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Natural and anthropogenic factors of flooding in the Saptakoshi alluvial fan, east Nepal

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ABSTRACT

The Saptakoshi alluvial fan (SAF), located in front of the Sub Himalaya near the Chatara village, is one of the largest fans in the world. Floods bring about severe loss of lives and property in the middle and lower reaches of the Saptakoshi River. This paper attempts to assess the natural as well as anthropogenic factors responsible for flooding in the SAF. Some of the major factors of flooding are continuous and high-intensity monsoon rainfall, huge discharge of the Saptakoshi River, unconsolidated sediments and soft rock constituting steep slopes, deforestation, and land degradation. A risk zonation map of the SAF was prepared by analysing these factors, and the SAF was classified into low, medium, and high risk zones. The villages situated in the south-western part of the SAF (i.e., Belardaha, Bhardaha, Joginia, Hanumannagar, Birpur, and Tilathi) lie in a high risk zone, whereas those lying in the eastern portion (i.e., Chatara, Mahendranagar, Singra, Inaruwa, and Diwanganj) belong to a low risk zone. The flood risk level on the south-western bank is high mainly because of water impoundment by the barrage and indiscriminate release of floodwater towards the western flank of the Saptakoshi River.

INTRODUCTION

The Saptakoshi alluvial fan (SAF) is located in the frontal part of the Sub Himalaya, near the Chatara village in east Nepal (Fig. 1). The Saptakoshi River is recognised for its high sediment-carrying capacity and rapid channel-shifting nature (Holmes 1965; Singh et al. 1993). Its watershed covers about 806.5 million ha in the Nepalese territory (Jha et al. 1995) and extends from the Tibetan plateau in the north to the Indo-Gangetic plain in the south. The Spatakoshi River is fed by seven major tributaries, which cause frequent flooding and inundation during the monsoon season. The impact of flooding on the middle and lower reaches of the SAF, mainly on the right bank of the Saptakoshi River, is devastating and the flood causes a severe loss of lives and property. These areas lie in medium to high hazard zones (Thakur and Tamrakar 2002). The flood risk level in the SAF has significantly increased owing to a rapid population growth, migration of communities in marginal lands, and construction of vulnerable infrastructures in hazardous areas. This paper summarises the natural as well as anthropogenic factors of flooding and their impact on the SAF.

GEOLOGICAL SETTING

The seven sub-basins of the Saptakoshi River, which contribute to flooding in the SAF, originate in the Higher Himalaya and the Trans Himalaya (Fig. 1). The Saptakoshi River incises the rocks of the Siwalik Group between Barahakshetra and Chatara, and fans out from Chatara with a narrow head, and then widens southwards in its distal portion, near the confluence with the Ganges. The SAF covers parts of the Siwalik hills and Indo-Gangetic plain. In the proximal part of the SAF, a neo-tectonic fragile landscape is developed and it regularly supplies sediments to the downstream region.

