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Research Article

HUMAN INDUCED BANK FAILURES ALONG THE LOWER BALASON RIVER IN DARJEELING DISTRICT, WEST BENGAL

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ABSTRACT
Balason River with a total length of 46.40 km is the most important right bank tributary of Mahananda River having its origin from Lepchajagat (2361 m). Failure of the banks along the lower Balason river has been noticed as the river undergoes lateral adjustment due to high fluctuating discharge with frequent flow diversions, cohesiveness of the bank materials and anthropogenic effects in the form of human occupancy on the bank and extensive bed material extraction. Mostly, extraction sites close to the bank are preferred as it reduces both labour and transportation costs. The effect of such near-bank extraction is the ultimate lowering of the bed and in many sites such extraction process has created scours which results into diversion of channel towards the bank during high discharge, hence increasing the bank failures. The retreat of side banks are favoring the widening of the river, possessing threat to local inhabitants. The failure of exposed banks are also acting as local sediment sources for the river and due to continuous bank failure at few stretches, the finer sediments are being carried away by the river during monsoon flows. Such suspended loads are being deposited in the lower segments causing siltation near its confluence. Although the concerned authorities are constantly considering the bank retreat through construction of embankments and other necessary actions after 1970's, the gradual increase in encroachment of the flood plains by the growing worker population engaged in bed material extraction should also be restricted. The adverse consequence of increased stream bank erosion results not only in accelerated sediment yields, but also to changes in stream channel instability and associated stream type changes.

Key Words: *Bank Failures, Bed Material Extraction, Human Occupancy*

INTRODUCTION
The adjustments of the channel width by mass-wasting and related processes can be represented as an important mechanism of channel response and energy dissipation in alluvial channels (Simon *et al.*, 1999). Under such lateral adjustments, the channel initiates bank failure depending upon the flow energy and shear strength, composition and environmental setting of the banks. Failure of the banks along the lower Balason River (figure 1) has been noticed as the river undergoes lateral adjustment due to high fluctuating discharge with frequent flow diversions, cohesiveness of the bank materials and anthropogenic effects in the form of human occupancy on the bank and extensive bed material extraction. During monsoon high peak flood flows, sudden outburst of water in the channel increases its shear stress causing failure of the exposed banks annually (Tamang, 2012). The bank erosion rates were observed following the monsoon season and the recession or further erosion after monsoon flush were compared with the pre monsoon bank conditions with reference to selected permanent structures (houses, roads, pillars, trees, etc) along the bank line. Bank line survey using GPS are superimposed with past bank conditions from available satellite imageries which indicate that the bank failure has been prevalent and is amongst the important modifications by the lower Balason River under increasing human interferences (figure 2).

The Study Area
The Funnel shaped Balason basin has its source from a place named Lepchajagat, located on the Ghum-Simana ridge at an altitude of 2361 m and with latitude of 27˚03´55″N and Longitude of 88˚14´12″E. It is the major right bank tributary of Mahananda River covering an area of 367.42 km^2. The Balason being a

perennial river has a total length of about 48.4 km of which 24.27 km is in the hills and remaining 24.13 km flows in the plain region. The right bank tributaries of Balason River are Pulungdung Khola, Rangbang Khola, Marma Khola, Manjwa jhora and Dudhia jhora. The left bank tributaries are Bhim khola, Rangmuk khola, Pachhim khola, Rinchigtong Khola and Ghatta Hussain Khola. At an altitude of 305 m, Balason River starts its lower course and from this area onwards mostly transportation and deposition by the river could be noticed. In its lower course, the river is joined by Rakthi khola, Rohini Khola, Panighata Khola, Chenga, Manjha, etc. It finally mixes with the Mahananda River near Siliguri town (latitude 26˚48΄37˝N and longitude 88˚18΄30˝E).

