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Geomorphology, sedimentology, and hazard assessment of the Sapta Koshi alluvial fan in eastern Nepal

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ABSTRACT

The Sapta Koshi River that is known for exceptionally high sediment-carrying and channel-shifting nature forms a broad alluvial fan into the Indo-Gangetic Plain after its emergence from the Siwalik Hills. The Sapta Koshi alluvial fan has a radial length of about 45 km and width of about 15 km in the Nepalese territory, where it forms a proximal to midfan segment extending from NE to SW, showing various geomorphic surfaces characterised by gravel to fine sand and mud lithofacies associations. The alluvial fan deposits are of Holocene epoch, and are unconsolidated and vulnerable to rapid erosion. Flooding, river oscillation and soil erosion are the main environmental problems in the alluvial fan region.

The flood hazard assessment was made using criteria such as slope, relative relief, distance from the active channel and its shifting pattern, engineering protection-structures, and man-induced activities. The alluvial fan region was zoned into three hazard levels such as high, medium and low. The western bank of the Sapta Koshi River, around Balardaha, Bhardaha, and Hanuman Nagar are identified to be highly prone to flooding and waterlogging. Man-induced activities play important role in increasing the hazard level in these areas. Therefore, short- and long-termed preventive measures have been suggested.

INTRODUCTION

The Sapta Koshi River is one of the major tributaries of the Ganga River (Fig. 1), and is known for exceptionally high sediment carrying and rapid channel shifting nature; 112 km/246 years (Holmes 1965; Goel and Chittale 1966; Wells and Dorr 1987; Singh et al. 1993). The river is an union of seven large snowfed-tributaries originating at an average altitude of 5,500 m. The watershed of the Sapta Koshi River covers 8,065 lakh hector in Nepalese territory (Jha et al. 1995) and extends from the Tibetan plateau (north) to the Indo-Gangatic Plain (south). The Sapta Koshi River flows through Kotha gorge and emerges out through Chatara into the Indo-Gangatic Plain where it forms the Sapta Koshi alluvial fan (Fig. 2), which is a braided fluvial fan (Stanistreet and McCarthy 1993). The alluvial fan covers approximately 675 sq. km in Nepalese territory where it extends for about 45 km from NE to SW and represents the proximal part. Further southwest, it extends into Indian Territory forming the distal segment.

The climate of the Sapta Koshi alluvial fan is controlled by the southeast monsoon. The average annual rainfall between December and February is around 32 mm, and during March and May is 350-530 mm. During the monsoon, the Sapta Koshi Watershed receives 80% (550-725 mm) of the annual precipitation. Therefore, the monsoon period is the time of flooding in the alluvial fan.

The Sapta Koshi alluvial fan possesses a long history of annual flooding. Flood/water logging, haphazard channel oscillation, bank scouring, floodplain siltation and soil erosion are the phenomena encountered due to flooding. Major aggravating factors are sudden high river discharge during monsoon, topographic pattern, weak lithology, soft soil cover and human encroachment in catchment and fan areas. To prevent and minimise annual flooding in the Sapta Koshi alluvial fan, identification of flood-prone area is the important task. Therefore, the target of this study was to assess flood hazard of the Sapta Koshi alluvial fan. For this, geomorphology and sedimentology of the alluvial fan were studied and criteria such as engineering constructions, hydrology and human induced activities were considered as input parameters in flood hazard assessment.

GEOMORPHOLOGY

The Sapta Koshi alluvial fan represents an extensive wet alluvium that widens towards south with low-sinuosity meandering distributaries, similar as the Okavango fan of Botswana, one of the largest subaerial fans in the world (Stanistreet and McCarthy 1993). The general trend of the

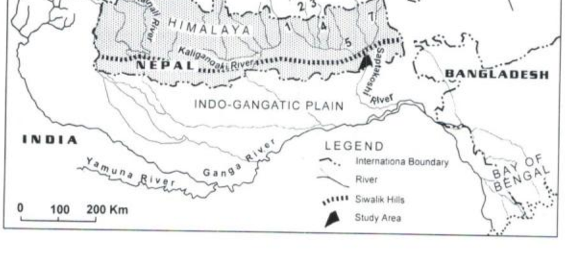


Fig. 1: Location map of the study area.

