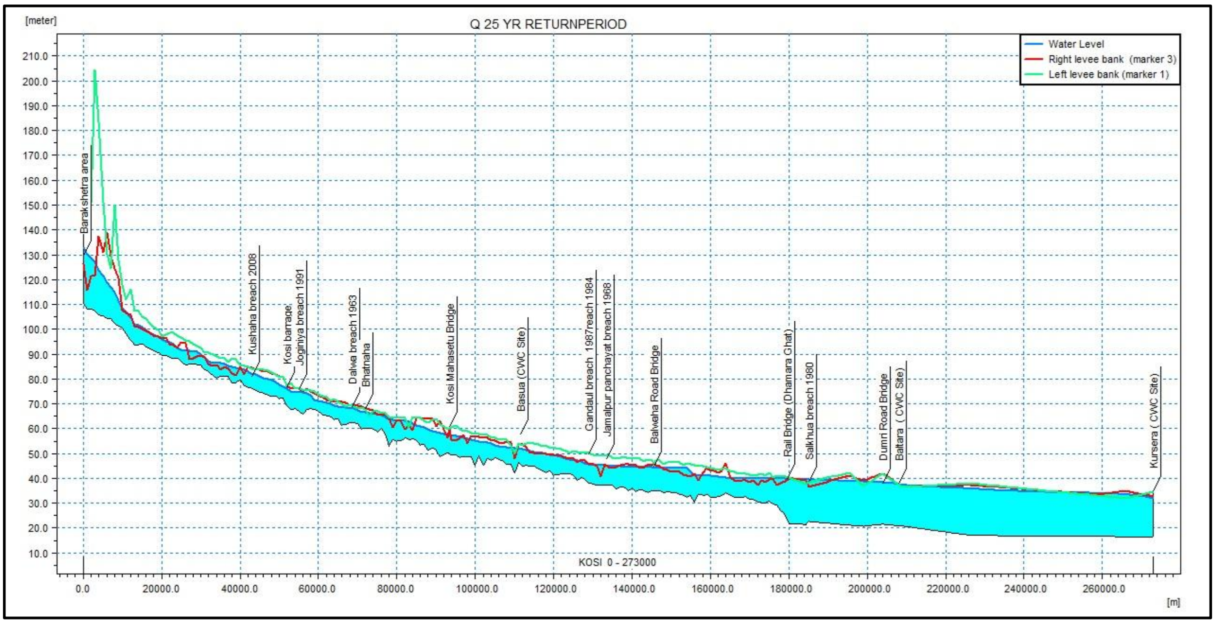


**Figure 12: simulated water level for discharge of 25 year return period**

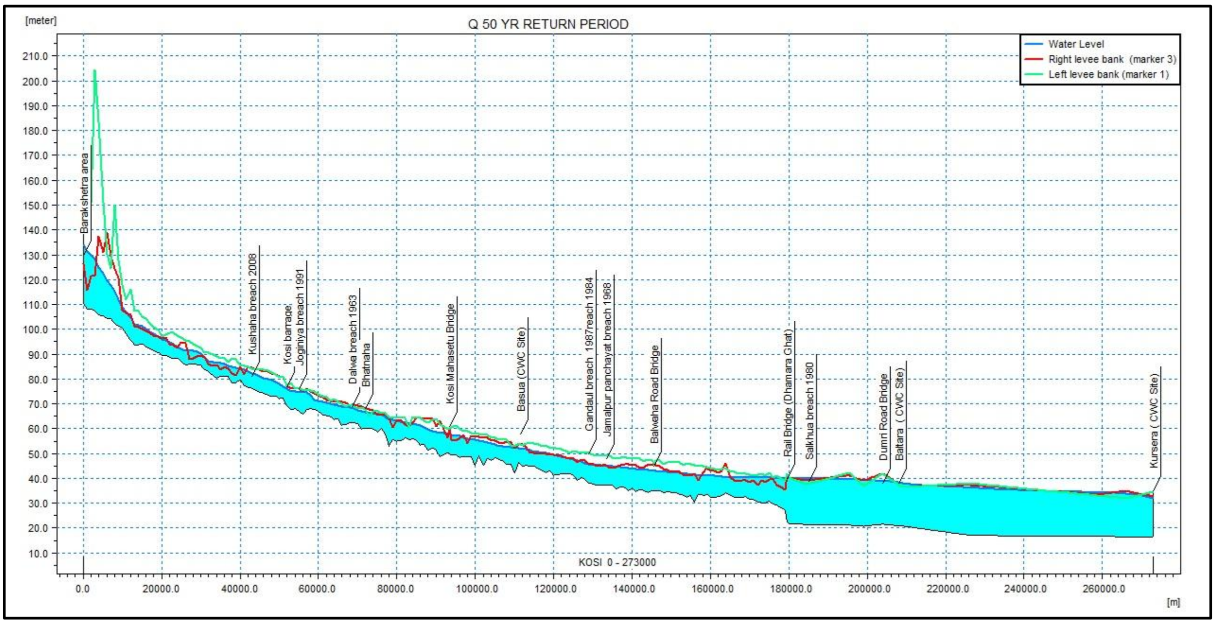


**Figure 13: simulated water level for discharge of 50 year return period**

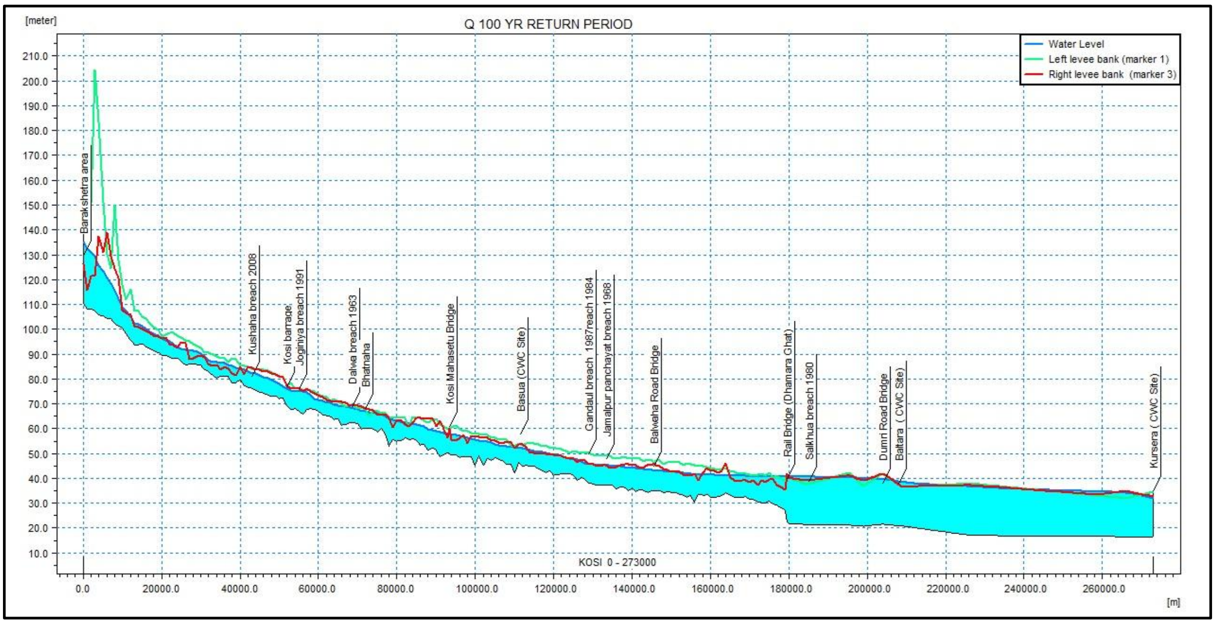


**Figure 14: simulated water level for discharge of 100 year return period**

## 5.3 Simulated longitudinal velocity profiles

Velocity profile for the discharges of 25 and 50 year return period are shown in Figure 15 and Figure16.