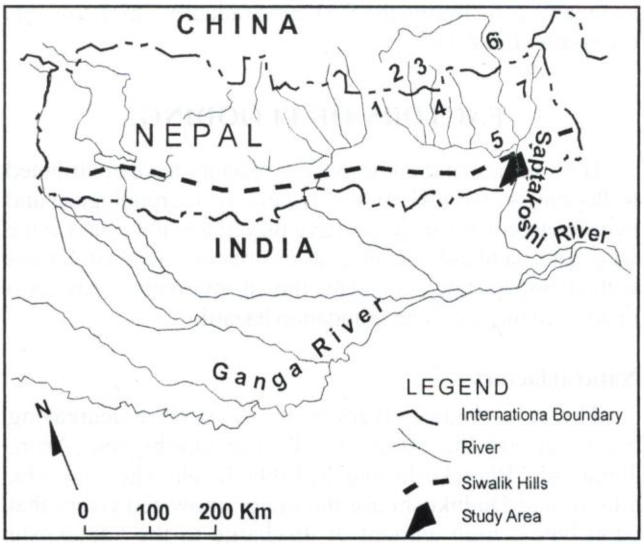

Fig. 1: Location map of study area

Table 1: Subdivision of geomorphic surfaces and lithology

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

Source: Thakur and Tamrakar 2002

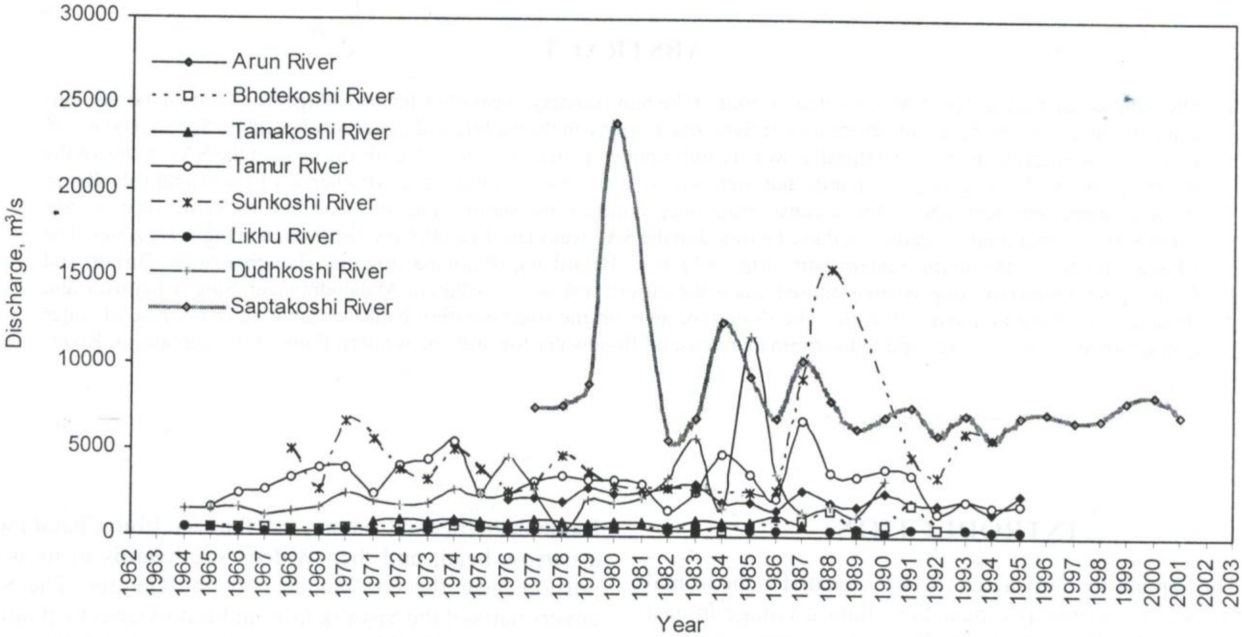

Fig. 2: Annual peak discharge between 1964 and 2001 for seven major tributaries and the Saptakoshi River (DHM 1998)

A series of depositional geomorphic surfaces are developed on both banks of the Saptakoshi River. The sediments constituting the SAF are gradually fining towards the south (Table 1).

FACTORS OF FLOODING

Both natural and anthropogenic factors have contributed to flooding in the SAF. In this regard, geomorphological and hydrometeorological factors have played a major role. On the other hand, land use changes and construction of infrastructures without due consideration to the fluvial environment have also intensified the flood and inundation hazard.

Natural factors

The seven major rivers in terms of their decreasing discharge are the Sunkoshi, Tamur, Dudhkoshi, Arun, Tamakoshi, Bhotekoshi, and the Likhu Khola. The Sunkoshi, Tamur, and Dudhkoshi are the major snow-fed rivers that contribute a high amount of discharge to the Saptakoshi River (Fig. 2). Almost all these rivers flow approximately in the north–south direction with a number of tributaries from steep and rugged slopes. Since discharge is directly proportional and infiltration rate is inversely proportional to slope angle, the mountainous terrain with steep topography produces a high surface runoff. With a high surface runoff, the lag time reduces and the peak discharge increases, resulting in severe flooding in the SAF.

Flood Frequency Analysis

Flood frequency analysis was carried out using gauge data and peak annual discharge data of DHM (1998) to obtain the flood level and discharge for various return periods. Twenty-four years of flood records were used to evaluate future possibilities of such occurrences (Table 4). Peak annual discharge and gauge-height were used to derive the return period by Log Pearson Type-III method. In this method, the variable is first transformed into a logarithmic form (base 10), and the transformed value is then analysed. If X is the variable of a random series, a series of Z variables (where Z = log X) is obtained. For any recurrence interval T, the equation for Z series is as follows.

$$Z_T = Z_{AVG} + (K_Z * Z_{STDV})$$

where

Z_{AVG} = Mean of Z values;

Z_{STDV} = Standard deviation of the Z variable; and

K_Z = Frequency factor from Table with values of coefficient of skew, G, and recurrence interval T.

The coefficient of skew G is given by:

$$G = \frac{N}{(N-1)(N-2)} \frac{\sum (Z - Z_{AVG})^3}{(Z_{STDV})^3}$$

where N = Number of years of record.

After deriving Z_T, the corresponding value for X_T is obtained by

X_T = Antilog Z_T

The rating curve at the Kothu gorge is shown in Fig. 3. A corresponding gauge height can be obtained at a desired discharge value from Fig. 3. Fig. 4 is the discharge frequency curve. The average discharge is 7762 m^3/s. The recurrence interval at the average discharge as derived from the linear regression equation is 3.2 years.

Table 2 lists the results of frequency analysis of gauge height using Log Pearson Type-III method. The gauge heights (X_T) expected to be obtained at the return periods of 2, 10, 25, 50, 100, and 200 years are 6.66, 8.47, 9.61, 10.56, 11.58, and 12.69 m, respectively (Table 3). Because the terrace level at Chatara is higher than the maximum gauge height to be expected during long return periods (i.e., 100 and 200 years), the proximal part of the SAF lies in a low hazard zone.