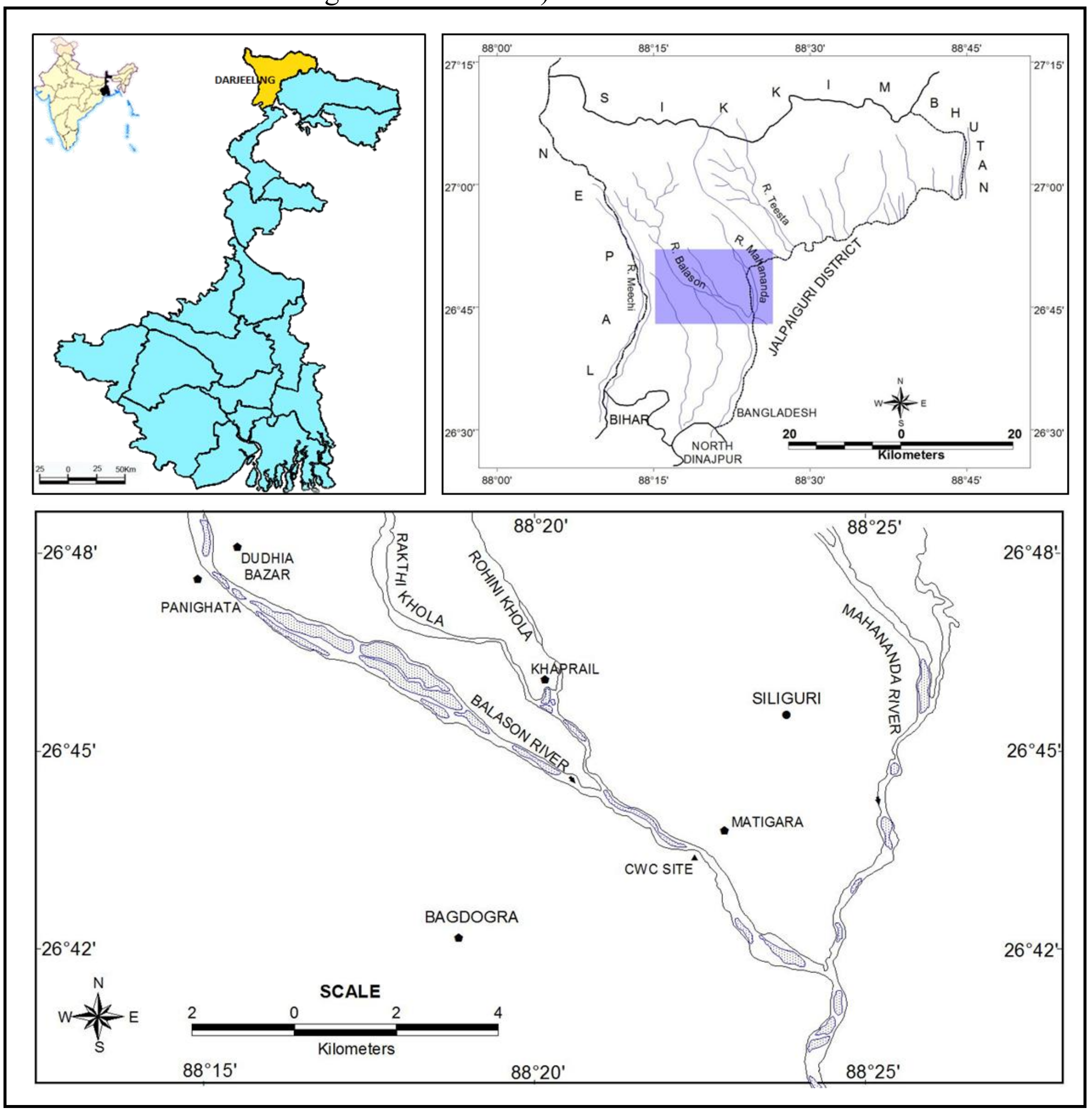

Figure 1: Location of the study area showing the lower course of Balason River with its two major tributaries, Rakthi and Rohini khola

Bank Conditions in the lower Balason River

The banks of the lower Balason River consist of loose unassorted colluvial sediments transported by the river during extreme flood events. Such sediments are being further eroded during annual peak flows by the river and moreover the finer sediments are being added over it through surface run-off thus producing the upward fining tendency (Jana and Dutta, 1995). The vertical distribution of bank materials varies as the river proceeds downstream with larger unassorted sub-angular boulders (1024-4096 mm) mixed with coarse sands and gravels in the upper piedmont segments till 6 km downstream. The compactness and cohesiveness is high with ample top soil favoring vegetative growth. The middle segments mostly consists of medium sized boulders (256-1024 mm), gravels (64-256 mm) mixed with sand. The coarse sand layer with distinct cross bedding thins out to fine sand and the cohesiveness is less as materials come out when plucked. The top soil is very thin layered and as such vegetative growth is also less compared to upper piedmont segments. In the lower segments, there exist mostly finer particles with fewer mediums to small sized gravels (12-128 mm). The sand and silts with distinct flood deposit layer are visible on the exposed banks. The formation of top soil layer is almost nil and only few grasses grow over the finer sand and silt deposited annually by the river during monsoon flows.