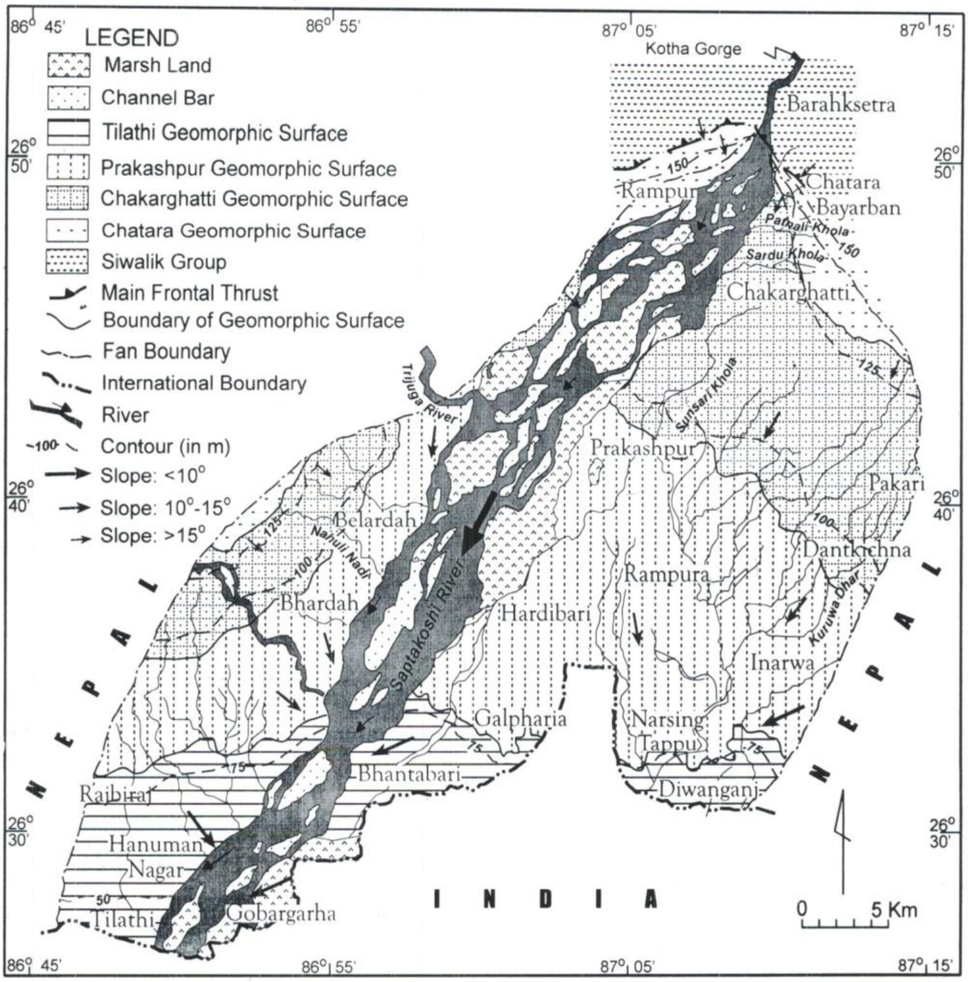


Fig. 2: Geomorphological map of the Sapta Koshi alluvial fan.

fan-slope is 5-10° SW. The Siwalik Hills located around fanhead border the Sapta Koshi River. Adjacent to the hills is situated a crushed zone produced by thrusting and landsliding. This indicates that the Siwalik Hills are uplifting actively (neo-tectonic activity). Therefore, the alluvial fan receives sediments continuously.

A number of geomorphic surfaces are developed around the local domal axis of the Sapta Koshi River. Depositional patterns are horizontal as well as sequential, and fining towards south. All the geomorphic surfaces are of depositional type.

A distributary system is developed in the Sapta Koshi alluvial fan. Several imprints of paleo-channel, paleo-levee, palaeo-blocked channel lakes, oxbow lakes, and flood plains are situated in the fan. The existing channel may represent one of the linear depressed zones in the area, suitable for water conduit. Similarly, other tributaries of the Sapta Koshi River also follow the nearest depressed conduits. Most probably almost all the conduits are affected by local neo-tectonic activities.

Geomorphic surfaces

The Sapta Koshi alluvial fan is divided into five geomorphic surfaces existing between the altitudes of 150 m and 40 m, applying the concept of morpho-stratigraphic classification. They are Chatara, Chakarghatti, Prakashpur, Tilathi and Active channel-flood plain geomorphic surfaces (Table 1). The former four geomorphic surfaces are distributed respectively from the north to the south of the Sapta Koshi alluvial fan. Several streams dissect these surfaces and typically the distributaries that behave like water conduits bypass these surfaces during the monsoon.

Chatara geomorphic surface

This surface located immediately south of the Siwalik Hills is the uppermost surface in the Sapta Koshi alluvial fan (Fig. 2 and 3). The surface is developed in both flanks of the Sapta Koshi River with altitude between 120 and 150 m (Table 1). The surface gradually widens towards the south and is dissected by several seasonal gullies, for example, Ratnali Khola, Sardu Khola, etc.

Table 1: Showing subdivisions of geomorphic surfaces and lithofacies associations

Geomorphic surface	Altitude (m)	Lithofacies association	Thickness (m)	Main composition	Distribution
Active channel-flood plain	40-60	Active channel-flood plain	10 (?)	gravel, sand, silt and clay	Present day channel
Tilathi	60-75	Tilathi	15	mud/clay	Tilathi, Bhantabari, Diwanganj
Prakashpur	75-90	Prakashpur	15	medium to fine sand	Prakashpur, Bhardah, Belardah, Hardibari, Rajbiraj, Narsing Tappu
Chakkarghatti	90-120	Chakkarghatti	27	coarse to medium sand	Chakkarghatti, Pakari, Chapki, Rampur
Chatara	120-150	Chatara	25	Matrix-supported gravel	Chatara, Rampur, Bayarban

Fig. 3: View of the Chatara geomorphic surface towards south.

Fig. 4: View of the Chakkarghatti geomorphic surface towards southwest.

Chakkarghatti geomorphic surface

This surface is developed in both the flanks of the Sapta Koshi River and the south of the Chatara geomorphic surface, and ranges in altitude from 90 to 120 m. The surface is covered by thick forest, farmland and many villages (Fig. 4). The imprints of paleo-channel, palae-lakes and paleo-levees are abundantly observed in the surface. Seasonal gullies such as Sunsari Khola and Dant Kichna Nadi dissect the surface remarkably.

Prakashpur geomorphic surface

This surface (Fig. 5) is developed further south of the Chakkarghatti geomorphic surface. The surface ranges in altitude between 75 and 90 m, and gradually widens towards the south around the Narsing Tappu and represents the lower part of the middle alluvial fan. The remnants of old fluvial channel, ox-bow lakes, sand mounds and natural levees are abundantly distributed in this surface. Many seasonal gullies and distributaries (for example, Kurua Dhar, Sunsari Khola, etc.) dissect the surface.

Tilathi geomorphic surface

The southernmost surface developed in the Nepalese territory is the Tilathi geomorphic surface (Fig. 6). The surface ranges in altitude from 60 to 75 m, and represents old fluvial channels with several paleo-lakes and marshes. Most part of the surface is in the form of marsh and only a small part is utilised as farmland and settlement at present. The surface is dissected by many seasonal distributaries (Khanro Khola, Mahuli Dhar, Tiljuga Nadi, etc.).

Active channel-flood plain surface

The lowermost and the newest surface developed by the active channel and recent flood plain is categorised as the Active channel-flood plain surface. This surface has altitude ranging between 40 and 60 m. The active channels are characterised by undulatory landforms of channel bars and scour surfaces, whilst the flood plains are characterised by marsh lands and inter-channel surface containing sheet flood deposits.

SEDIMENTOLOGY

Lithofacies and their composition, texture and sequence were studied in the Sapta Koshi alluvial fan to understand distribution of sediments in the fan, processes of sedimentation and flooding signatures.