Table 4 displays the results of frequency analysis of peak annual discharge data. The discharge values obtained for return periods 2, 10, 25, 50, 100, and 200 years are 6952.80 m^3/s, 11244.50 m^3/s, 15300.65 m^3/s, 19463.91 m^3/s, 24863.94 m^3/s, and 31866.91 m^3/s, respectively (Table 5). The analysis indicates that the magnitude of a hundred-year flood is roughly three times the average flood in SAF. Such a flood may severely affect most of the high hazard zones and some medium hazard zones in the SAF.

Anthropogenic factors

Land use changes are related to economic activities. People clear forest for cultivation. Forest and cultivated land are often cleared during urbanisation and industrialisation. Such activities are also associated with encroachment of river banks and floodplains. All these activities are pronounced north of the SAF, mainly on the right bank of the Saptakoshi River.

ELEMENTS AT RISK

According to Wu et al. (1996), specific risk is an expected degree of loss due to landslides or other phenomena. Specific risk is also a product of probability of occurrence of a phenomenon within a given area (hazard) and the degree of expected loss of the element at risk (vulnerability). Factors that influence specific risk are (1) hazard intensity, (2) time of occurrence and duration of flooding, (3) status and quality of infrastructures, (4) status of communication network, and (5) availability of relief assistance (casual management and relief networking).

Elements at risk are categorised as shown in Table 6. A risk zonation was made on the basis of these criteria.

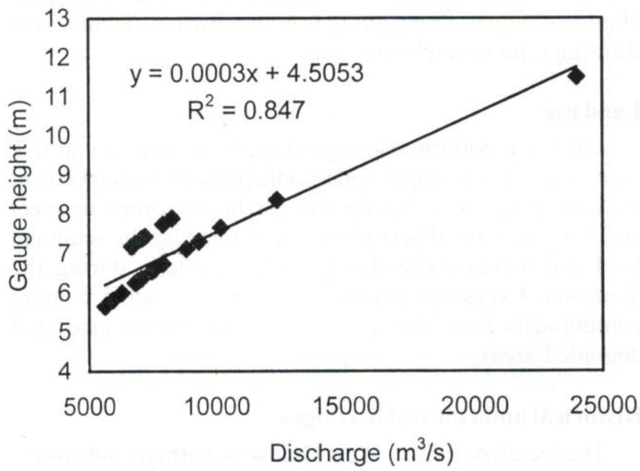

Fig. 3: Rating curve at Kothu gorge

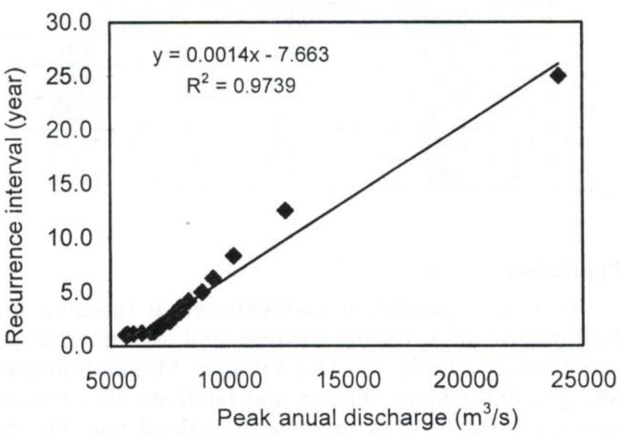

Fig. 4: Discharge frequency curve

Table 2: Frequency analysis of gauge height by Log Pearson Type-III method (DHM 1998)

Year	Rank	Annual peak, X (m)	Recurrence interval (years)	Z=logX	$Z-Z_{AVG}$	$(Z-Z_{AVG})^2$	$(Z-Z_{AVG})^3$
1980	1	11.50	25.0	1.06	0.22	0.05	0.01
1984	2	8.35	12.5	0.92	0.08	0.01	0.00
2000	3	7.88	8.3	0.90	0.06	0.00	0.00
1999	4	7.73	6.3	0.89	0.05	0.00	0.00
1987	5	7.65	5.0	0.88	0.04	0.00	0.00
1996	6	7.42	4.2	0.87	0.03	0.00	0.00
2001	7	7.37	3.6	0.87	0.03	0.00	0.00
1985	8	7.30	3.1	0.86	0.02	0.00	0.00
1998	9	7.25	2.8	0.86	0.02	0.00	0.00
1997	10	7.18	2.5	0.86	0.02	0.00	0.00
1979	11	7.11	2.3	0.85	0.01	0.00	0.00
1988	12	6.73	2.1	0.83	-0.01	0.00	0.00
1978	13	6.58	1.9	0.82	-0.02	0.00	0.00
1991	14	6.58	1.8	0.82	-0.02	0.00	0.00
1977	15	6.54	1.7	0.82	-0.02	0.00	0.00
1993	16	6.37	1.6	0.80	-0.04	0.00	0.00
1990	17	6.30	1.5	0.80	-0.04	0.00	0.00
1995	18	6.29	1.4	0.80	-0.04	0.00	0.00
1987	19	6.25	1.3	0.80	-0.04	0.00	0.00
1983	20	6.25	1.3	0.80	-0.04	0.00	0.00
1989	21	6.00	1.2	0.78	-0.06	0.00	0.00
1992	22	5.82	1.1	0.76	-0.08	0.01	0.00
1994	23	5.69	1.1	0.76	-0.08	0.01	0.00
1982	24	5.66	1.0	0.75	-0.09	0.01	0.00
			SUM	20.15	-0.01	0.10	0.01
			Z_{AVG}	0.84			
			Z_{STDV}	0.066046876			

