Chapter 2

Mapping Flood Hazard and Risk in a Vulnerable Terai Region:

The Ratu Watershed

Planted land on the banks of the Ratu Khola illustrates the risks floods pose to agriculture.

Introduction

The extent of natural hazards, losses and damage caused by them, and vulnerability to them at national and district levels were discussed in Chapter One. There is evidence that losses caused by floods have been increasing in the country as a whole and that the Terai and Inner Terai regions are affected the most. Experience shows that the adverse impact of flood disasters can be reduced substantially if appropriate disaster-preparedness plans and mitigation measures are developed and implemented. This chapter deals with the mapping and zoning of flood hazard, risk, and vulnerability in the Ratu Watershed. Hazard, risk, and vulnerability mapping and zoning are effective tools in this respect and provide a basis for devising appropriate preparedness plans and mitigation measures. In this context Ratu watershed in the Terai Region, a region that has been frequently affected by floods, was selected for a case study in order to develop an appropriate methodology by focusing on the use of remote-sensing techniques and GIS tools for mapping flood hazards, risks, and vulnerability. Ratu is not a unique watershed, its biophysical and socioeconomic settings are more or less similar to those of other rivers originating from the Middle Mountains and Siwaliks and draining the Terai physiographic region, which is prone to flooding, throughout the country. Hence it is expected that the findings of this study will be applicable for the Terai region of Nepal and the adjacent plains of the HKH region as a whole, and useful for an attempting to reduce the risk of and vulnerability to flood disasters

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A flood-hazard, risk, and vulnerability map provides easily understandable information on the extent of inundation and river instabilities such as channel shifting, bank cutting/erosion, overland flow, debris flow, and gully erosion together with the potential risk to human habitats, property, activities, and the environment. The ultimate goal of hazard, risk, and vulnerability mapping is to minimise damage from flood disasters by improving the response and resilience of local people to disasters of this kind.

Objectives

The main objective of this study was to prepare flood-hazard, risk, and vulnerability maps and to identify an appropriate disaster-preparedness plan and mitigation activities for the Ratu Watershed as a whole at pre-feasibility level. The specific objectives were as follows.

- Assess the nature of floods in terms of type, magnitude, and recurrence intervals and impacts in terms of losses.
- Identify and delineate areas affected by floods and other water-related disasters such as channel shifting, bank erosion in the past, and areas susceptible to the same in future.
- Assess and map the degree of risk, incorporating all the elements of biophysical, socioeconomic, and service infrastructure located in areas susceptible to floods with probable magnitude and recurrence intervals.

- Assess and map the vulnerability to flood hazards in terms of perception, response, and recovery capabilities of individuals, households, communities, and government and non-government institutions in the study areas.
- Recommend appropriate disaster mitigation and management strategies and activities at watershed level.

The Study Area

Location

Ratu Watershed is located in the southern part of Nepal between 26° 37’ 43” to 27° 8’ 3” N and 85° 46’ 13” to 85° 58’ 47” E. The area covers 532 sq. km, and shares part of the Sindhuli district in the north and the Mahottari and Dhanusa districts in the south (Figure 2.1). Its elevation ranges from 61m near the Indo-Nepal border in the south to 740m in the north. The basin’s maximum north-south and east-west aerial distances are 58.46 and 13.14 km, respectively. About 48 VDCs, the smallest administrative units of the country, lie within this watershed.

Geology

A distinct geological characteristic is found in the upper and lower reaches of the basin. The upper reach comprises the Siwalik Hills, while the lower reach is in the Terai, the northern extension of the Indo-Gangetic Plain. The upper reach has all the three subgroups of the Siwaliks, namely, the Lower Siwaliks, the Middle Siwaliks, and the Upper Siwaliks. The Lower Siwaliks are composed of brown sandstone and clays. The Middle Siwaliks are characterised by thick beds of sandstone. The Upper Siwaliks form the major part of the watershed and are composed of conglomerates with pebbles and boulders. The topography of the Upper Siwaliks is highly dissected, coarsely textured, and subdued. To the south lies a depositional zone of very low relief and gentle slopes. The plains are a few hundred metres above sea level and usually 400 to 600m thick. They are composed of recent Quaternary alluvium.

Geomorphology

The general geomorphology of the watershed is characterised by the hill slopes and inner valleys of the Siwaliks in the north (Churia region); the Piedmont areas with active and inactive fans of the Bhabar in the south of the Churia; the upper alluvial plains of the Middle Terai, and, finally, the lower alluvial plains of the southern Terai (Figure 2.2). The north-south profile of the basin, depicting the major geomorphic features is given in Figure 2.3. Low relief and gentle slope characterises the larger part of the watershed in the south.

The Siwaliks or Churia hills and inner river valleys cover 24.5% of the total area of the Ratu Watershed. The relative relief is 528m. Similarly, the average slope is 14°. It is basically a sediment production zone. Inner river valleys consist of the river bed including the flood plain and two to three tiers of river terraces at several reaches. At the river confluence and topographic breaks, a fairly large alluvial and colluvial fan can be seen. The inner river valleys cover about 24.14 sq.