Lithofacies association

Five sedimentary lithofacies associations are distinguished based on study of lithofacies, composition and texture, and on distribution of lithofacies in the Sapta

Fig. 5: View of the Prakashpur geomorphic surface towards south.

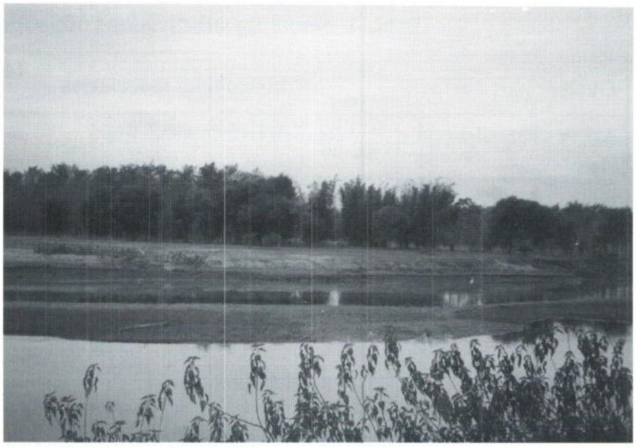


Fig. 6: View of the Tilathi geomorphic surface towards southwest.

Koshi alluvial fan. These are Chatara, Chakkarghatti, Prakashpur, Tilathi and Active channel-flood plain lithofacies associations (Table 1). All these lithofacies associations are concordant with geomorphic surfaces (Fig. 8). The lithofacies gradually change from boulder via pebbly sand and fine sand to silt and clay-dominated deposits, respectively, from the north to the south.

Chatara lithofacies association

The Chatara lithofacies association is widely distributed in the proximal fan area. It comprises medium- to very thick-bedded, matrix-supported, cobble pebble, boulder cobble pebble, pebbly sand (Fig. 7), normal- to reverse-graded cobble pebble, and few mud layers with dispersed gravel (Fig. 8 and 9). Samples analysed were all sandy cobble pebble comprising substantial amount of gneiss and quartzite clasts and few sandstone, mudstone, siltstone and dolomite clasts (Table 2).

Chakkarghatti lithofacies association

The Chakkarghatti lithofacies association is distributed from proximal to the upper midfan segment. This lithofacies association is mainly composed of pebbly, coarse- to medium-grained and light brown to light green sand (Fig. 10 and Table 2) with occasionally developed brown organic clays, brown silt and mud layers (Fig. 8 and 12). The gravel sample (SC7) of this lithofacies association has sandy cobble-pebble texture (matrix-supported) and is characterised by increased proportion of clasts of sandstone and siltstone compared to those of gneiss and quartzite. Most of these sedimentary clasts show affinity towards source of the Siwalik Hills, and few towards source of the Lesser and Higher Himalayas.

Prakashpur lithofacies association

This lithofacies association is distributed between the Chakkarghatti and the Tilathi lithofacies associations and is mainly composed of medium- to fine-grained sand with rare clay veneers (Fig. 8, 11 and Table 3). The lithofacies show old fluvial channels in the form of local plains, ox-bow lakes, sand mounds and natural levees. The clay veneers show water-logged areas or ox-bow lakes while sand deposits exhibit natural levees and splays which were produced during sheet flood events.

Fig. 7: Matrix-supported cobble pebble of the Chatara lithofacies association observed in Chatara village (see Fig. 3 for location).

Tilathi lithofacies association

The Tilathi lithofacies association is deposited in the south of the Prakashpur lithofacies association and is comprised of fine-grained sand and clay (Fig. 13). Sand samples show 88% fine sand and 12% mud (Table 3). Clay layers associated with sand are usually organic rich and black. The lithofacies association represents paleo-swamp, marsh land and channel deposits. Modern swamp and crevasse splays occupy vast area of the deposits.

Active channel-flood plain lithofacies association

The recent riverbed comprises sand and gravel in the channel and channel bars (marginal and middle), whilst silt and clay in flood plains (marshes and levees). Generally, sediments in the Sapta Koshi River grade from coarse gravel to fines from the proximal to midfan segments of the fan.

Lithofacies and flooding signature

Debris flow and cohesionless flow are the major processes involved in depositing the Chatara lithofacies