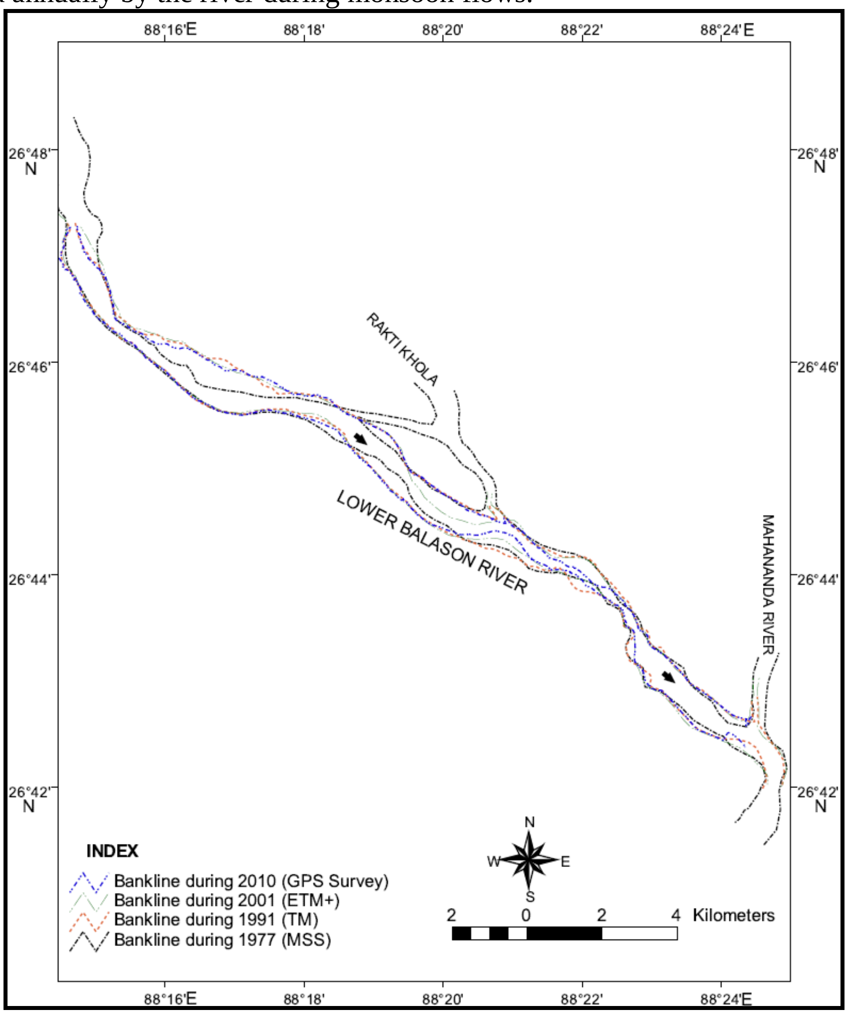

Figure 2: The changes in bank line along the lower Balason River from 1977 to 2010

In the upper piedmont segment, due to high compactness of bank materials and presence of the vegetation growth, the bank heights are quite high ranging between 10-12 m on its right bank and with almost similar compositions the height of its left bank also ranges between 8-10 m. The middle segment is the most failure prone zone with highly instable banks and the bank heights are also highly variable along this segment of the river. On the right bank at few places the bank raises to more than 7 m but the left is quite stable at 3 m height with presence of embankments and human settlements. Along the lower segment the bank height reduces to 1.5-2 m with very loose sand and silt. Although in this segment the embankments

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has been constructed on both banks, due to the human occupancies within floodplains near embankments the main channel flow remains mostly near the banks and has raised the bank heights.

Causes of Bank Failure in the Lower Balason River

The bank failure in lower Balason River is associated with several factors like high rainfall and fluctuating discharge, formation and migration of ephemeral bars near the banks, channel scouring actions, sediment load and energy of the channel flow during monsoon periods. Cohesiveness and configuration of the bank materials, anthropogenic effects in the form of human occupancies near banks and most importantly through extraction of bed materials from the river bed as well as adjacent flood plains and terraces cause such failure.