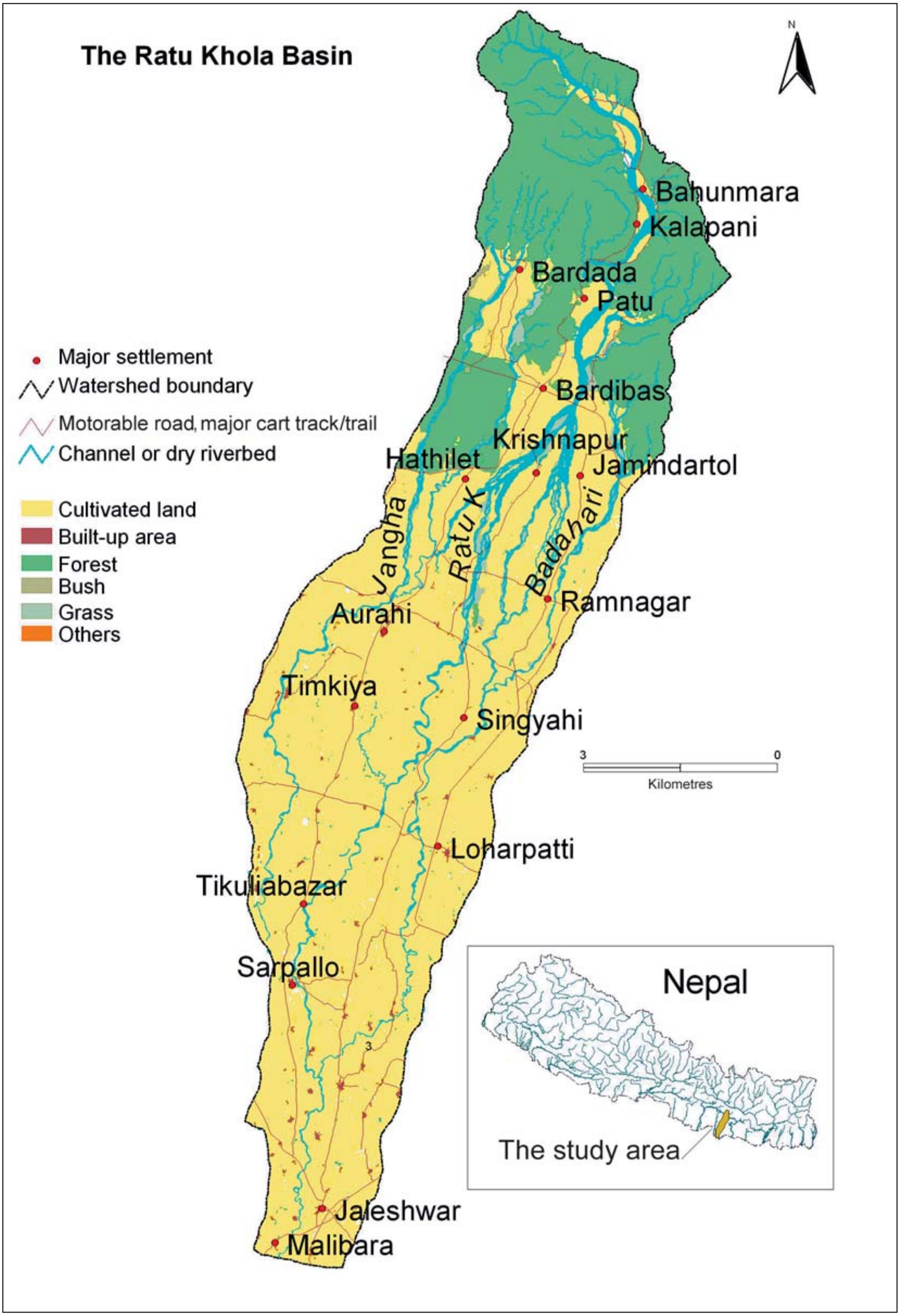

Figure 2.1: **Map of the study area**

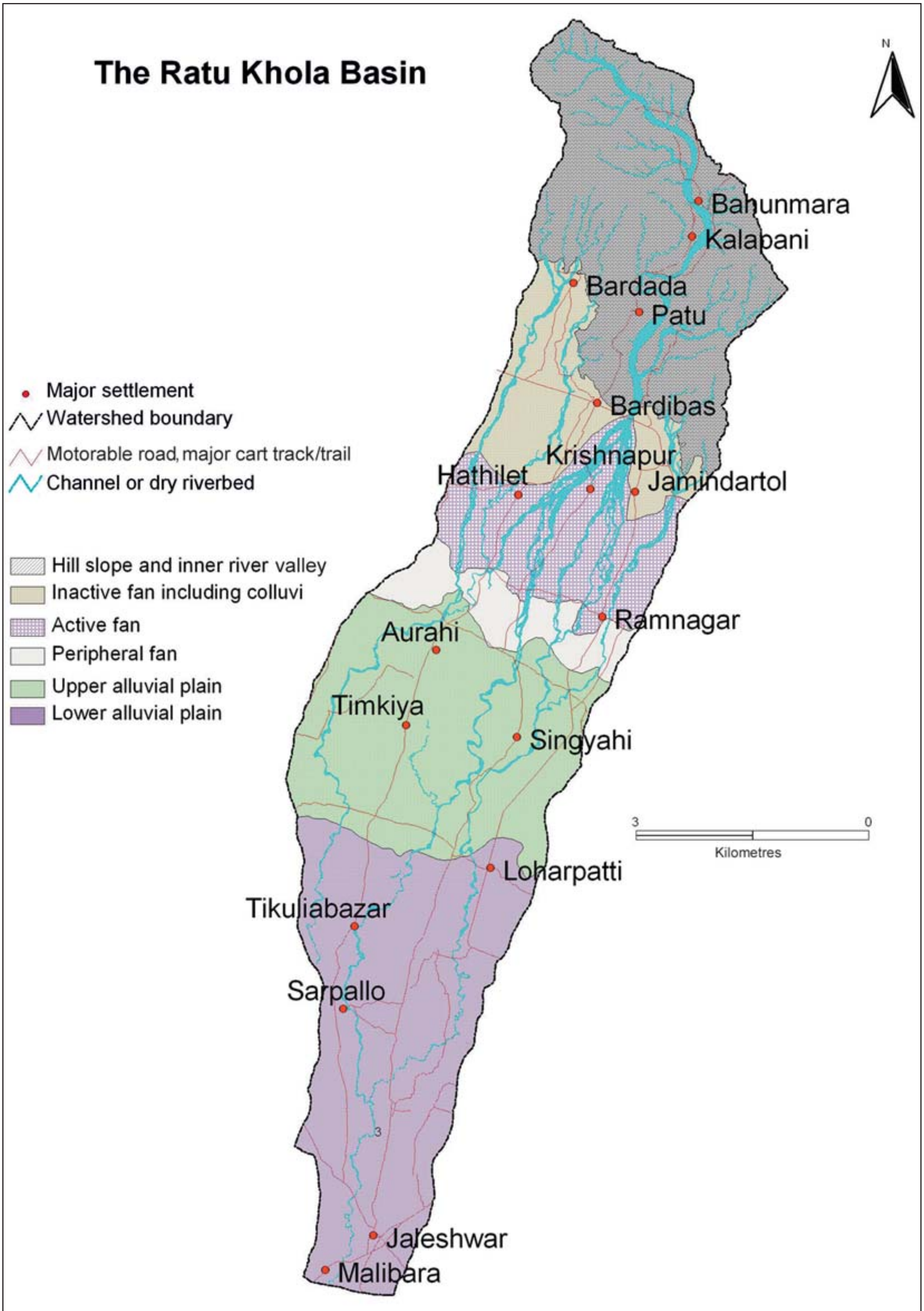

Figure 2.2: **General geomorphology of the Ratu Khola Basin**

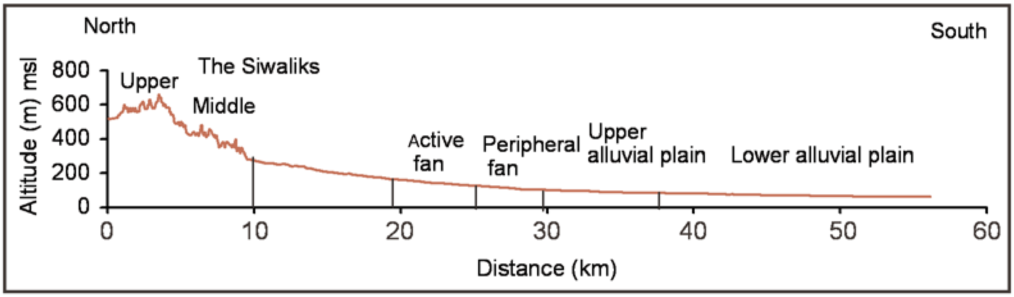

Figure 2.3: **Topographic profile of the basin along a north-south cross-section**

km, of which 12.46 sq. km form the river bed. The width of valley floors at several reaches such as at Rajas, Kalapani, and Patu is more than one km. The maximum width of these valleys is 1.8 km. Similarly, the width of the active riverbed in many places is more than 500m. The formation of wider river valleys is mainly attributable to reworking of the loose conglomerates of the Upper Siwaliks by fluvial processes.

The upper piedmont area of the Bhabar consists of both the active and inactive fans at the topographic break delineating the Siwaliks and the Terai. It is essentially a coalescence of several alluvial fans, colluvial talus, and cones produced by deposits of rivers, gullies, and debris flows. The river morphology is relatively stable: braiding or branching is virtually absent. This area was densely forested three decades ago and a considerable portion of it is still moderately dense forest.

The active fan is unstable and reworked by the river during flooding. The average slope of the fan is 0.8% and its maximum distance is 4.8 km. It covers 11.5% (61 sq. km) of the total area of the Ratu Khola Watershed. Since the fan is active, as evident from the fresh deposits of sediment consisting of sand, gravel, and boulders, it is subject to frequent changes in the flow path. Bifurcation and braiding of the Ratu Khola are characteristics in this zone. A considerable part of the active fan was also under forest cover before 1953, indicating stability of the fan for a long time. At present, however, a large part of it has been cleared for agricultural use and is becoming unstable.

There are other peripheral fans. These are downward extensions of the active fan where the fan merges with the alluvial floodplain. Marginal fans of the Ratu Khola and its tributaries are characterised by very low gradients (0.6%), low channel depths, indiscernible boundaries of channels and bank, and unconfined and unpredictable flow paths. The lower margins of such fans are marked with the seepage lines of springs and the re-emergence of perennial streams.

To the south of the peripheral fans is the upper reach alluvial plain. This zone will be known as the middle Terai hereafter. It extends 8-12 km and covers 23% of the total watershed area. Its slope is less than 0.5%. This area is composed of pebbles and loose sand beds, with a few clay parings. Meandering of channels is another characteristic of this zone. Various old meanders, including the traces of oxbow lakes, chute cuts, and avulsions and anastomosing of channels at several sites are also common in this zone.

The low reach alluvial plain or the lower Terai, hereafter, is the southernmost part of the basin. The surface gradient is very low. Sediments consist of fine silts and clay. The water table is high in this area; therefore inundation and water logging during rainy periods are common. The river bed is narrow but relatively deeper than on the upper plains. Inter basin boundaries are not discernible and inter basin water flow is common.

Climate and hydrology

Since the elevation of the Ratu Khola Basin is less than 1,000 masl, the basin experiences a sub-tropical monsoon climate. Summer months (March-Sept.) are very hot with maximum temperatures exceeding 30°C, and winter months are mild with average monthly temperatures between 15 and 20°C. There are four distinct seasons of precipitation: dry pre-monsoon (March-May) characterised by thunderstorms; monsoon (June-Sept.) with heavy precipitation; post monsoon (Oct.); and dry winter (Nov.-Dec.).

Temperature and precipitation

The mean monthly temperature at Jaleshwar in the south is 25.3°C. The mean maximum and minimum temperatures are 30.9 and 19.7°C, respectively, whereas the absolute maximum and minimum temperatures are 45 and 4°C respectively (Figure 2.4). May and January are the hottest and coldest months, respectively. The mean monthly rainfall figures for Tulsi and Jaleshwar are depicted in Figures 2.5 and 2.6, respectively. The mean annual rainfall figures for Tulsi and Jaleshwar are 1609 mm and 1035 mm, respectively. Tulsi and Jaleshwar receive 85 and 82% of the annual rainfall in the monsoon season, respectively. Tulsi, located in the north, receives more rainfall than Jaleshwar in the south, mainly because of the orographic effect on the prevailing summer monsoon. Western disturbances bring scanty rain in the winter season and thunderstorms are frequent in the months from March to May.