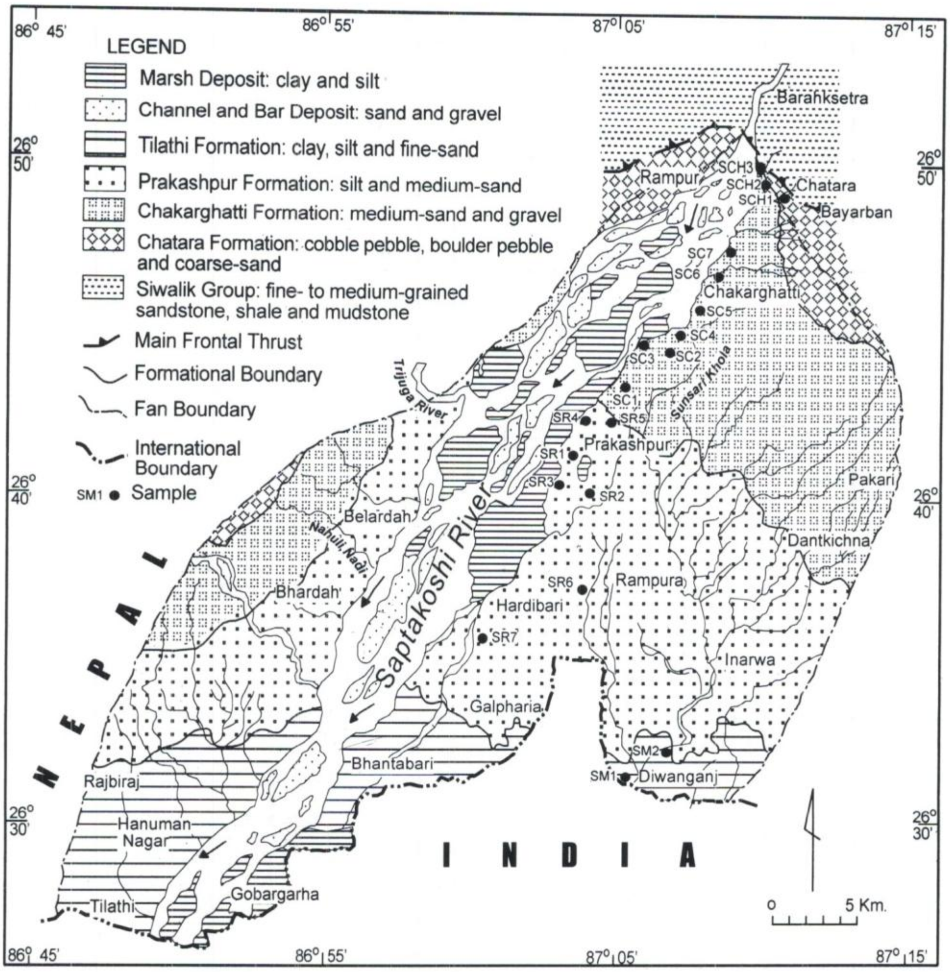


Fig. 8: Map showing lithofacies associations of the Sapta Koshi alluvial fan.

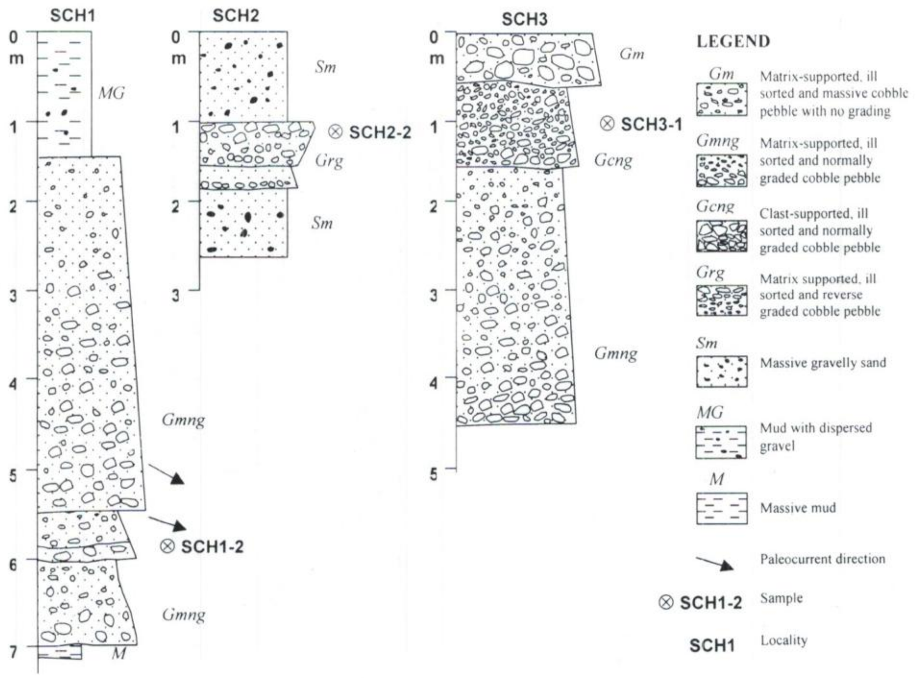


Fig. 9: Columnar sections of the Chatara lithofacies association.

Table 2: Texture and compositon of lithofacies from the Sapta Koshi alluvial fan.

Sample	Lithofacies association	Texture			Description	Clast composition of gravel bed (%)						
		%G	%S	%M		Gn	Sl	Qzt	Dol	Sst	Mst	Slst
SCH1-2	Chatara lithofacies association	74	23	3	sandy cobble pebble	14	13	42	-	16	-	15
SCH2-2		70	25	5	sandy cobble pebble	14	2	22	3	13	17	19
SCH3-1		80	16	4	sandy cobble pebble	35	4	44	5	6	4	3
SC1	Chakkarghatti lithofacies association	-	80	20	very fine sand							
SC2		-	99	1	fine sand							
SC3		1	98	1	medium to fine sand							
SC4		-	93	7	medium to fine sand							
SC5-1		7	89	4	medium to fine sand							
SC5-2		5	91	4	medium to fine sand							
SC5-3		2	83	15	very fine sand							
SC5-4		-	82	18	fine to very fine sand							
SC6-1		4	90	5	medium sand							
SC6-2		2	70	28	fine sand							
SC6-3		2	71	27	fine sand							
SC7		70	24	6	sandy cobble pebble	1	15	41	-	24	2	18
				6								
SR1	Prakashpur lithofacies association	-	90	10	fine sand							
SR2		-	52	48	silty to very fine sand							
SR3		-	46	54	silty to very fine sand							
SR4		-	69	31	very fine sand							
SR5		-	87	13	fine sand							
SR6		-	94	6	fine sand							
SR7		-	81	19	fine sand							
SM1	Tilathi lithofacies association	-	88	12	fine sand							
SM2		-	88	12	fine sand							

G = gravel, S = sand, M = mud (silt and clay), Gn = gneiss, Sl = slate, Qtz = quartzite, dol = dolomite, Sst = sandstone, Mst = mudstone and Slst = siltstone.

Fig. 10: Medium-sand of the Chakkarghatti lithofacies association observed in Chakkarghatti village.

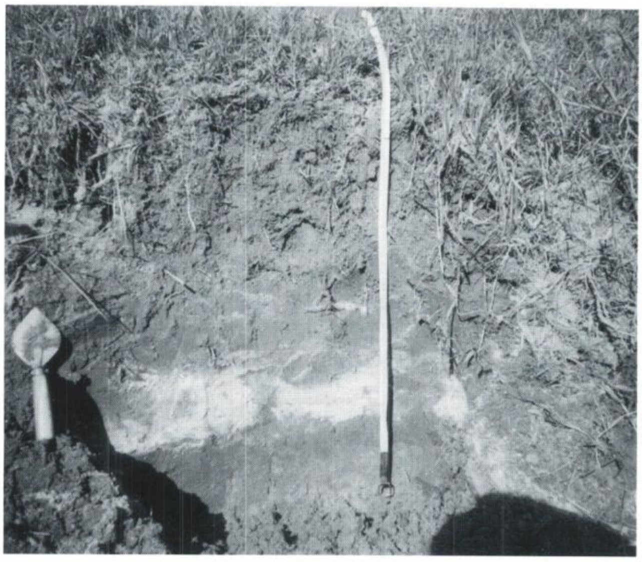


Fig. 11: Fine sand of the Prakashpur lithofacies association observed in Rajabas village.