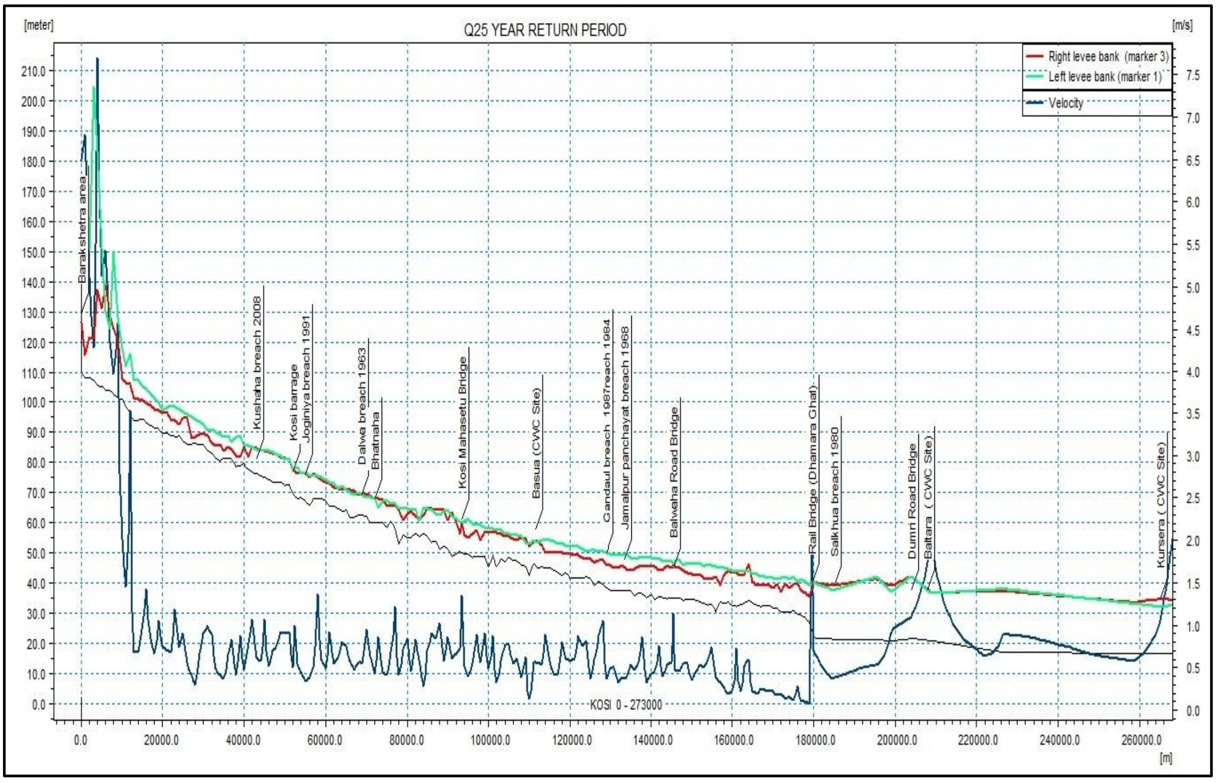


**Figure 15: Velocity profile for discharge of 25 year return period**

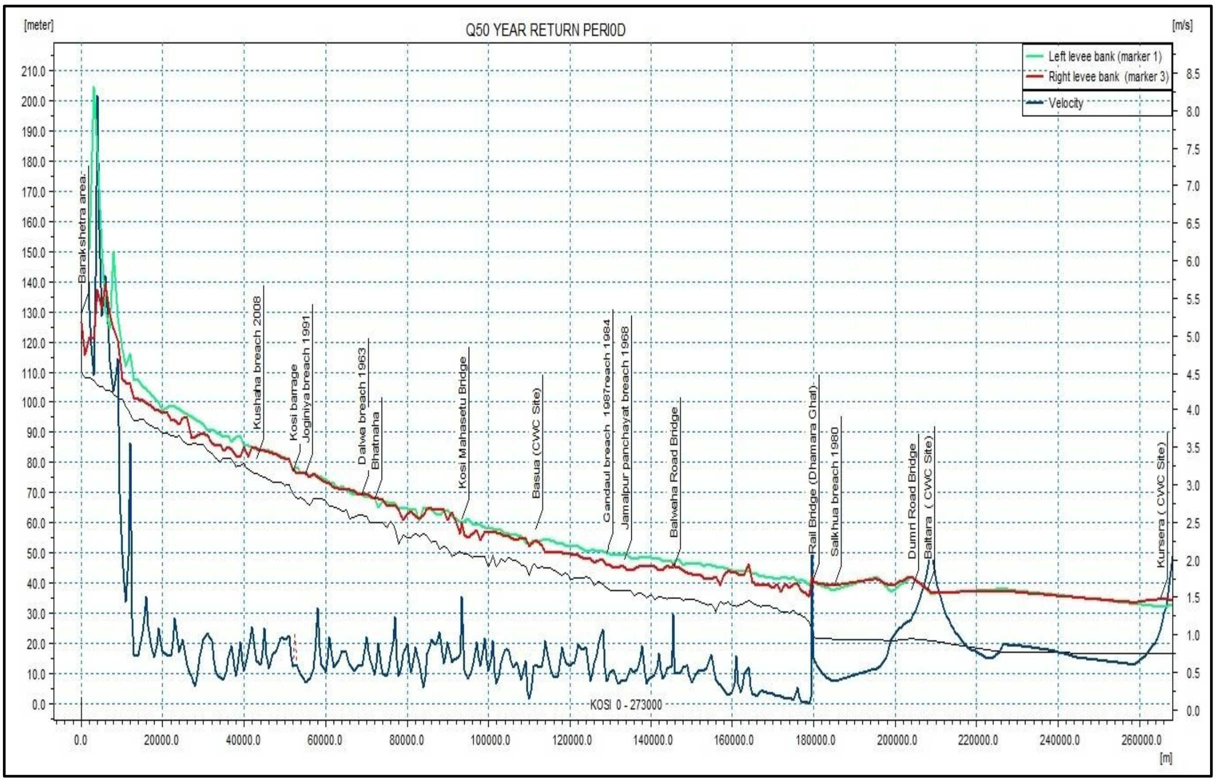


**Figure 16  Velocity profile for discharge of 50 year return period**

### 6.0 Analysis of water and sediment flows

The following are the outputs from model analysis of the water and sediment flows in the main river channel, the fan and the flood plains.

### 6.1 Main River Channel

1) Water levels and discharges along the river course

2) Long term aggradations of bed level, and possible future equilibrium condition

3) Scour depths at vulnerable locations

4) The velocity near the banks for protection measures

### 6.2 Fan and Flood Plains

1) Flood plain inundation for reaches without embankment

2) Inundation of the fan from breaches in the river embankment

### 6.3 Mitigation Measures

The following mitigation measures have been tested with the mathematical models:

1) Effectiveness of protection measures at vulnerable locations

2) Impact of embanking unprotected reaches

3) Potential for diversion and storage of water and sediment from the main river over the fan.

4) Monitoring, flood forecasting and warning system

5) Impact of possible future scenarios: storage dam upstream Chatra, climate change and soil conservation measures upstream.

### 7.0 Recommendations

Watershed management measures in the upstream catchment and the construction of a large storage dam at Chatra will have a major beneficial impact on sedimentation in the lower catchment. Actual implementation is not seen to be imminent, and measures to mitigate disastrous flooding and sedimentation in the lower basin are required urgently.

Progressive basin-wide implementation would normally suggest relatively high capital investment, with low annual maintenance costs. Implementation of upstream watershed management would render much of the high initial capital investment redundant, and reduce maintenance costs.

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