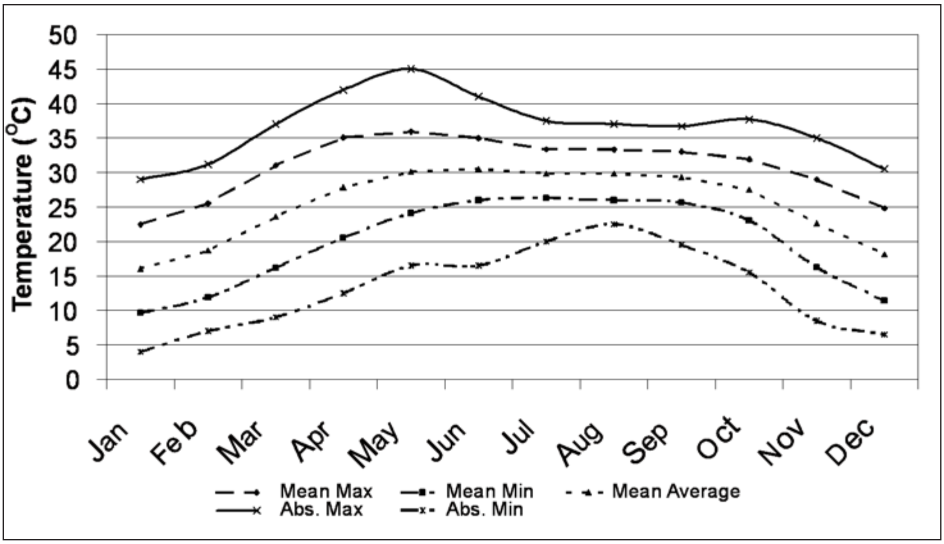

Figure 2.4: **Mean monthly temperature recorded at Jaleshwar, 1969-1996**

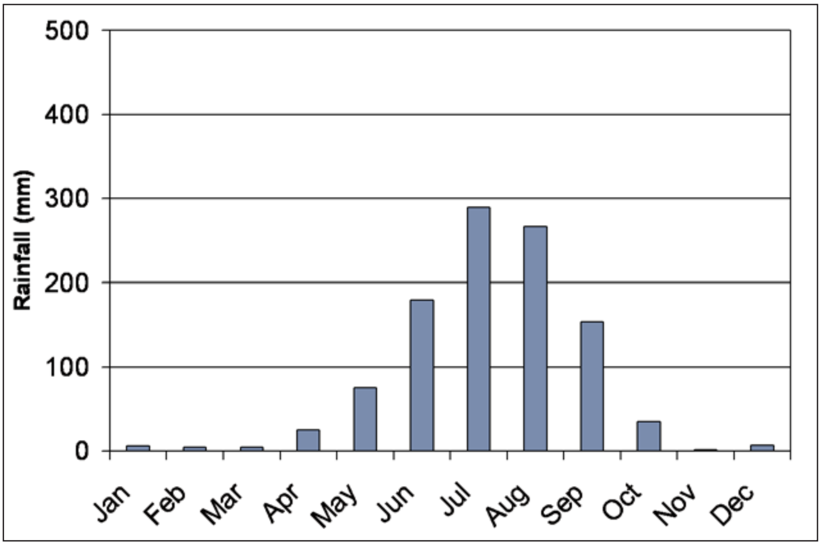

Figure 2.5: **Mean monthly rainfall recorded at Jaleshwar, 1969-1996**

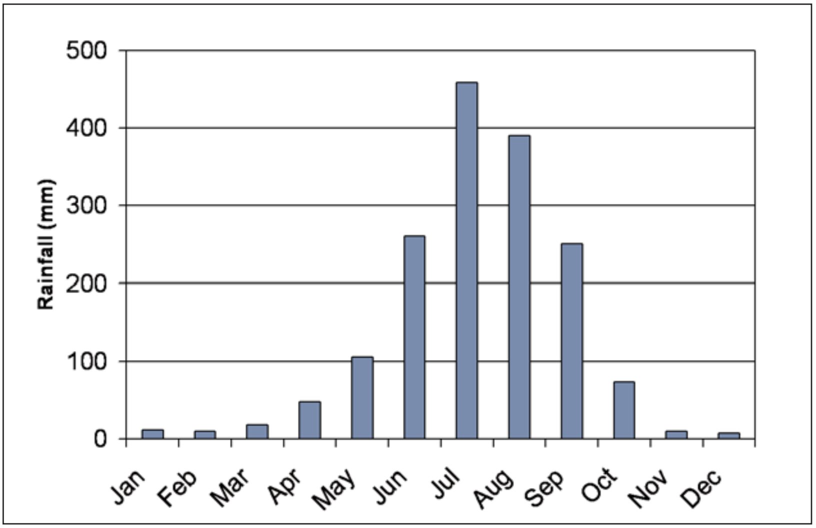

Figure 2.6: **Mean monthly rainfall recorded at Tulsi, 1956-1996**

Frequency analysis for rainfall was carried out for Tulsi and Jaleshwar. The one-day, two-day and three-day maximum amounts of rainfall have been calculated for various return periods of 2, 5,10, 25, 50, and 100 years with the extreme value Type-I distribution (Gumbel Distribution), Log normal distribution, Pearson Type II, I, and Log Pearson Type III distribution. Gumbel distribution was found to be more appropriate and was adopted for the rainfall analysis. The one-day, two-day, and three-day maximum amounts of rainfall with various return periods are presented in Table 2.1.

Table 2.1: Maximum rainfall at Tulsi and Jaleshwar with various return periods												
Maximum rainfall (mm)	Tulsi Return periods (years)						Jaleshwar Return periods (years)					
	2	5	10	25	50	100	2	5	10	25	50	100
1-day	125	172	203	242	271	300	100	127	145	168	185	202
2-day	165	231	274	329	370	410	142	179	204	235	258	281
3-day	196	266	312	371	414	457	152	193	220	254	279	304

Source: calculated based on precipitation data published by DHM, HMG/N.

Drainage network

The Ratu Watershed is drained by more than 1,000 streams and rivers including distributaries with a total length of 1,439 km. The Ratu Khola, according to the topographic map (1:25,000), is a fifth order river. The drainage density of the entire basin is 2.7 km/km^2. However, there is wide variation in drainage density with varying geomorphic units.

The Ratu Khola originates from Maisthan in the north at an altitude of 740 masl. The total length of the main channel is 82 km within the territory of Nepal. It flows through relatively wide valleys within the Siwaliks (25 km), fan (10 km) and alluvial plain (47 km) and finally across the Nepal-India border. Its major tributaries are the Jangha Khola, the Sunjhari Khola, and the Badahare Khola. These rivers originate in the Siwaliks. The Jangha Khola joins the Ratu Khola in the west at Sarpallo, and the Sunjhari Khola and the Badahare Khola meet the Ratu Khola in the east at Patu and Bhuchakrapur, respectively.

The general slope of Ratu Khola is 0.76% and it decreases from north to south with varying topographic units (Figure 2.7). In the Siwaliks it is 1.65%, 0.89% in the fan zone, and less than 0.2% in the alluvial plain.

The river channels are more or less straight in the upper part and sinuous in the lower part. The overall sinuosity index of Ratu Khola is 1.74. Compared to the Ratu Khola the sinuosity of the Jangha Khola is low.

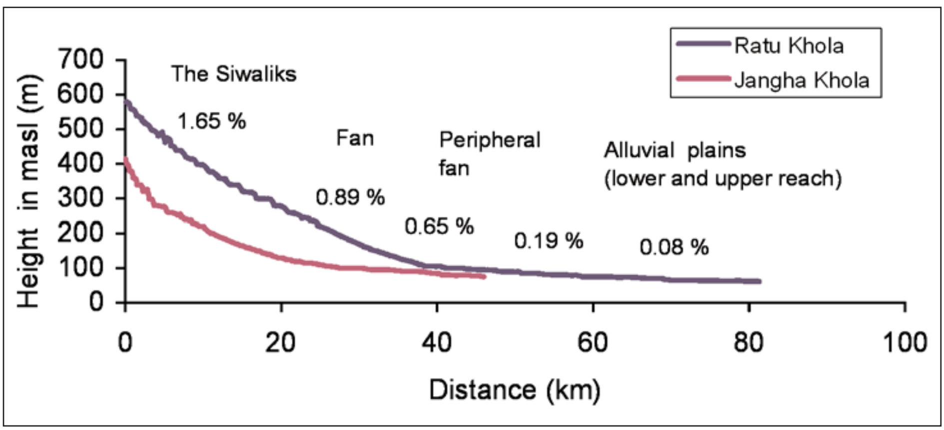

Figure 2.7: **Longitudinal profile of the Ratu Khola and Jangha Khola**

The channel morphology of the Ratu Khola is dynamic. There have been remarkable changes in the number of distributaries, channel width, flood plain width, and catchment size as indicated in the aerial photographs and satellite images taken at different periods. Considerable change in channel morphology was noticed 20-30 km downstream from the source of the Ratu Khola (Figures 2.8 and 2.9). There have been fluctuations in the number of distributaries between 1954 and 1999, with a general declining trend in recent periods. Such a reduction in the number of distributaries in recent times could be attributed to increased river training activities.