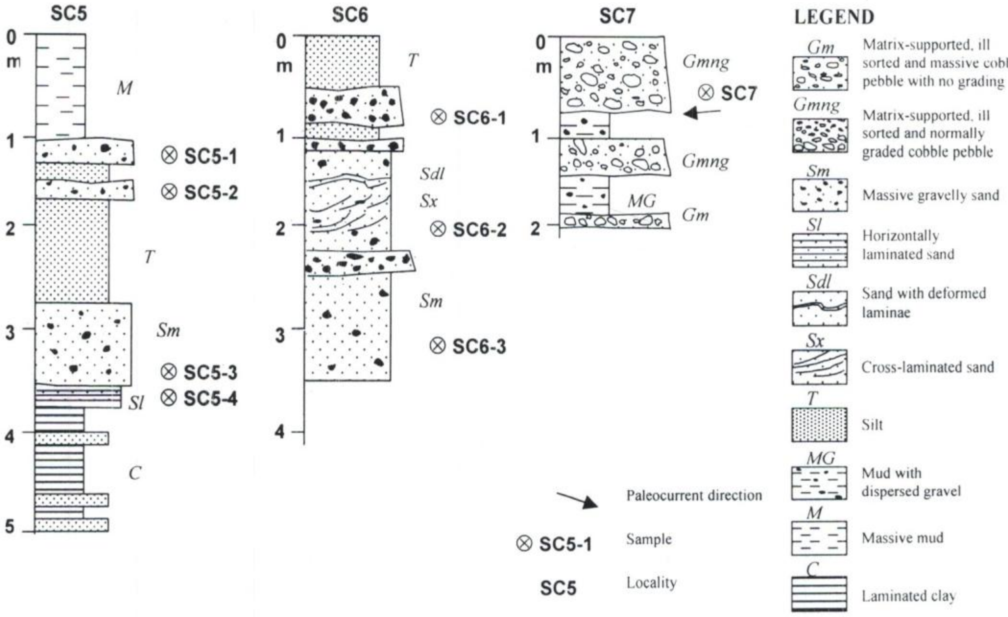


Fig. 12: Columnar sections of the Chakkarghatti lithofacies association.

Table 3: Monthly average water and silt discharge at Koshi barrage during June 1986 to May 1988.

Months	Water discharge (Cusec)		Silt discharge (gm/L)	
	1986-87	1987-88	1986-87	1987-88
June	93560	72272	1.394	1.42
July	153625	178492	2.452	1.849
August	108899	163149	1.691	1.57
September	103988	163149	1.691	2.5
October	53906	60152	0.603	1.47
November	24940	33132	0.268	0.828
December	19451	21999	0.198	0.202
January	7005	12348	0.075	0.06
February	7229	9247	0.086	0.077
March	7671	13057	0.156	0.118
April	16477	14890	0.476	0.233
May	22475	27173	0.0333	0.452

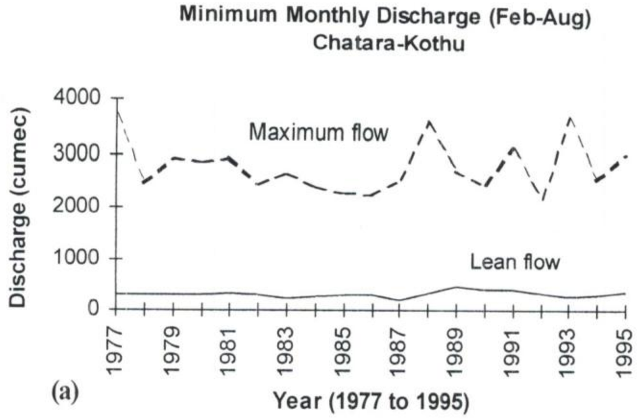
Fig. 13: Fine sand and silt of the Tilathi lithofacies association observed in Diwanganj village.

association. The Chakkarghatti lithofacies association indicates that sediments were deposited from cohesionless flow (sheet flooding) and flood-waning resulting vertical accretions of sediments. Mainly the pebbly and sandy facies were deposited in channel and its bar by streamflow and debris flow processes, whereas occasionally developed clay veneers and mud facies were deposited in the local depositional flood basins by vertical accretion. The Prakashpur and the Tilathi lithofacies associations represent distant source of sediment. The fineness of sediment was caused by periodic sheet-flooding and extensive water logging resulting marshy environment and abandonment of distributaries causing fine sand, silt and clay to deposit.

Sediment load and discharge

Huge volume of sediments (1000-6000 $m^3/km^2/year$) is transported by the Sapta Koshi River owing to soft lithological composition in source area, high velocity of water, long and continuous rainfall, and continuing deforestation in the catchment area. The sediment volume carried by the Sapta Koshi River is one of the largest for alluvial fans in the world.

The minimum monthly discharge recorded from February to August during 1977-1995 shows maximum range between 2500 and 3700 cumec (Fig. 14a), whereas lean flow between 200 and 300 cumec. On the other hand the maximum monthly



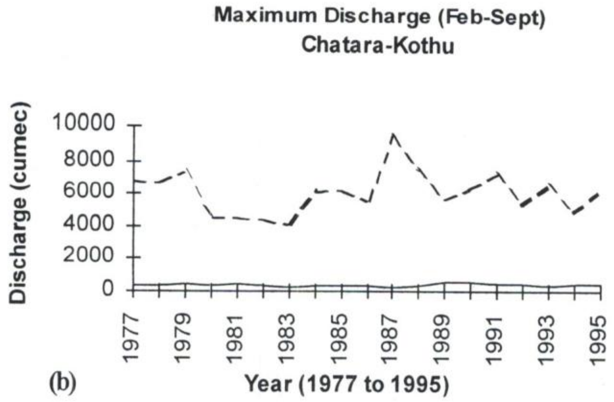


Fig. 14: Monthly discharge in Chatara-Kothu area recorded during 1977-1995: (a) Minimum monthly discharge (Feb.-Aug.) and (b) Maximum monthly discharge (Feb.-Aug.).

discharge (Fig. 14b) shows maximum flow between 4000 and 9500 cumec and lean flow between 300 and 500 cumec. Similarly, the data obtained between June 1986 and May 1988 at Koshi barrage (Table 3) show maximum water discharge and silt discharge during July-September, whereas minimum discharge during January-February. There are rapid fluctuation and extreme variation in the discharge and sediment load concentration in the Sapta Koshi River, resulting into destructive features owing to an extremely flushy hill torrent.