1. Study of the Natural Causes

In the lower Balason River, the in-depth study of the channel morphological and hydraulic characteristics reveals that due to its high peak monsoon discharge with high velocity and sediment load produces the required shear stress to erode its bed and adjacent banks. Frequent diversions of flows towards banks aggravate under cutting and the top exposed bank materials collapses increasing the sediment load of the river. The ephemeral bars near banks which migrates frequently and remains submerged during high flows further pushes the channel flow towards bank base causing undercutting (plate 1A). Such phenomenon is very common along the right bank of the lower Balason River and due to continuous undercutting by the river, the bank heights have increased substantially and narrowing of the channel width can be noticed. Thus the channel action near the bank base causes scouring of the banks base and the beds. The high monsoon rainfall also lowers the shear strength of the bank materials and cracks on the bank surface can be noticed due to the absence of vegetative cover.

2. *Study of the Anthropogenic Causes*

The construction of houses and roads near banks has further aggravated the failure of exposed banks as the extractors prefer to settle near the banks for easy access to river bed (plate 1B). The accumulation of extracted bed materials over banks during monsoon high flows when entering into river bed is not possible. Such overweight undercuts the banks. The human settlements have also reduced the vegetative growth over banks which lead to collapse of bank materials during monsoon downpour (Tamang and Mandal, 2010). The construction of roads near banks for transporting extracted materials and entry paths used by extractors for entering into the river has also reduced the bank shear strength creating vibrations due to continuous running of heavy trucks laden with extracted bed materials. In few places it has been noticed that the bank materials are directly extracted from bank base as well as from the bank surface. Such acts along with extensive lowering of river bed due to extensive bed material extraction during non-monsoon periods together have been largely responsible for the existing condition of banks along the lower Balason River.

Types of Bank Failure in the Lower Balason River

During the study of the extent and nature of bank failure in the lower Balason river the author has noticed some variations in the type of failure of banks with undercutting and rotational slips being common in upper piedmont and middle segments of the river but along the lower segments mostly the block slumping of bank materials occurs.

1. *Undercutting or Undermining*

This type of failure of banks caused due to impinging high velocity channel monsoon flow which results in slumping of bank materials (Shrestha, 2007) have been noticed mostly at concave bends along the upper piedmont segments of the lower Balason River. The banks at such bends are almost at right angle and undercut has formed holes with deposits of upper loose bank materials at the base of the bank (plate 1C).

2. Rotational Slips

The right banks at some places in the middle segments with compact clay deposits and the top loose gravels and sands has created rotational slip of upper bank materials. This is largely due to the imbalance between accumulation of dry loose materials on top face and under cutting by channel flow at the bank

Research Article

base. The frequent use of overbank surface due to human occupancies and running of trucks have caused slips of loose materials at the base (plate 1D).

3. Block Slumping

In the lower segment (near the confluence), the banks are composed of loose finer materials with few gravels. Here human settlements within floodplains near embankments and channel flow at bank base have triggered the mass slumping of loose top materials. The top grass covered blocks of banks at bank base can be noticed at many places along this segment of the lower Balason River (plate 1E).

Study of Bank Failure Rate at Selected Sites

For better understanding of the processes of bank failure in lower Balason River, two stretches with severe bank failure along the right bank of 1 km each in the middle segment (figure 3) has been surveyed and studied in detail. The bank failure rates were recorded following the planimetric resurvey method (Lawler *et al.*, 2001) by which the distance of bank top has to be measured from selected permanent structures. For measuring the failure rates the points at every 200 m were marked and the distance of bank top from the nearest permanent structures (houses, roads, house fencing and trees) within 50 m were measured during pre-monsoon period and post-monsoon period in order to get the annual rate of bank failure.