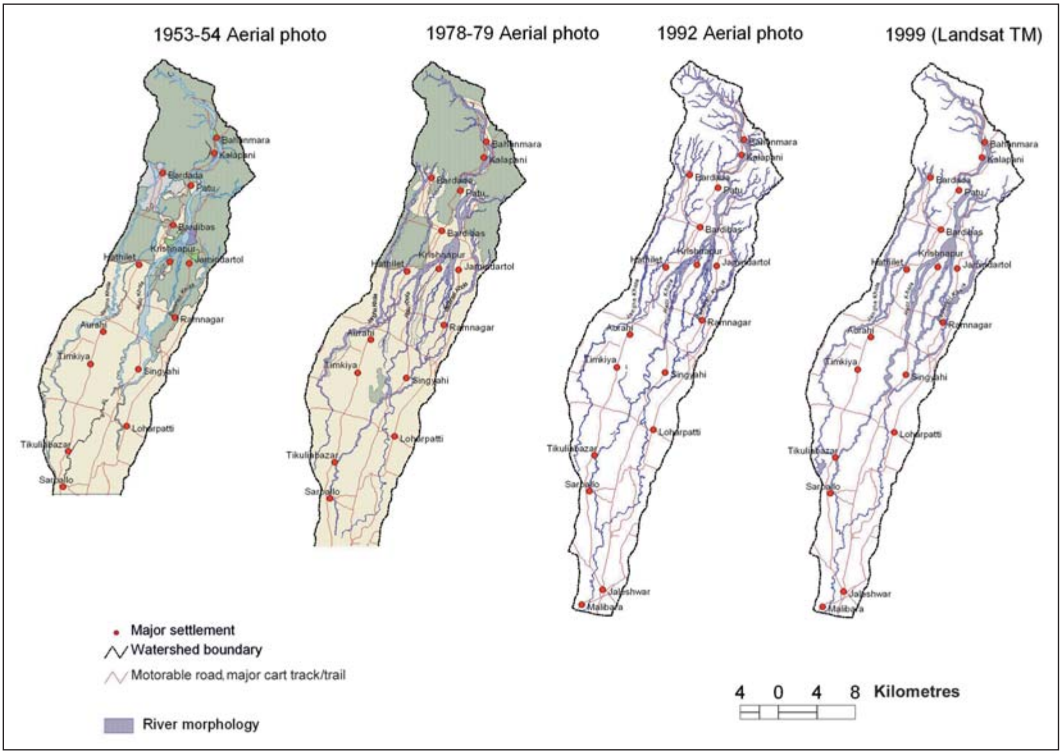

Figure 2.8: **River network traced from aerial photos and imagery at different periods**

Figure 2.10 shows the channel width measured on 12-17 cross-sections along the Ratu Khola at 3,000m intervals in a north-south direction. The channel width is comparatively very high in the middle part of the watershed. There has been an increase in channel width in almost all the cross-sections. Changes in channel width are more pronounced in the fan zone. The average channel width in the river valleys within the Siwaliks confinement increased from 310m in 1954 to 416m in 1996, whereas in the fan zone it increased from 770m in 1954 to 1187m in 1999. In the Middle Terai, the width of the river channel increased from 414m in 1954 to 623m in 1996. Similarly, the width of the river channel has increased from 159m in 1992 to 222m in 1996.

The distance between the two distributaries in the extreme right and left of the main channel is greater in the middle and lower part of the watershed. Rivers have changed their courses more frequently in the fan zone than in the middle and lower Terai.

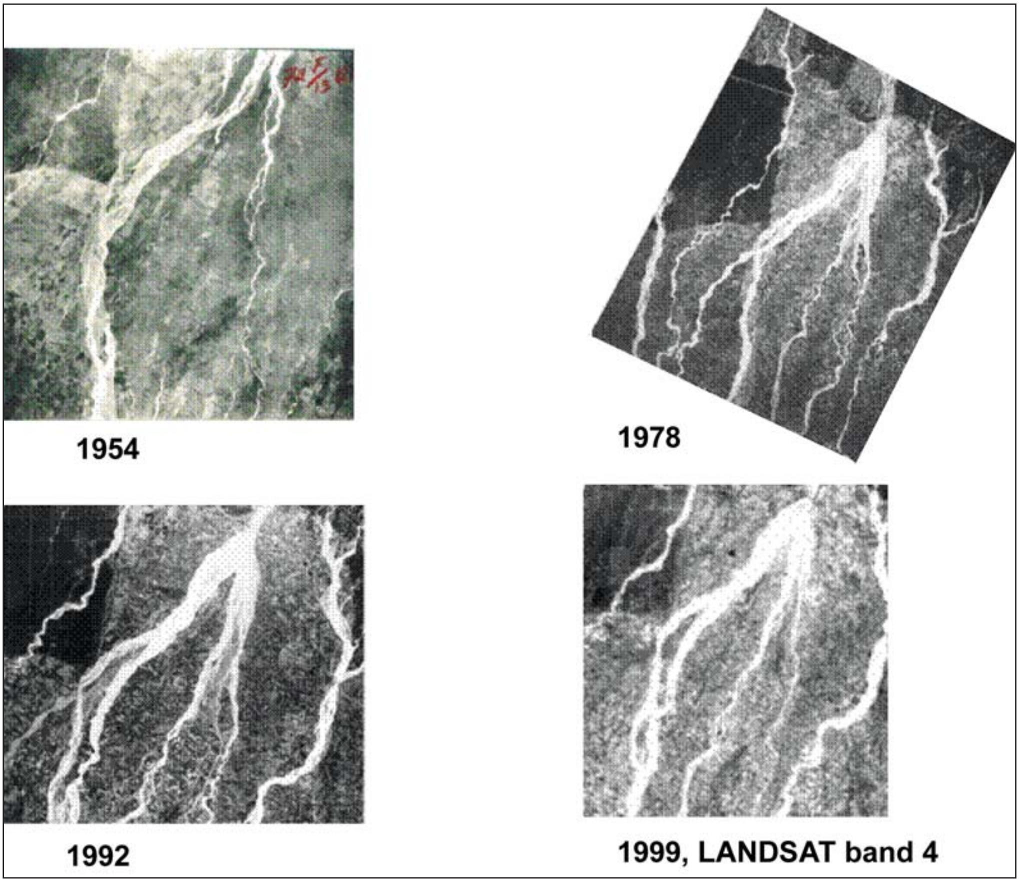

Figure 2.9: **A closer view of the river channel network, 1954-1999**

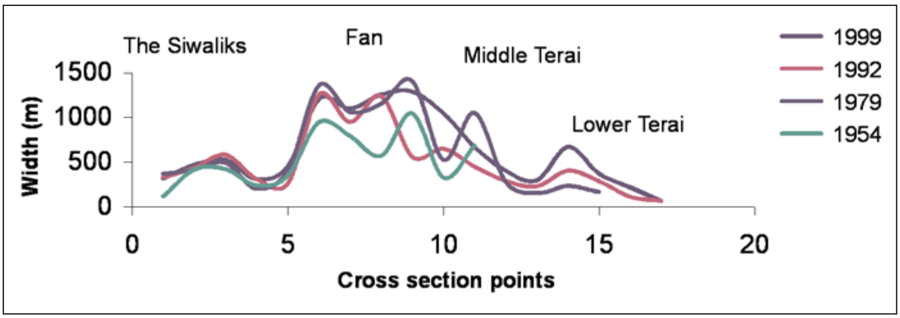

Figure 2.10: **Channel width of the Ratu Khola measured at different cross-sections**

Hence, it is evident that the Ratu Khola morphology has been changing with expansion of its bed width due to heavy sediment loads, rise in bed level, intense bank cutting, and frequent channel shifting; and hence affecting thousands of families and destroying hectares of agricultural land.

Discharge

The Ratu Khola is not gauged. Therefore the peak discharges for various return periods have been calculated by empirical methods; the results are presented in Table 2.2. Bahunmara is located in the upper watershed with peak discharges ranging frm 92-287 m^3/s. The Jaleshwar reach is in the lower Terai area where floods cause inundation over an extensive floodplain for a prolonged number of days.

Table 2.2: Peak discharges at various sites along the Ratu River

Sites at	Methods	Peak Discharges (cumecs) for Return Periods (years)					
		2	5	10	25	50	100
Bahunmara (69.8 km from INDO - Nepal Border)	Dicken's (modified)	68	107	136	174	203	232
	WECS	46	81	108	137	179	214
	Richardson's	92	139	172	217	251	287
Bardibas (55.6 km from INDO - Nepal Border)	Dicken's (modified)	129	192	240	303	351	399
	WECS	98	163	212	264	338	399
	Richardson's	135	204	252	316	366	417
Jaleshwar (5.4 km from Indo - Nepal Border)	Dicken's (modified)	460	618	738	896	1016	1136
	WECS	447	680	846	1013	1241	1421
	Richardson's	270	396	482	598	688	780
At Indo-Nepal Border	Dicken's (modified)	469	630	752	912	1034	1156
	WECS	459	696	866	1036	1268	1451
	Richardson's	270	394	480	595	684	775

Source: ICIMOD 2003

Land use and land cover

About two-thirds of the basin is under cultivation. Only 4% of the total cultivated land lies in the valley floor of the Ratu Khola and the Sunjhari Khola (Table 2.3 and Figure 2.11). The remaining 96% lies in the fan and the alluvial plain. Forests occupy 124 sq. km, or 23% of the total watershed area. Of that,103 sq. km are on the hill slopes with the remaining forests situated on the inactive fan. The active fan zone has no forested area and the alluvial plain in the south has only 2.91 sq. km of forest land.

A considerable portion (6.1%) of the basin area comprises bare ground with recent sand and gravel deposits. The grass area located within and around the river bed (old sand and gravel deposits) accounts for 1.6% of the total area. This is wasteland subjected to frequent flooding. A huge proportion of the sand and gravel is concentrated in the upper and middle reaches, i.e., the inner river valley (33.5%) and fan zone (55.5%).