Channel shifting

Two main autogenic processes in fluvial distributary systems can be observed; the avulsive shifting and a cycle of trenching and back filling. The experimental work of Schumm and Brakenridge (1987) and the observation of DeCelles et al. (1991) and Fraser and DeCelles (1992) suggest that these processes are intimately related.

The Sapta Koshi River in the proximal fan segment is shifting towards the east while in the midfan segment it is shifting towards the west. Further south, around Koshi Tappu, the eastward shifting repeats. The trend of shifting looks like river strolling. The higher level of geomorphic surfaces and comparatively sound and coarse-sediment prevent much scouring towards east resulting into strolling oppositely. In the upper part of the midfan, shifting trend is towards the east and is continuing towards the west in the lower portion of the midfan.

The overall westward shifting and scouring is continuous into the southernmost part of the Sapta Koshi alluvial fan. The possible factors responsible for westward shifting may be neotectonic activities, lithological composition and regional slope direction.

FLOODING IN THE SAPTA KOSHI ALLUVIAL FAN

Annual flooding, water logging, river course shifting and soil erosion are the main environmental phenomena occurring in the Sapta Koshi alluvial fan, affecting agricultural and settlement areas in the fan. The western bank of the Sapta Koshi River, around Balardaha, Bhardaha and Hanuman Nagar suffer from flooding and water logging to a varying extent. These areas have weak engineering constructions (embankments) which are not well functioning as in the eastern bank of the river, considering slope and altitude being the same.

Generally, in Nepal and India, dams store 8-10% of the total flow but remaining 80-82% would still be free and make floods during excessive discharge (Rao 1975). Therefore, one of the major aggravating factors for flooding in the Sapta Koshi alluvial fan is the barrage built in the lower portion of the midfan segment (Fig. 15).

Major causes of flooding

Flood occurs due to excess flow of water (which exceeds the carrying capacity of any channel) within its course resulting into overflows on to the flood plains. Two main factors responsible for floods are (1) increased runoff in the watershed and (2) the reduction in the draining capacity of the channels.

Increase runoff

Heavy rainfall, snow melting, glacial-lake bursting, sudden and excessive release of impounded water from temporary landslide dams and other causes are responsible for excess flow of water in the basin. For example, a rainfall of 10 cm on just one sq. km area results 100,000 m^3 (=30 million gallons) of water (Ghosh et al. 1980). The larger the catchment area and greater the magnitude of rainfall, the greater the volume of runoff.

Various factors play a decisive role in increasing runoff, such as lithological composition, climate, slope, vegetation covers, etc. Runoff may be of two types: Surface and sub-surface, which contribute flooding. The surface runoff contributes directly as excess amount of water into river channel, and certain amount is absorbed by the dry soil and changed into sub-surface runoff.

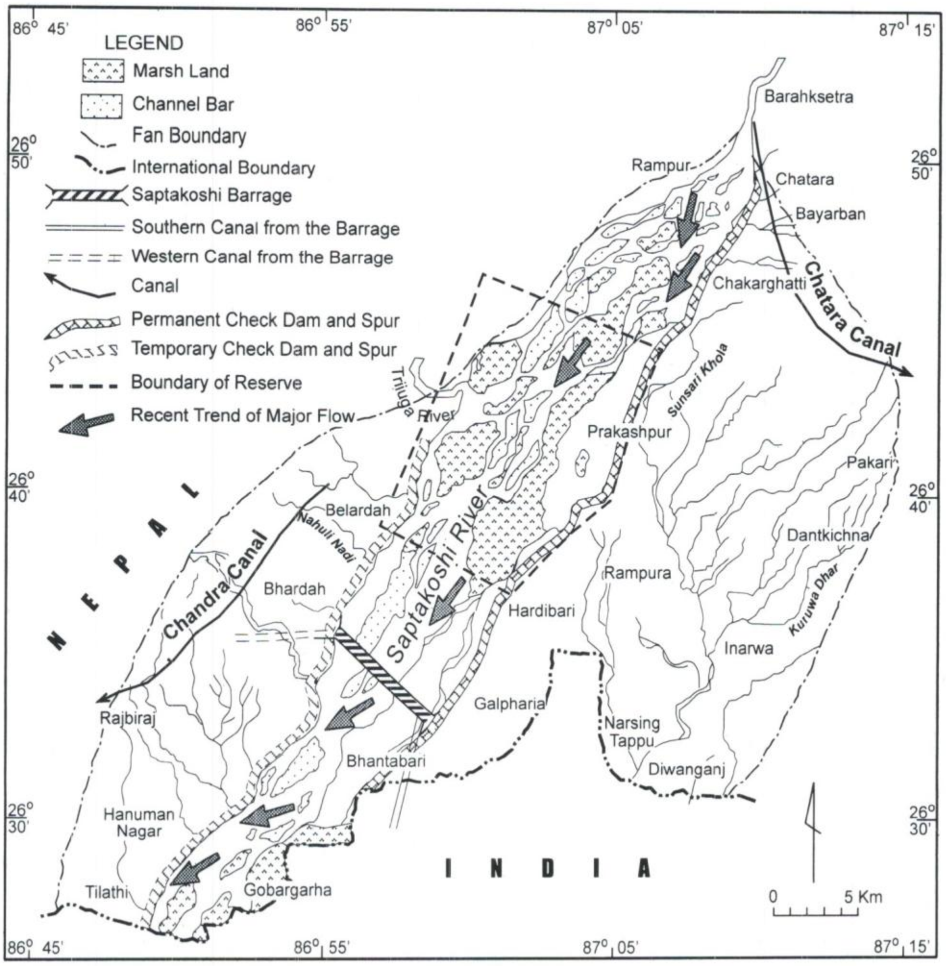


Fig. 15: Map showing existing engineering infrastructures in the Sapta Koshi alluvial fan.