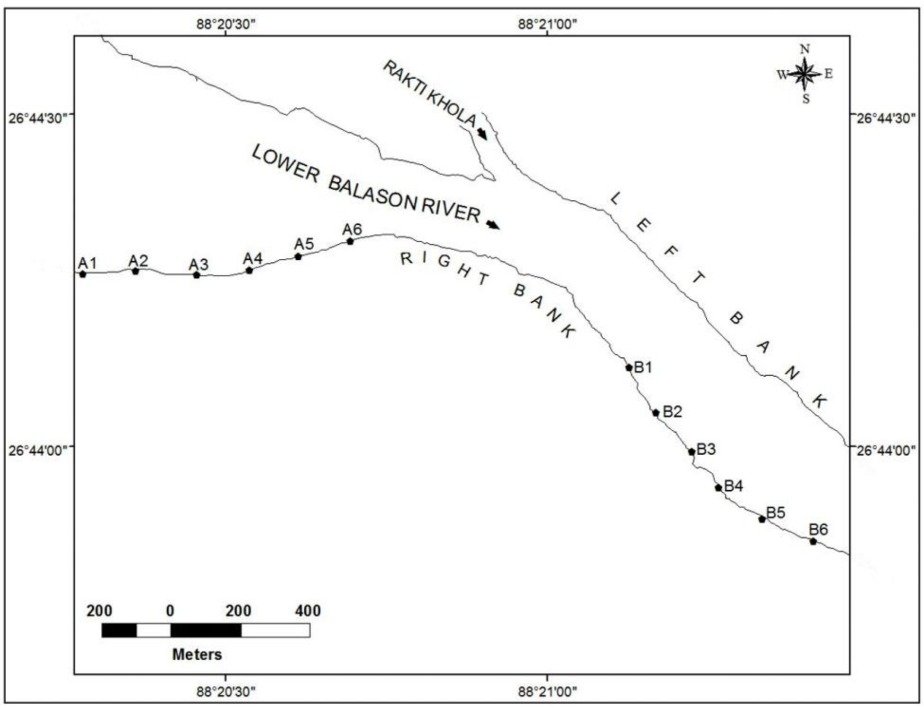

Figure 3: Location of the stretch and points considered for measuring the bank failure rates

The stretches along right bank is composed of unassorted large to medium sized boulders (256-1024 mm), gravels (24-128 mm) and coarse sand in the middle and lower layers with occasional layer of silt and clay at the middle portions. The top soil is very thin with few grasses followed by layer of coarse sands and smaller gravels (4 – 32 mm). The bed height at this stretch varies from 2.500 to 3.100 m at stretch A (till 1 km downstream) and from 4.650 to 7.000 m in stretch B. Although at this stretch channel flows at bank base have undercut the bank, the construction of roads and housed, less vegetative cover on bank top and the extraction of bank materials near bank base as well as over bank surface are responsible for decreasing bank heights and consequent failure. The distance measurement of bank top from the nearest pre-selected permanent structures within 50 m during pre and post monsoon condition from 2008 to 2010 (table 1) shows that at stretches having less vegetative growth on top of the bank and scouring at

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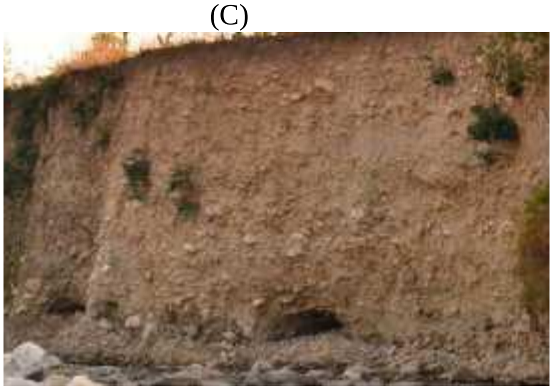
the bank base resulting under cutting, the bank failure was higher with maximum of 1.480 measured during 2010 at A5 and 1.335 m measured at B2 during 2008. The nearness of human settlements and roads has also affected the bank conditions and annual retreat of bank has been noticed (A3, A4 and A5).

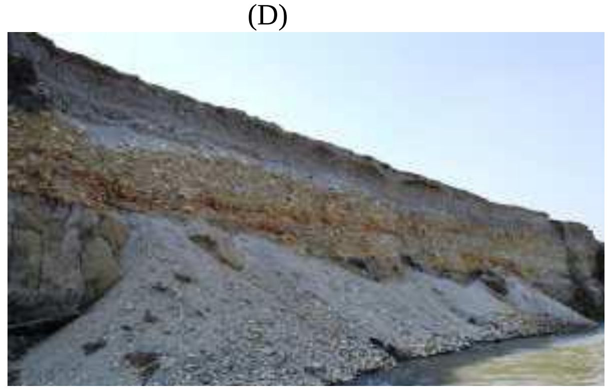
(A)

(B)

(C)



(D)



(E)

(F)

Plate 1: Channel flows during monsoon period undercutting bank base (A), human occupancies near retreating banks in the middle segment (B), the undercutting of banks forming holes at base common in the upper piedmont segment (C), rotational slips accumulating the loose bank materials at the base common in the middle segment (D), slumping of bank tops common in the lower segments (E) and direct extraction of bank materials (F) along the lower Balason river *(Photographs by the author)*.