Other land uses, such as built-up areas, orchards, and ponds, cover 3.3% of the total area. Built-up areas and ponds are concentrated on the alluvial plain. Houses are generally scattered on the fan and in the river valleys.

Table 2.3: **Area under different land-use and land-cover types**

Land use and land cover	Area (in ha)	%
Cultivation	34,718.0	65.3
Forest	12,402.0	23.3
Bush	81.4	0.15
Grasses on point bars and along the river	846.6	1.59
Orchards or nurseries	1,011.9	1.90
Built-up areas	400.3	0.75
River channels	275.75	0.52
Sand and gravel	3,209.35	6.03
Ponds and lakes	256.62	0.48
Total	**53,202**	**100**

Source: Topographical Maps, Topographical Survey Department, GoN 1996

A change in land use and land cover could be seen by comparing the aerial photos from 1953-54 and those from 1992. In Bhabar, the area under forest cover had decreased from 177 sq. km (including a few small patches of cultivated land amidst the forest in the fan region) to 124 sq. km, which is a decline of 30% in forest cover during the last 50 years. Most of the deforestation took place before 1979. Settlements like Bhulke, Laminanda, Prasai, Lotagau, Rajbas, Upper Patu, Gumastatol, and Dhapsar in the valleys of the Ratu Khola, and its tributary the Sunjhari Khola, did not exist before 1954. Similarly, the Bhaktipur area in the upper Jangha Khola catchment was under forest cover. There was moderately dense to dense forest interspersed by patches of cultivated land around the settlements located in the active fan area. These settlements are Lalgadh, Lalbhiti, Bandra, Bengadarbar, Jamindartol, Chaulikha, Krishnapur, and Krishnagar. These settlements, with some houses and small patches of cultivated area, are recorded in the 1959 topographic maps.

Demography

There are 53,323 households with a total population of 310,994 and a density of 584/km^2. The density of population is generally higher in most of the VDCs located in the middle and lower Terai than in the northern counterpart (Figure 2.12). There are more than 60 ethnic/caste groups in the watershed. Most are of Terai origin (80%). Households of people whose origin is in the hills account for about 20%. The northern part (Bhabar and the Churia and Bhabar region) of the watershed is inhabited mainly by people from the hills.

Nearly 7.4% of households migrated into the watershed after the 1950s. The percentage share of in-migrant households increases from 2.5% in the lower part to 6.5% in the middle and 22.2% in the upper part of the watershed. Large numbers of people migrated from the hills and mountain regions and settled in the northern areas. As a result, wide areas of forest were cleared for settlements and agricultural use.