Table 3: Gauge height at various recurrence interval of flood calculated using Log Pearson Type-III

RT	G	K_Z	$Z_T=Z_{AVG}+K_Z*Z_{STDV}$	$X_T=\text{Antilog}Z_T$
2	1.6	-0.254	0.82	6.66
10	1.6	1.329	0.93	8.47
25	1.6	2.163	0.98	9.61
50	1.6	2.78	1.02	10.56
100	1.6	3.388	1.06	11.58
200	1.6	3.99	1.10	12.69

Population

A large population is concentrated at Inaruwa and Rajbiraj, located on the eastern and western banks, respectively (Table 7). The villages Mahendranagar, Shingra, Prakashpur, Shripur, and Jabdi are also densely populated. Hence, they are at a high flood risk. On the basis of available information and ground survey, it has been estimated that about 200,000 people residing in or near the SAF are affected by annual flooding. Generally, the villages situated very close to the river, especially in the middle and lower reaches of the SAF (e.g., Balardah, Hanumannagar, Ramgarha, Joginia, Birpur, Tilathi, and Rajbiraj), are severely affected.

Land use

Land use pattern also significantly influences the risk level (Fig. 5). The upper and middle parts of the Saptakoshi watershed are quite fragile and are highly prone to sheet and gully erosion. These phenomena increase the sediment load and increase the flood level, especially during the monsoon. Excessive amount of sediment load is coming continuously from the agricultural land, barren land, and degraded areas.

Historical and cultural heritages

The location of East–West Highway, barrage, industries, built-up areas, natural wealth and cultural places are shown in Fig. 6 and 7. These structures increase the flood risk level in different areas of the SAF.

Table 4: Frequency analysis of peak annual discharge data by Log Pearson Type-III method (DHM 1998)

Year	Rank	Peak annual Discharge (m^3/s)	Reccurence Interval (years)	Z=logX	$Z-Z_{AVG}$	$(Z-Z_{AVG})^2$	$(Z-Z_{AVG})^3$
1980	1	24000	25.0	4.38	0.49	0.24	0.12
1984	2	12400	12.5	4.09	0.20	0.04	0.01
1987	3	10200	8.3	4.01	0.12	0.01	0.00
1985	4	9340	6.3	3.97	0.08	0.01	0.00
1979	5	8860	5.0	3.95	0.06	0.00	0.00
2000	6	8290	4.2	3.92	0.03	0.00	0.00
1988	7	7930	3.6	3.90	0.01	0.00	0.00
1999	8	7930	3.1	3.90	0.01	0.00	0.00
1978	9	7580	2.8	3.88	-0.01	0.00	0.00
1991	10	7580	2.5	3.88	-0.01	0.00	0.00
1977	11	7490	2.3	3.87	-0.02	0.00	0.00
1996	12	7220	2.1	3.86	-0.03	0.00	0.00
1993	13	7100	1.9	3.85	-0.04	0.00	0.00
2001	14	7100	1.8	3.85	-0.04	0.00	0.00
1990	15	6950	1.7	3.84	-0.05	0.00	0.00
1995	16	6930	1.6	3.84	-0.05	0.00	0.00
1983	17	6840	1.5	3.84	-0.05	0.00	0.00
1986	18	6840	1.4	3.84	-0.05	0.00	0.00
1998	19	6840	1.3	3.84	-0.05	0.00	0.00
1997	20	6700	1.3	3.83	-0.06	0.00	0.00
1989	21	6320	1.2	3.80	-0.09	0.01	0.00
1992	22	5950	1.1	3.77	-0.12	0.01	0.00
1994	23	5690	1.1	3.76	-0.13	0.02	0.00
1982	24	5630	1.0	3.75	-0.14	0.02	0.00
			SUM	93.41	0.05	0.39	0.12
	X_{AVG} =	7762	Z_{AVG}	3.89			
			Z_{STDV}	0.13			

A number of historical and cultural assets are also facing threats by annual flooding. During the flood, almost all low-lying villages are inundated for 24 to 36 hours. A thick layer of silt and clay buries the important historical and cultural sites located in the low-lying areas.

Economic activities

The floods disrupt the economic activities by blocking the road network, commerce, and communication with rest of the nation. People have to save their life and property in a number of ways. There is also a continuous threat to stored food-grains, cattle, buildings, and other infrastructures as well as industries and industrial products.

Engineering structures

Many large engineering structures are present in the SAF, and a few of them are still incomplete. Some of the well-functioning structures include the Koshi barrage, eastern embankment (Thakur and Tamrakar 2002), spurs and dykes, and the Chatara irrigation canal. Due to the absence of any protection works on the western bank, a number of villages located in the west of SAF have been suffering from floods every year.