Moreover, near-bank extraction of bed materials has resulted in diversion of channel towards the bank during high discharge thus increasing the bank undercutting and consequent failure in stretch B (B2 and B3). But at this stretch it can be noticed that failure has gradually decreased (B4, B5 and B6) due to substantial increase in vegetative cover on bank top.

Table 1: The distance (m) of bank top at different points from the pre-selected permanent structures during per-monsoon (PRE) and post-monsoon (POST) survey from 2008 to 2010

POINTS	P. STRUCTURE	PRE08	POST08	PRE09	POST09	PRE10	POST10
A1	ROAD CULVERT	38.715	37.500	37.500	37.395	37.395	36.350
A2	HOUSE	41.240	41.045	41.045	40.940	40.940	40.330
A3	HOUSE	26.115	24.950	24.950	24.920	24.920	24.280
A4	HOUSE	24.570	23.225	23.225	23.105	23.105	21.990
A5	HOUSE FENCE	30.030	28.550	28.550	27.690	27.690	27.515
A6	HOUSE	43.560	43.475	43.475	43.240	43.240	43.105
B1	HOUSE	12.380	12.310	12.310	12.115	12.115	11.960
B2	HOUSE	10.805	9.470	9.470	9.220	9.220	8.840
B3	HOUSE FENCE	22.460	22.350	22.350	21.940	21.940	20.650
B4	TREE	19.225	19.100	19.100	18.895	18.895	18.670
B5	HOUSE	15.240	15.220	15.220	15.045	15.045	14.440
B6	TREE	9.250	9.200	9.200	8.985	8.985	8.985

(Based on field records by the author)

Table 2: The annual failure rate (m) at different surveyed points from the pre-selected permanent structures from 2008 to 2010

POINTS	2008	2009	2010	AVERAGE	AVERAGE
A1	1.215	0.105	1.045	0.788	
A2	0.195	0.105	0.610	0.303	
A3	1.165	0.030	0.640	0.612	**0.615**
A4	1.345	0.120	1.115	0.860	
A5	1.480	0.860	0.585	0.975	
A6	0.085	0.235	0.135	0.152	
B1	0.070	0.195	0.155	0.140	
B2	1.335	0.250	0.380	0.655	
B3	0.110	0.410	1.290	0.603	**0.319**
B4	0.125	0.205	0.225	0.185	
B5	0.020	0.175	0.605	0.267	
B6	0.050	0.150	0.000	0.067	
AVERAGE (m)	**0.600**	**0.237**	**0.565**	**0.467**	

(Computed by the author based on field records)

On the basis of the bank top distance measurements, it can be said that along the stretches surveyed on right bank of the lower Balason river, the banks are eroding at an average rate of 0.615 m for stretch A and 0.319 m at stretch B and at 0.467 m for the entire stretch of 2 km (table 2). The variation of failure rate in this two stretches is largely due to the bank composition, the extent of under cutting and the extraction of bed materials.

CONCLUSION

The study of the nature and extent of the bank failure along the lower Balason river revels that the right bank is more failure prone compared to its left bank in the upper and middle segments but in its lower segments (near the confluence) failure have been noticed on the left bank. This has been largely due to frequent diversion of channel flows depending on the monsoon peak flows causing scouring and under cutting at bank base, the extent of human occupancies and extraction of bed materials (plate 1F) which are largely triggering the rate of bank failure. The failure of exposed banks are acting as local sediment sources for the river and due to continuous bank failure at few stretches, the finer sediments are being carried away by the river during monsoon flows. Such suspended loads are being deposited in the lower segments causing siltation near its confluence.

Although the concerned authorities are constantly considering the bank retreat through construction of embankments and other necessary actions after 1970's, the gradual increase in encroachment of the flood plains by the growing worker population engaged in bed material extraction should also be restricted. The adverse consequence of increased stream bank erosion results not only in accelerated sediment yields, but also to changes in stream channel instability and associated stream type changes.

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