The minimum capacity of absorption (i.e., temporary subsurface runoff) by the ground to a sizable part (even, 1 sq. km of area) is able to accumulate such a vast amount of water which flows as surface runoff later, suddenly increase the surface runoff, resulting into catastrophic events.

Reduced carrying capacity of rivers

Capacity of channels is gradually reduced by the accumulation of sediments derived from erosion and transportation in the watershed. Any encroachment in the channel either due to natural phenomena or due to human activities is responsible for the reduction in carrying capacity of any channel, for example, bridges with piers and protruding abutments, and flood plain occupation for urbanization and industrial development (Valdiya 1987). A floodway is designated as the area that can convey water of the 100 year flood (1% chance of recurrence) without increasing the water-surface elevation of that floodway more than one foot at any point (Palmer 1976).

Mechanism of flooding

The areas such as Tilathi, Gobargarha, Banarjhulla and Hanuman Nagar are often flooded. The floodwater at first over-spilling the channel bank inundates the near bank areas. Later, excess water causes widespread inundation of low-lying areas mentioned above. The water logging is mainly caused by accumulation of rainwater in the adjacent low land. High seasonal discharge of the Sapta Koshi River followed by chocking up of its tributaries and distributaries, contribute to flooding and water logging.

Flooding and water logging generally occurs. Such events has been reduced considerably due to construction of flood detension-cum-irrigation cannals in the alluvial fan (Jha et al. 1995; Thapa and Pradhan 1995). However, it has been observed that the extent of flooding and water logging duration of inundation are higher in the western bank compared to the eastern bank of the Sapta Koshi River (Thakur and Tamrakar 2001).

INFRASTRUCTURES IN THE SAPTA KOSHI ALLUVIAL FAN

Many engineering structures were made in the Sapta Koshi alluvial fan chiefly for irrigation and flood controlling purposes. These included irrigation canals, barrage, embankments, spurs and dykes. Chatara irrigation canal begins from Chatara and ends at Bakara River, 53 km east. It has total cultivable command areas of 58,000 hectors. The intake and the headworks have the capacity of 4.3 m^3/sec (600 cusec). The barrage of 1150 m built in Bhimnagar. From either side of the barrage, two irrigation canals known as western and southern irrigation cannals extend in Nepalese and Indian territories (Fig. 15). The western cannel extending for about 35 km (Thapa and Pradhan 1995) is not in functioning condition.

Two masonry embankments along the either side of the Sapta Koshi River were built. The eastern one (Fig. 16), which was built in 1957 extends for about 40 km in Nepalese territory (Sanyal 1980). The western embankment, which was built much later is out of functioning, therefore requiring maintenance. However, the concerning authorities are not serious for its regular maintenance.

Series of dykes and spurs were biult along with the embankments in both banks of the Sapta Koshi River. The newest spurs and dykes are functioning well (Fig. 17) whereas the older ones are malfunctioning (Thakur and Tamrakar 2001).

HAZARD ASSESSMENT

Hazard is a measure of danger in space and time. Risk involves life and property in hazardous area. Proper management and awareness can minimize the bad effects of hazard. To undertake any management and preventive measure, a flood hazard map identifying different levels of hazard is necessary to develop. A flood hazard map of the Sapta Koshi alluvial fan was prepared (Fig. 18) using the factors such as slope, altitude, position from the channel, protection works, and position in relation to human induced activities.

(1) Slope of the area: Slope is a decisive factor especially for flooding. Steeper slopes are generally safe whereas the gentle slopes are prone to flooding. Considering this, the areas up to 10° was given rating 1, slope up to 15° rating 2 and slope >15° has rating 3 (Table 4).

(2) Altitude of the area: In general the low land is very prone to flooding in comparison to high altitude. In the present case it is feasible to divide the whole area into three groups and rating all of them individually. The area lying up to 50 m was given rating 1, the area up to 100 m rating 2 and the area above 100 m rating 3 (Table 4).

(3) Position from the channel: Another factor considered is the position from the active channel. Flood potentiality is higher near the channel than the areas situated far from it. Areas locating near the channel or in the channel are severely influenced by channel shifting, scouring and crevassing. The area situated within 1 km was rated 1, between 1 and 5 km was rated 2 and beyond 5 km from the active channel was rated 3.

(4) Protection works: Engineering protection works play very decisive role in the extent and behavior of flood. In the area that is fully protected by such protection works, the hazard potential becomes less than the areas lacking such constructions. For example, the eastern bank of Sapta Koshi River is much safer than the western bank. Therefore, the Sapta Koshi alluvial fan was characterised into non-protected, partially protected and well-protected areas and was given rating as shown in Table 4.

(5) Position in relation to human induced activities: Human induced activities such as barrage, reservoir, dykes, spurs, deforestation, aforestation, green belt creation, etc are very useful to control the flood in one hand but in other hand they influence local flooding and impoundment also. For example, in the present case the Sapta Koshi barrage area has changed into permanent water logged area. The area within 5 km of human induced activities was

Fig. 16: Engineering construction in the west of Chakkarghatti village.

Fig. 17: Spur and part of the eastern embankment in the west of Chakkarghatti village.