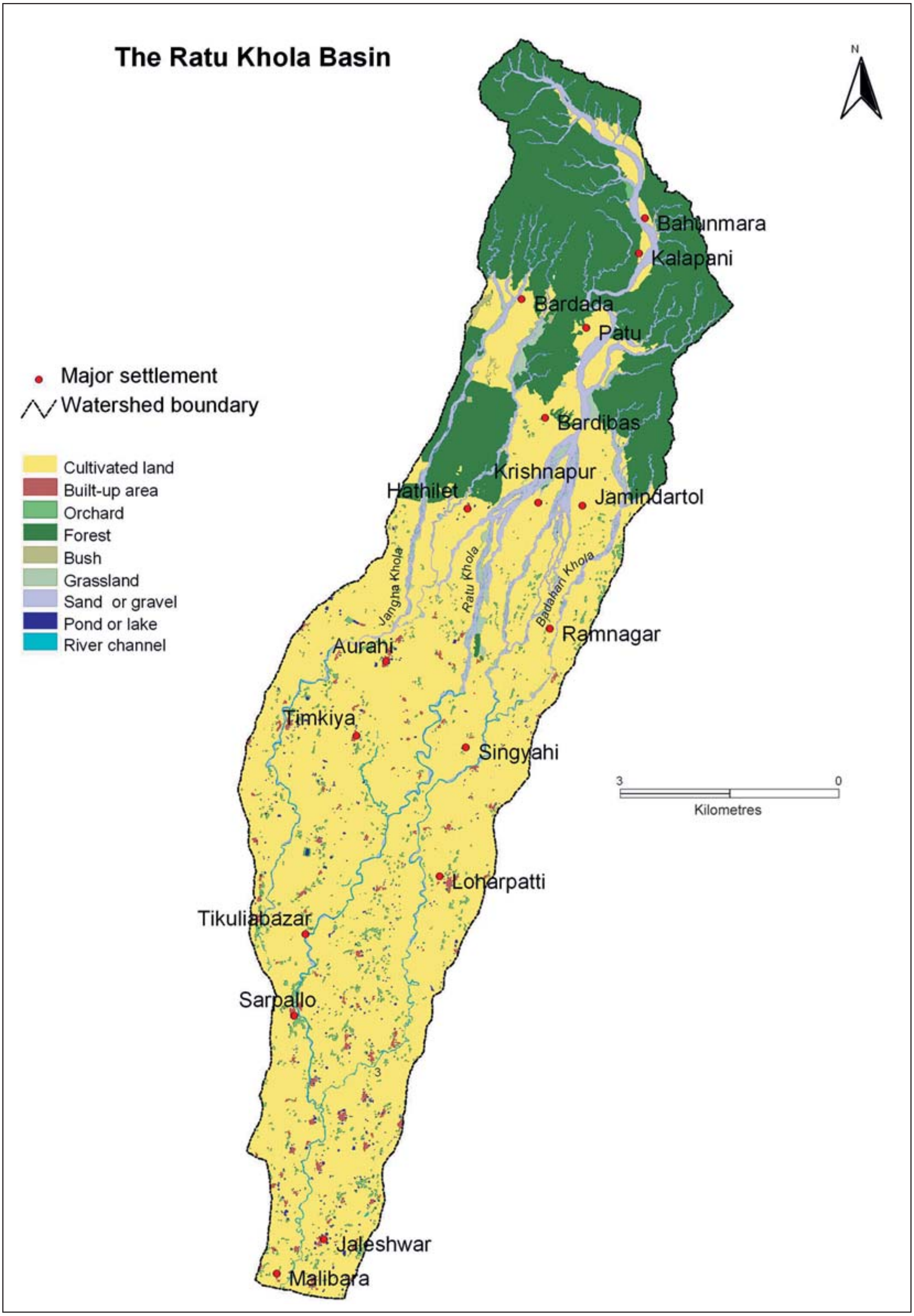

Figure 2.11: **Land use and land cover types, 1996**

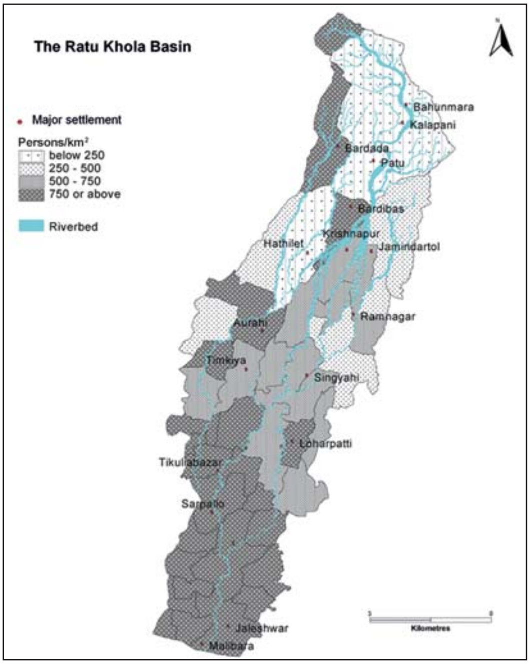

Figure 2.12: **Population density by VDC**

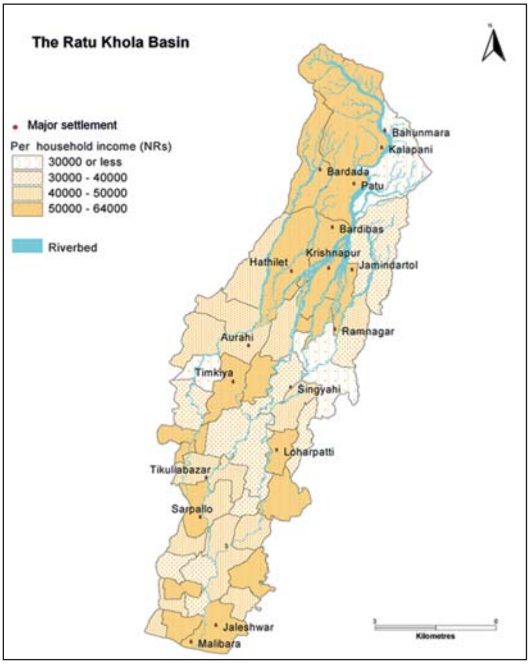

Figure 2.13: **Level of income by VDC**

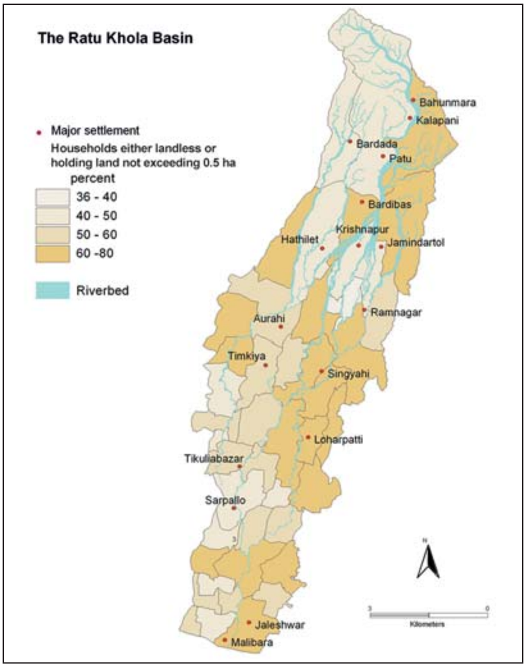

Figure 2.14: **Percentage of landless and marginal farm households by VDC**

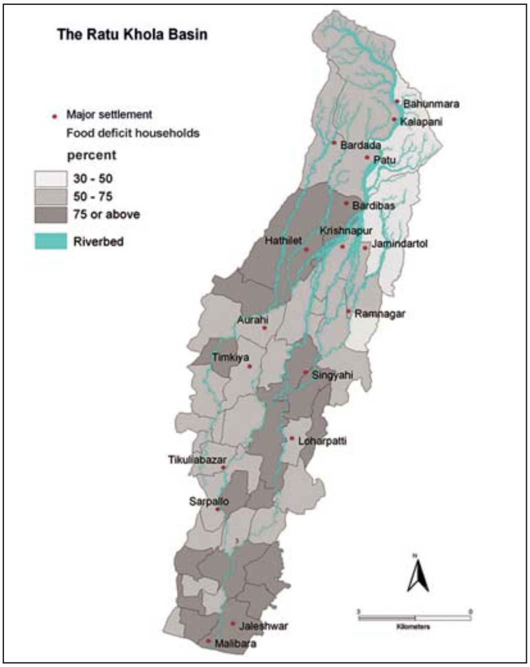

Figure 2.15: **Percentage of food-deficit households by VDC**

The literacy rate among males and females is 39% and 16%, respectively. These figures are very low compared to the national average literacy rate (59.6%) and literacy rate among females (48.3%). The average percentage of school-going boys and girls 6-16 years old is about 67% and 36%, respectively.

Economic activities

Agriculture, wage labour, trade and business, and services are the major sources of family income. The major source of income for 44% of households is agriculture, followed by wage labour (30%), trade and business (8%), services (6%), industry (3%), and others (9%).

Many families are poor. Nearly 16% of the families have annual incomes of less than Rs 20,000, less than Rs 3,448 per person per year. Similarly, 38% of families have annual incomes of Rs 20-40,000. Families having annual incomes of Rs 40-80,000, 80-100,000, and above 100,000 are 27%, 16%, and 3%, respectively. The income level by VDC is presented in Figure 2.13.

Nearly 21% of the families (11,241) are landless. Marginal farm households with farm sizes of less than 0.5 ha comprise 38% (20,050) of the total households. The percentage of landless and marginal farm households by VDC is shown in Figure 2.14. Small farm households with landholdings of 0.5 to 2 ha comprise 29%. Only 12% of households have landholdings above 2 ha. More than 22% of families are tenants who cultivate others' land for their subsistence. Nearly 11% of the families rent out their land to other families.

Production and food sufficiency

The average household produces about 1.23 tonnes (t) of rice, 0.25t of wheat, and less than 0.05t of maize annually. Paddy comprises 22.5% of the total agricultural production followed by wheat, potatoes, and maize. Millet, barley, and buckwheat are also produced in small quantities. The main cash crop grown is sugarcane; it accounts for 67% of the total agricultural production. Other cash crops are mustard seed, groundnuts, linseed, and sesame. Vegetable crops like cauliflower, tomatoes, and cucumber are produced to a marketable scale. Leguminous crops such as soybean, black gram, red gram, grass peas, lentils, gram, peas, green gram, horse gram, and cow peas are also grown. Spice crops such as chilli, onions, garlic, ginger, turmeric, and coriander are also produced on a small scale. Mangoes, jackfruit, bananas, and papaya are the main fruit products. Lemon, guava, litchi, pineapple, pomegranate, and watermelon are also grown. A few households sell their agricultural products. Nearly 11% of the total households sell food grain and 13% sell fruit.

The study area is food-deficit; only 12% of families have surplus food production. About 34% of the families produce barely enough food for three months. Families having their own food for 3-6 months, 6-9 months, and 9-12 months account for 23, 17, and 14%, respectively. However, the percentage of food-deficit households varies by VDC (Figure 2.15).

Many households keep cattle, buffaloes, goats, and sheep. The average number of cattle per household is two. Per household average number of buffaloes, goats, sheep, pigs, chickens, and ducks/pigeons is 0.7, 1.7, 0.01, 0.1, 2.2, and 0.4, respectively. About 14% of households sell livestock products.

Industry and Infrastructure

There are 851 industries of small to medium scale in the watershed. Rice mills comprise nearly 70% of the total number of industries; others include furniture industries (5.4%), sugar mills (9.2%), brick kilns (2.9%), saw mills (2.8%), cutting, netting and weaving (2.1%), cigar production (1.9%), and tile industries (1.8%), employing about 6,000. Out of these more than 48% are employed in brick industries, 24.8% in sugar mills, 12.8% in rice mills, 4.7% in furniture industries, 3.1% in tile industries, and 2.1% in saw mills.

There are three colleges and higher secondary schools, 33 high schools, 29 lower secondary schools, and 158 primary schools in the watershed. There are 43 sub-health posts, four health posts, three primary health care centres, and three hospitals. There are also eight ilaka post offices and 41 additional post offices. Service institutions such as agricultural institutions (12), veterinary posts (11), rural banks (13), commercial banks (4), cooperatives (15), nurseries (7), police stations (12), cinema halls (4), and market centres (18) are also located in the watershed. Local level groups/institutions such as savings groups (39), forest user groups (25), women's groups (24), consumer groups (51), youth clubs (67), INGOs (15), and NGOs (35), are also established in different parts of the watershed. However, only a few institutions are dealing with the management of hazards and disasters.

One can reach every part of the watershed within two hours from the road head. The Bardibas-Sindhuli road connects VDCs located in the north. Almost all the VDCs are connected by earthen roads accessible by carts except during the monsoon period.

It is against this biophysical and socioeconomic background of the Ratu Watershed that flood-hazard and risk mapping was carried out using the following methodology.

Methodology

Approaches

A hazard is defined as the probability of occurrence, within a specified period of time and within a given area, of a potentially damaging phenomenon (Varnes 1984 and UNDRO 1991). Hence, flood hazard is a flood event likely to occur in a given time period within a given area, with the potential to harm or damage. Similarly, flood risk has been defined as the expected degree of loss due to flooding. The risk depends on the extent of the exposure of different elements in flood-susceptible areas and their vulnerability. In this sense, there is no socioeconomic risk if there are no people and property to be affected. Similarly, vulnerability is the ability of the exposed elements to withstand or recover from the flood hazard. It depends on the capability in terms of response and resilience. In other words, hazard is the probability of stress of a different magnitude, whereas vulnerability is the strength to withstand or recover and risk is the product of both the hazard and vulnerability.

Flood hazard is closely associated with the frequency and magnitude of a flood event, on the one hand, and features of the terrain and its location on the other. The areas most susceptible to flood hazards are those which are frequently flooded and unstable due to frequent changes in a river channel, its bed, and bank. Terrain units likely to be affected by flood hazards are topographic depressions, flood plains, and river channels. These areas highly susceptible to flood hazard can be identified and delineated through careful geomorphological mapping.

Another strategy frequently adopted for flood-hazard mapping is to establish the relationship between river discharge and channel capacity to hold discharge controlled by micro-topographic conditions. Inundation, due to overflow from the bank, commonly occurs when/where the discharge is higher than the channel's capacity to hold it. The depth of inundation is also determined based on the volume of discharge and micro-topographic variations along the river channel and its surrounding areas. Similarly, areas with different degrees of susceptibility to flood hazards can also be identified and delineated based on the experiences of local people.

Ratu Khola is not gauged, so there are no measured time-series' discharge data as in many rivers originating from the Siwaliks. This river is very wide and shallow, particularly in the middle and upper part of the basin. Inundation due to overflow from the bank, and channel shifting resulting in loss of life and property are common phenomena. Moreover, lowland areas with very high water tables, even if they are located far from the river channel, are easily inundated for a longer duration after every heavy precipitation event. It is in this context that these three different approaches; viz., i) flood-hazard, risk, and vulnerability mapping based on geomorphic concepts using GIS and remote sensing; ii) inundation-hazard mapping based on river discharge and micro-topographic variation using the HEC-RAS model; and iii) social flood-hazard mapping based on local people's experiences; were adopted for this study.

Sources of data

The information needed for hazard, risk, and vulnerability mapping was obtained/derived from three different sources: i) maps, aerial photographs, and imagery; ii) field survey and group discussions; and iii) published and unpublished documents.