Natural wealth

It includes forest and wildlife resources, which are commonly not considered as personal property but controlled and preserved by governmental agencies. Due to the annual flooding, a large number of flora and fauna near the active channel are directly affected. For instance, the upper part of the Koshi Tappu Wildlife Reserve near Kusaha and Balardah, and the area south of Mahendranagar bear a high risk.

Table 5: Discharge at various recurrence interval of flood calculated using Log Pearson Type-III

RT	G	K_Z	$Z_T = Z_{AVG} + K_Z * Z_{STDV}$	$X_T = \text{Antilog} Z_T$
2	2.6	-0.368	3.84	6952.80
10	2.6	1.238	4.05	11244.50
25	2.6	2.267	4.18	15300.65
50	2.6	3.071	4.29	19463.91
100	2.6	3.889	4.40	24863.94
200	2.6	4.718	4.50	31866.91

Table 6: Population of major VDCc

Location	VDC (Population*)
EASTERN BANK	Barachetra (11236), Mahendranagar (22195), Prakashpur (13605), Singia (10904), Madhuban (7409), Inarwa NP (23200), Gautampur (3783), Shripur Jabdi (12937), Diwangunj (6498).
WESTERN BANK	Fatepur (10192), Dhodhanpur (4879), Diman (3933), Hariharpur (4598), Portaha (4592), Bhardaha (6434), Dighawa (3461), Joginia (7449), Rajbiraj NP (30353), Hanumannagar (5751), Koiladi (4564), Birpur (6180), Tilathi (3679).

*Source: CBS (2002)

Table 7: Components and their rating for flood risk

Components	Rating Categories
Population	
1. < 2000	1
2. 2000-2000	2
3. 3000-4000	3
4. > 4000	4
Land use	
1. Thickly Vegetated	1
2. Agricultural	2
3. Urban Centers	3
4. Barren Lands	4
Historical/cultural heritage	
1. Recent	1
2. Medieval	2
3. Historical	3
4. Ancient	4
Economic activities	
1. None	1
2. Scattered	2
3. Partly Dense	3
4. Highly Dense	4
Engineering Infrastructure	
1. Well functioning	1
2. Mal functioning	2
3. Temporary	3
4. Absent	4
Natural wealth	
1. Absent	1
2. Poor	2
3. Rich	3
4. Very rich	4

RISK ZONATION

The SAF was classified into the high, medium, and low risk levels using the criteria given in Table 6. The rating of element at risk was multiplied by the corresponding rating of flood hazard to obtain the risk factor, which was subsequently converted into the above three levels. The risk level is comparatively high in western and southern portions (Fig. 8). Identified high risk zones are the south-western part of the SAF with the villages Gobargarha, Tilathi, Bhardah, Bhantabari, Joginia, Koiladi, Birpur, Belardah, Shripur, Jabdi, and the south-eastern part of Rajbiraj. Galpharia, Hardibari, Rampura, and the eastern part of Prakashpur lie under the medium risk zone. Hariharpur, Diman, Inaruwa, Dewangunj, Dantkichna, Singra, Sundargundar, Bayarban, Madhuban, and Punarbas lie under the low risk zone. Regular monitoring and maintenance of infrastructures (such as dykes and embankments) is quite essential in the middle part of the SAF, especially near Chakkarghatti, Mahendranagar, Hardibari, Madhuban, Belardaha, Bhardaha, and Joginia. The embankment failure may cause the death of 25,000–30,000 people with severe loss of property and wildlife.

FACTORS INFLUENCING FLOOD RISK

The effects of natural factors are seasonal flooding and temporary water-logging during the mid monsoon, when the discharge is quite high (Fig. 9). Even though the discharge is high, the Saptakoshi River distributes its flow in a wide area of SAF, significantly reducing its impact. This would cause flooding and temporary water-logging only in the western areas of SAF, where the embankment does not function well. However, anthropogenic flooding and permanent water-logging problem exist immediately upstream and downstream of the barrage (Fig. 10). The water impoundment in the upstream portion of the barrage increases water level at Belardaha and Bhardaha. The barrage discharges water from its western outlet and diverts it to the western regions of SAF. As a result, Joginia, Hanumannagar, Birpur, and Tilathi are completely flooded and water-logged.