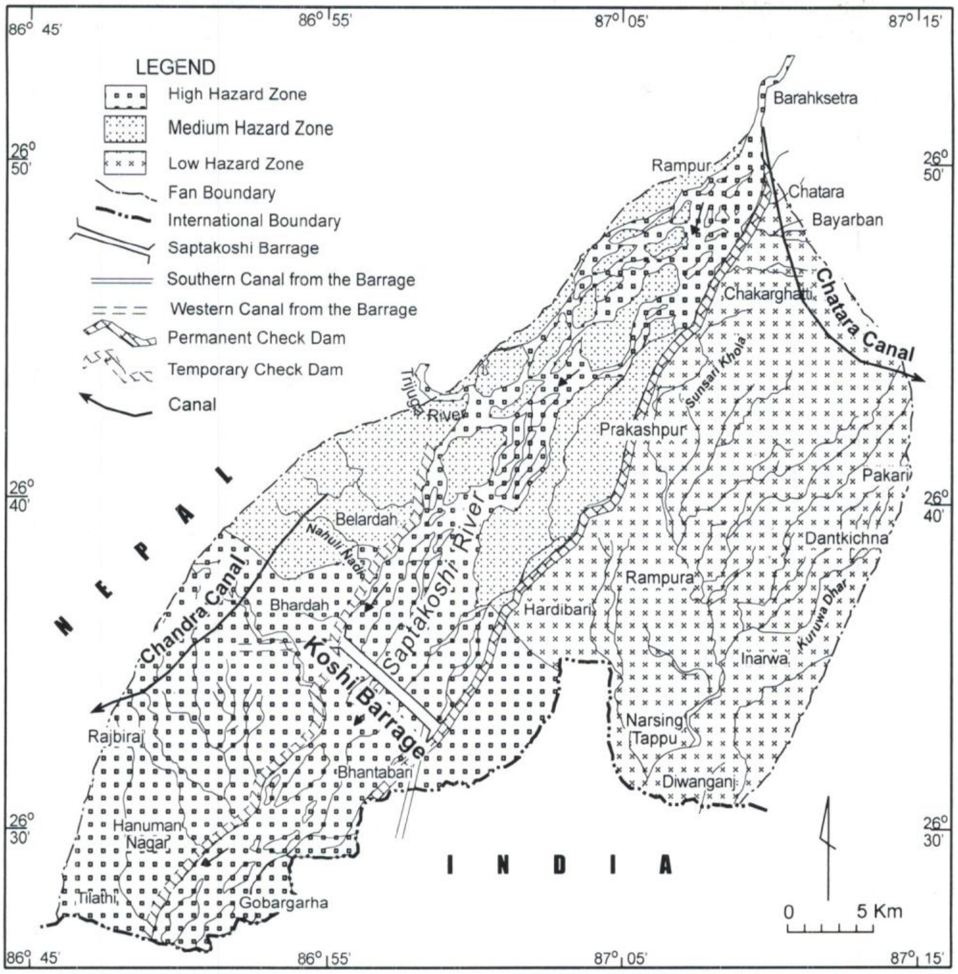


Fig. 18: Flood hazard map of the Sapta Koshi alluvial fan.

given high rating whereas that exceeding 7 km was assigned low rating (Table 4).

Considering the above mentioned five factors and hazard rating, the figures 2, 8 and 15 were used as overlays for assigning the rate in a grid. Subsequently, three hazard zones were categorised and prepared a flood hazard map of 1:25,000. The flood hazard map (Fig. 18) exhibits high, medium and low hazard zones as described below:

(1) High hazard zone: The southern lower reach of the Sapta Koshi alluvial fan such as Tilathi, Hanuman Nagar, Bhardaha, Rajbiraj, Bhantabari, Gobargaraha, etc. are recognized as highly hazardous. Around 160 sq. km of the area belongs to high flood hazard zone under Nepalese territory. Hazard levels of these areas are mainly influenced by low relief, water impoundments due to barrage and malfunctioning of the western embankment.

(2) Medium hazard zone: Factors 2, 3 and 4 greatly influence the area leading to the medium hazard zone. The western bank and channel areas from the apex to mid fan are lying in this zone.

Table 4: Factors for flood hazard rating.

Factors		Rating
Slope	5° to 10°	1
	10° to 15°	2
	> 15°	3
Altitude	up to 50 m	1
	50 to 100 m	2
	> 100 m	3
Position from the channel	within 1 km	1
	1 to 5 km	2
	> 5 km	3
Protection works	non-protected	1
	partially protected	2
	well protected	3
Position of area in relation to human induced activities	within 5 km	1
	5 to 7 km	2
	> 7 km	3

(3) Low hazard zone: The eastern bank of the Sapta Koshi River, which is properly protected by engineering masonries (embankment, spurs, dykes, etc) is lying under this zone. The area such as Chatara, Chakkarghatti, Prakashpur, Inarwa, Rampura and Hardibari lie in this zone.

FLOOD PREVENTIVE MEASURES

The flood management considers measures required for prevention of flooding. It includes the works related to drain out excess of impounded water, to spread the excess water as soon as possible and to return life normal.

Few factors such as proper engineering construction, minimising monsoonal adverse effects, and effective drainage and flood management systems play vital roles especially in the flood prone areas. If it is possible to avail well-trained and alert relief system, alarming system and medical team with sufficient volunteers, almost any type of risk can be overcome without severe damages. The following preventive measures should be considered in short- and long-termed bases to minimise the flood hazard:

Short-termed measures:

1. Renovation and reconstruction of masonry embankments
2. Establishing alarming system
3. Monitoring and recording data base with sufficient information
4. Disaster rescue team

Long-termed measures:

1. Ring damming in the lowland area, drainage networking and trimming
2. Discharge management and erosion control in the watershed area
3. Several storage ponds should be constructed in the flood prone area
4. Bio-engineering practices and green belt creation: Advancement of urban centers should be restricted within 1 km periphery of the river channel which must be developed as a green belt.
5. Relief fund and other utilities essential for rescue work

CONCLUSIONS

1. The Sapta Koshi alluvial fan is high sediment carrying, rapid channel shifting and highly active causing annual flooding aggravated by monsoon.
2. Southwest segment of the Sapta Koshi alluvial fan such as Hanuman Nagar, Tilathi, Gobargarha, Bhardaha and Rajbiraj is identified as high hazard zone. Similarly, permanent water logged areas such as Bhardaha, Galpharia and some parts of upper reach of the active channel also fall under high hazard zone.
3. Masonry embankment of the western bank, which is malfunctioning, must be renovated and reconstructed immediately. Repairing and monitoring works should be done properly in both banks of the river because the spurs and dykes are gradually damaging.
4. Discharge management and erosion control programmes would be effective in reducing flooding.
5. Short- and long-termed preventive measures must be considered by concerning authorities and be implemented as soon as possible.

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