Maps, aerial photographs, and imagery

Topographic maps (Sheet nos: 2785-16A, 16B, 16C and 16D; 2685-04A, 04B, 04C, 04D, and 08A on a scale of 1:25,000) compiled from 1:50,000 scale aerial photography taken in 1992 and field verification carried out in 1995 and published in 1996 by the Survey Department, Government of Nepal, were used and information on topographic variation; drainage, land use and land cover; roads and trails; house/building units; built-up areas, and other infrastructure were obtained. Aerial photographs taken in 1953-54, 1978-79, and 1992 were used for the study. The aerial photographs taken in 1953-54 were obtained from the Forest Survey Division, Forest Research and Survey Centre, Ministry of Forest and Soil Conservation, HMG/Nepal. Similarly, aerial photographs taken in 1978-79 and 1992 were obtained from the Topographical Survey Division, Survey Department, HMG/Nepal. Aerial photographs from 1953-54 cover only the Siwaliks and the fan zone of the basin which is 65% of the basin area, the only available photographs during the period. Similarly, aerial photographs taken in 1979 do not cover the downstream part of the lower Terai. The photographs cover only 80% of the basin area. Samples of aerial photographs used for mapping are presented in Figure 2.16. River morphology, old channels, flood-affected areas, river terraces, fans, floodplains of various flood levels, swamp areas, and forest cover were identified from these aerial photographs using interpretation keys developed based on tone, texture, shape, and association.

Satellite imagery from a Thematic Mapper (TM) with 30-metre resolution (path 141 and row 41) taken on March 10, 1999, was obtained from the Forest Survey Division, Forest Research and Survey Centre, Ministry of Forest and Soil Conservation, Government of Nepal. These digital images in individual spectral bands and various false colour composites (FCCs) were used to identify and delineate different terrain features such as active and old river channels, active and inactive fans, terraces, floodplains, flood-affected areas, moist areas, and areas under different land use and land cover. Tone, texture, colour, pattern, shape, and association of the images provided the basis for identifying these features (Figure 2.17). Before interpreting the images it was necessary to enhance their interpretability, for which filtering and contrast enhancement (stretching)

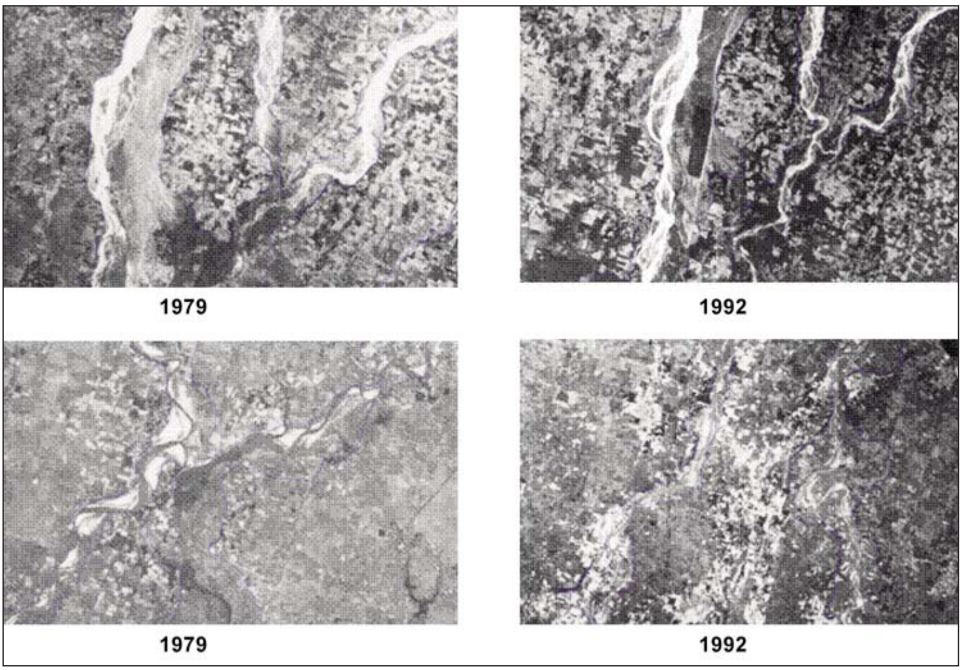

Figure 2.16: **Samples of aerial photographs used for mapping**

operations were applied using the Integrated Land and Water Information System (ILWIS) 3.0's image-processing capability (ILWIS, 3.0). The features clearly detected in different bands and colour composites are described in Table 2.4. Identified active fan and the fresh and active sediments relative to landform units in the Terai are also presented here.

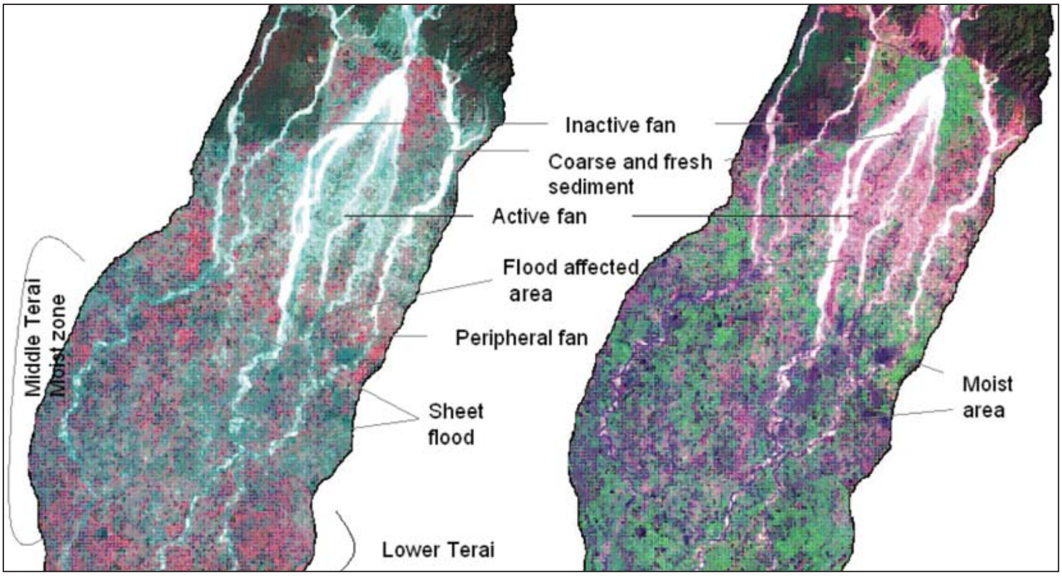

Figure 2.17: **Image interpretation using FCC, 432, and 751**

Table 2.4: Colour composites and individual bands of the LANDSAT Thematic Mapper and land features

Features	Colour composites (RGB*)	Individual band
Fan	541, 432	1,2,3,
Fresh sediments	432, 541, 632	1,2,3
Landslides	432	
River channels	432, 741	1,2,3, 4
Flood-affected area	432, 741, 541	1, 2, 3, 5
Areas of sheet flooding	751, 541, 432, 341	1, 2, 5, 7
Moist soil, swamp, and marshes	741, 752	4,5
Land Use and land cover	432	-

Note: RGB=Red Green Blue

Field survey and group discussion

A field survey was carried out to verify features identified from aerial photographs and satellite images on the ground. Group discussions were carried out in each VDC in the watershed (Figure 2.18). During group discussions, local stakeholders were requested to prepare flood hazard maps based on their experiences and knowledge about frequently flooded areas, sites of river bank cutting, and channel shifting. Accordingly, areas of high, moderate, and low hazard were delineated on the base map, i.e., topographic maps (1:25000), by local people. The high-hazard

Figure 2.18: **Delineation of flood-prone areas by local people during group discussion**

area in the watershed delineated by the people was the area where flood events causing loss of life and property occurred frequently.

Published and unpublished documents

Rainfall and river discharge data were obtained from the Department of Hydrology and Meteorology (DHM), Government of Nepal in order to determine the relationship between rainfall and runoff.

Data-processing methods and analytical tools

Different data-processing methods and analytical tools were used to prepare flood-hazard, risk, and vulnerability maps of the Ratu Watershed. A brief description of the methods and tools used for the three different flood-hazard mapping approaches mentioned above is given below.

Flood-hazard risk and vulnerability mapping using GIS and RS with a geomorphic approach

A GIS was used to capture and analyse spatial data. Data capture in GIS was carried out in two ways – screen digitisation, and digital image processing.

Topographic maps and aerial photos were scanned and entered into an ILWIS 3.0 GIS environment by digitising these features onscreen. For that, scanned maps, aerial photos, and images were geo-referenced with respect to their geographical position on the specified projection system and parameters mentioned in the topographic maps.

In addition, a digital elevation model (DEM) was prepared from the contour and spot heights and used for preparing a slope map, cross-section profile of the terrain, and river profile; and delineating potential sites for river-bank cutting, flood-prone areas, assuming a dam of a certain height at a given river reach. A DEM was also used to calculate the flooded area by incorporating it into the U.S Army Corps' Hydrological Engineering River System Analysis (HEC-RAS) flood-modelling software.

Information obtained from topographic map sheets, aerial photographs taken at different periods, and satellite images was integrated into a GIS environment and analysed. Terrain units with different features having different degrees of susceptibility to flood hazards were identified and delineated. These include frequently flooded areas, active and old river channels, floodplains (lower, middle, upper), topographic depressions (wet/moist area), gently sloping land with traces of fresh sediment (sheet flooding), sites of debris flows, and river-bank cutting (Figure 2.19).