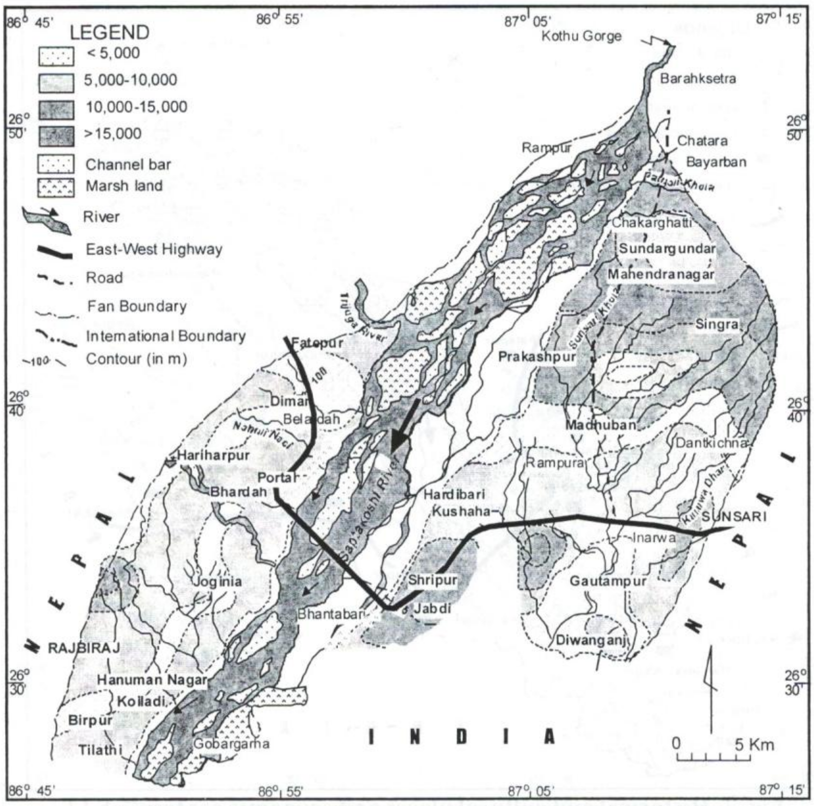

Fig. 5: Population distribuction in the Saptakoshi Alluvial Fan

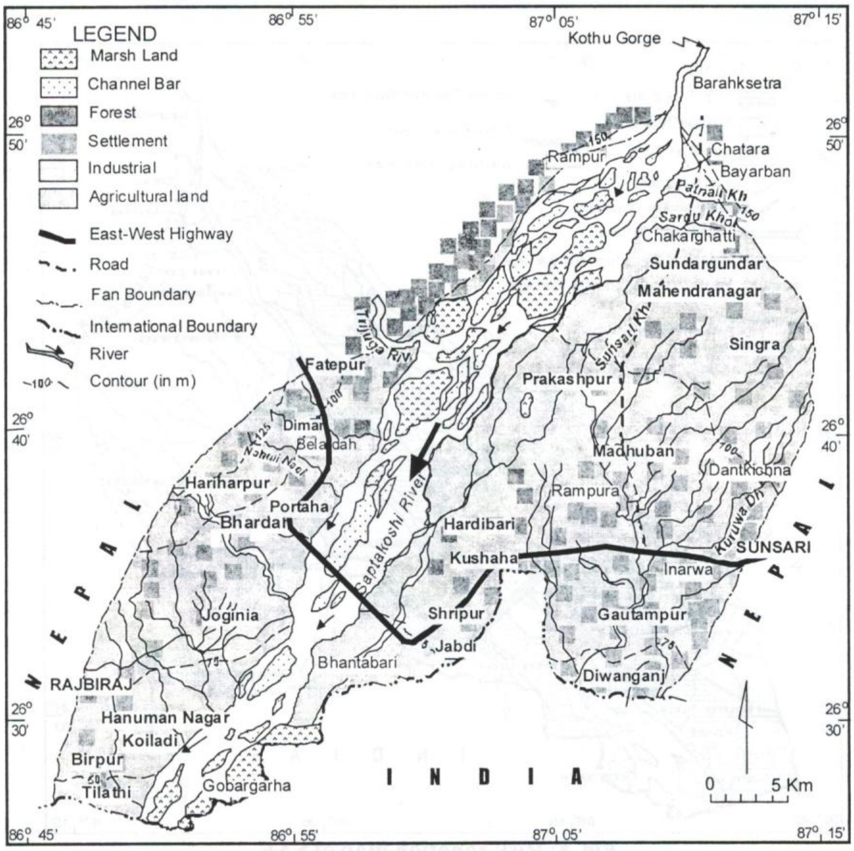

Fig. 6: Landuse map of the Saptakoshi Alluvial Fan

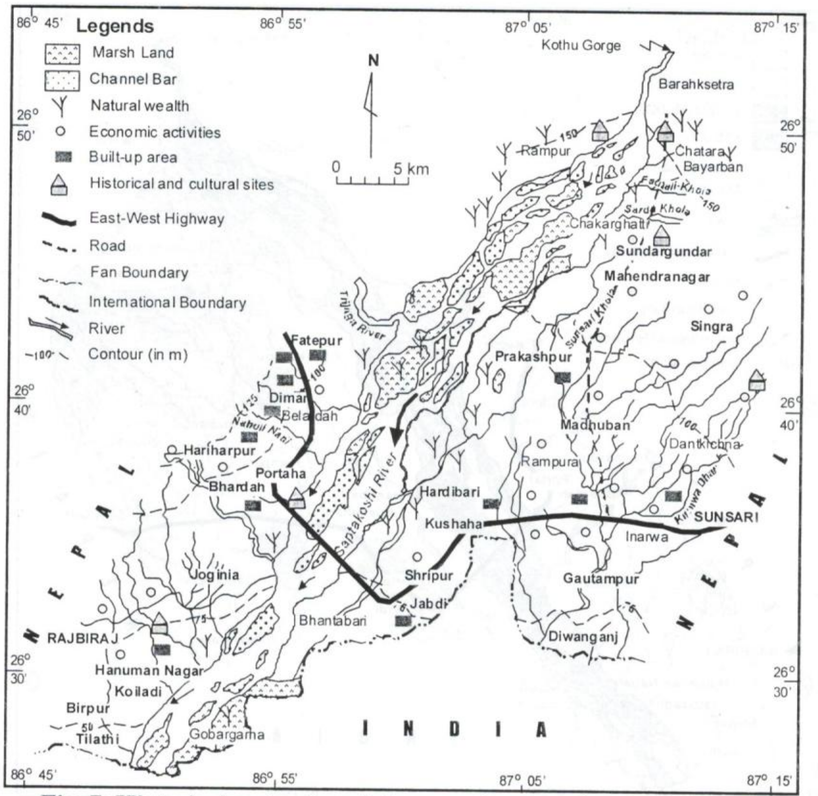

Fig. 7: Historical and cultural places and economic centres in SAF

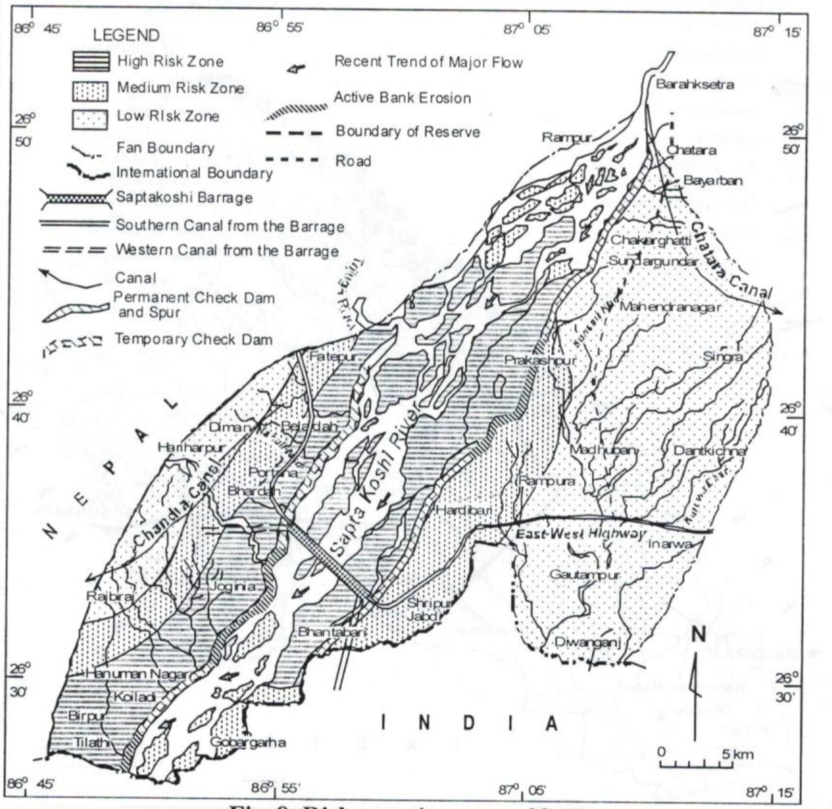

Fig. 8: Risk zonation map of SAF

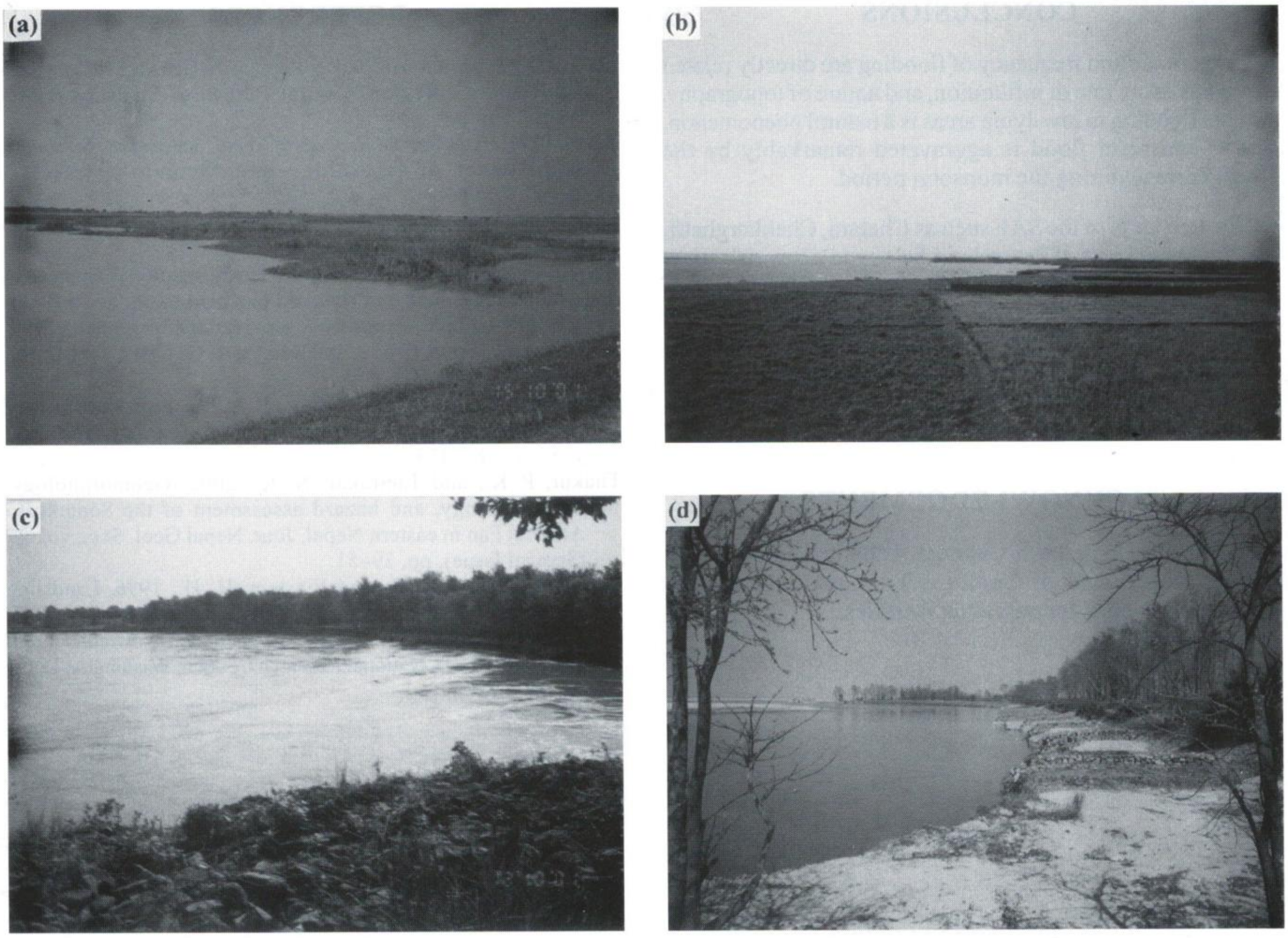

Fig. 9: Flooding and bank erosion in SAF: (a) Flooding near Hanumannagar, western bank, (view to NE), (b) Scouring of paddy field near Hanumannagar (view to NE), (c) Bank erosion in Kushaha (view to NE), and (d) Bank erosion near Rajabas, (view to NE)

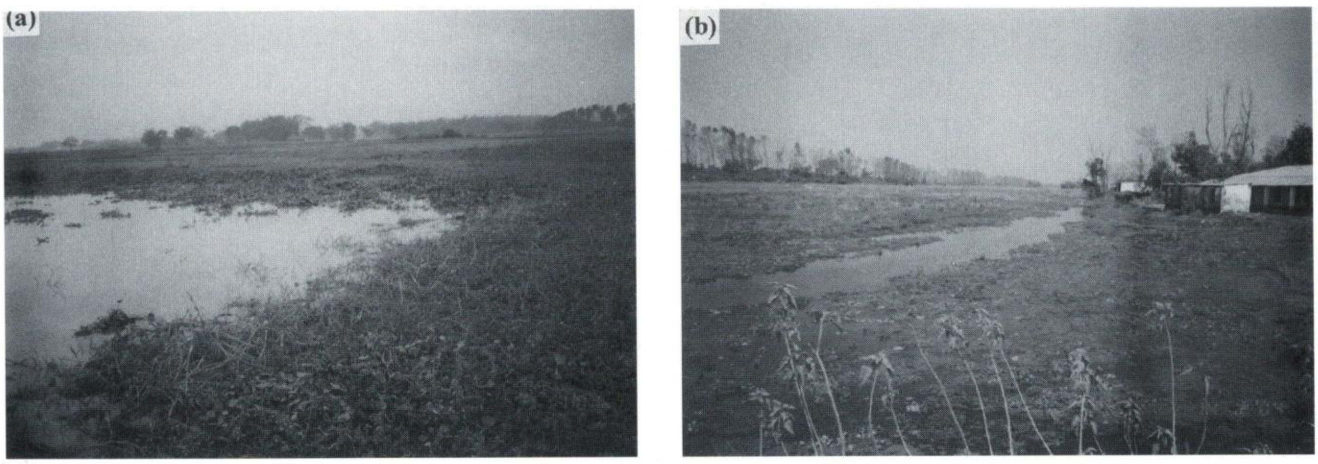

Fig. 10: Water logging in SAF: (a) Belardaha (view to N) and (b) Kushaha (view to N)

CONCLUSIONS

Magnitude and frequency of flooding are directly related to precipitation, rate of infiltration, and nature of topography. Annual flooding in low-lying areas is a natural phenomenon. The downstream flood is aggravated remarkably by the Koshi barrage during the monsoon period.

Eastern parts of the SAF such as Chatara, Chakkarghatti, and the eastern part of Prakashpur belong to a low risk zone, whereas Kushaha, Shripur, Jabdi, and the lower part of Prakashpur lie in a medium risk zone. In case of embankment failure, these areas will bear a high risk, and almost the whole Koshi Tappu Wildlife Reserve and adjoining areas will be flooded. Rajbiraj, Hanumannagar, Balardaha Joginia, Koiladi, Birpur, and Tilathi fall in a high risk zone.

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