In addition, an infrastructure-induced inundation-hazard map was prepared for the lower Terai where inundation is a severe problem during prolonged monsoon rain. The delineation of the inundation area is based on the hypothetical construction of a dam or a road one metre higher than the surface at the outlet of the Indo-Nepal border. At about one km distance from this outlet inside Indian territory is a paved road which is about 1.5m higher than the surrounding area. This road is aligned in an east-west direction, roughly following the international border: flooding due to this alignment is likely in Nepal. With reference to such infrastructure, the area under flooding has been delineated using DEM by means of iterative processes of neighbourhood operations available in ILWIS 3.0 software.

The methods for identifying areas susceptible to flooding and its associated hazard types are summarised in Figure 2.19. The cumulative area affected by flooding delineated in 1978-79, 1992 aerial photographs, and 1999 satellite images – including the river channels – are classified as high-hazard areas. Similarly, areas under inundation and potential sites for river-bank cutting and the

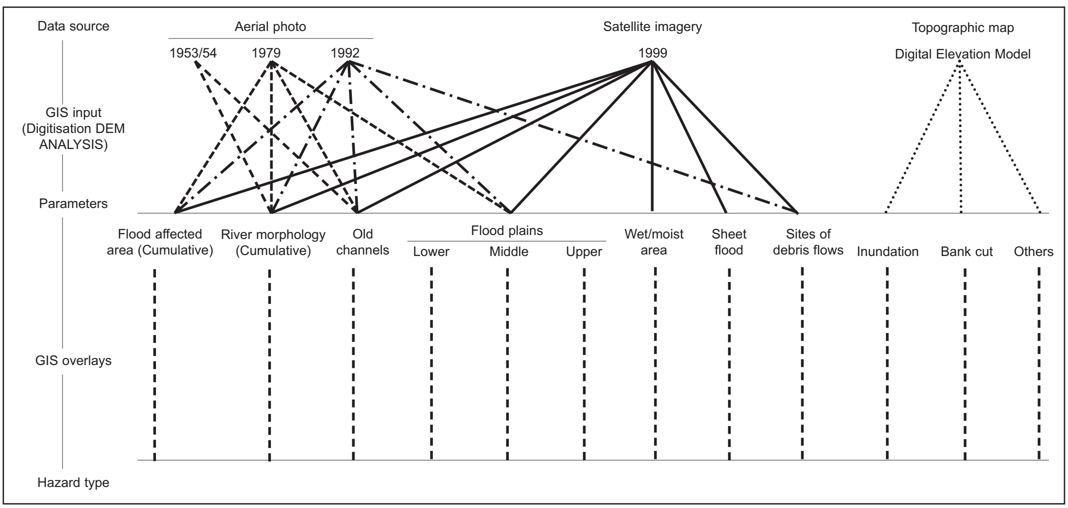

Figure 2.19: **Flood-hazard mapping scheme adopting geomorphic approach**

areas of active colluviums are considered high-hazard areas. Areas of moderately high hazard include the middle floodplain, moist depression areas, and damp and marshy sites. Moderate-hazard zones consist of the old channel course and the areas affected by sheet flooding. The rest are included in the low-hazard zone. Risk, as defined earlier, is obtained by the multiplication of probability of hazard and vulnerability. Owing to the absence of information on the frequency and magnitude of floods, extent of exposure, and response and resilience, the risk map for the Ratu Khola Basin was prepared by combining the flood-hazard map with the vulnerability map. It was possible to derive detailed information for only a few types of elements at risk and their spatial distribution from topographical maps. Only three parameters – house density, infrastructure (road and cart tracks and channels), and land use and land cover (built-up, agriculture, and others including forest which it was possible to quantify from topographical maps) – were taken into consideration for vulnerability and risk mapping. The scheme used for vulnerability and risk mapping is presented in Figure 2.20.

The socioeconomic impact of the loss of houses, infrastructure, and built-up areas is greater than from the loss of agricultural land, forest, grazing land, and wasteland. Therefore, the level of vulnerability due to loss of areas with dense housing, infrastructure, and other built-up areas is very high. Distance is taken as one of the bases for determining the level of vulnerability, i. e., the closer the distance from these features, the higher the vulnerability and vice-versa. A surface map of distance was prepared in an ARCView environment.

Three steps were included in preparing the vulnerability map: i) transforming the parameter maps into weight maps by assigning a weight value to each class of the parameter maps, ii) combining various weight maps by adding their corresponding values (the values for the combined weight map ranged from 3-18), and iii) preparing the vulnerability map by classifying the combined weight map into three classes, i.e., high (above 8), medium (5-8), and low (below 5). These threshold values were obtained after several trial and error manipulations of these values in order to obtain an appropriate vulnerability map. Finally, a risk map was

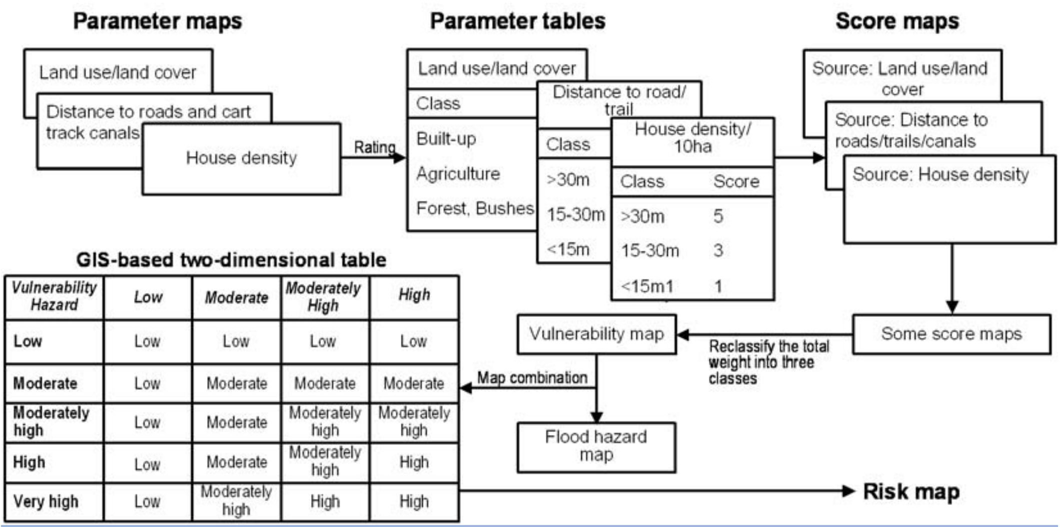

Figure 2.20: **Vulnerability and risk-mapping scheme**

prepared by combining the hazard map with the vulnerability map using a GIS-based two-dimensional table (Figure 2.20)

Inundation-hazard mapping using the HEC-RAS model with rainfall and runoff simulation

The extent and severity of damage from flooding are usually defined by water depth. Such an inundation analysis can be carried out effectively and efficiently by using numerical modelling tools on a GIS platform. This also provides a framework for the decision-support system and facilitates evaluation of alternatives for flood management.

For the numerical modelling, the whole catchment area was divided into three portions, namely, Bahunmara in the north, Bardibas in the middle, and Jaleshwar in the south. The length of the Ratu Khola and the length and elevation of the catchment were derived from the topographical maps (1:25,000). Since there are no recorded discharge data for the Ratu Khola, discharge were estimated based on rainfall and catchment characteristics. Frequency analysis of the maximum daily rainfall recorded in meteorological stations located within the catchment and nearby areas was carried out to determine the return period of different amounts. Discharge for different return periods was estimated using various approaches such as those of the Water and Energy Commission Secretariat (WECs), modified Dicken's, and Richardson's methods. The results are presented in Table 2.2.

For this work, the HEC-RAS version 3.1 was used to calculate water-surface profiles; ArcView GIS 3.1 was used for GIS data processing. The HEC-GeoRAS 3.1 for ArcView GIS was used to provide the interface between the systems. HEC-GeoRAS is an ArcView GIS extension specifically designed to process geospatial data for use with HEC-RAS. The extension allows users to create an HEC-RAS import file containing geometric attribute data from an existing digital terrain model (DTM) and complementary data sets. GeoRAS automates the extraction of spatial parameters for HEC-RAS input, primarily the three-dimensional (3D) stream network and the 3D cross-section definition. Results exported from HEC-RAS are also processed in GeoRAS. The ArcView 3D Analyst extension is required to use GeoRAS.

The general procedure adopted for inundation modelling consists basically of five steps: i) preparation of DEM in ArcView GIS, ii) GeoRAS pre-processing to generate a HEC-RAS import file, iii) running of HEC-RAS to calculate water-surface profiles, iv) post-processing of HEC-RAS results and floodplain mapping, and v) flood-risk assessment. Figures 2.21 and 2.22 explain these procedures in flow diagrams.

An integrated DTM was prepared based on information derived from topographical maps (1:50,000). The sources of information and processes used for the preparation of the DEM have been discussed earlier. Stream centreline, cross-sections, stream banks, and flow-path lines were defined to extract 3-D spatial data from the triangular irregular network (TIN) to develop 3-D polylineZ themes for GeoRAS pre-processing to generate a HEC-RAS import file. Geometric data of river cross-sections read from the HEC-RAS GIS were imported into HEC-RAS. The imported geometric data consist of 393 cross-sections including reach lengths

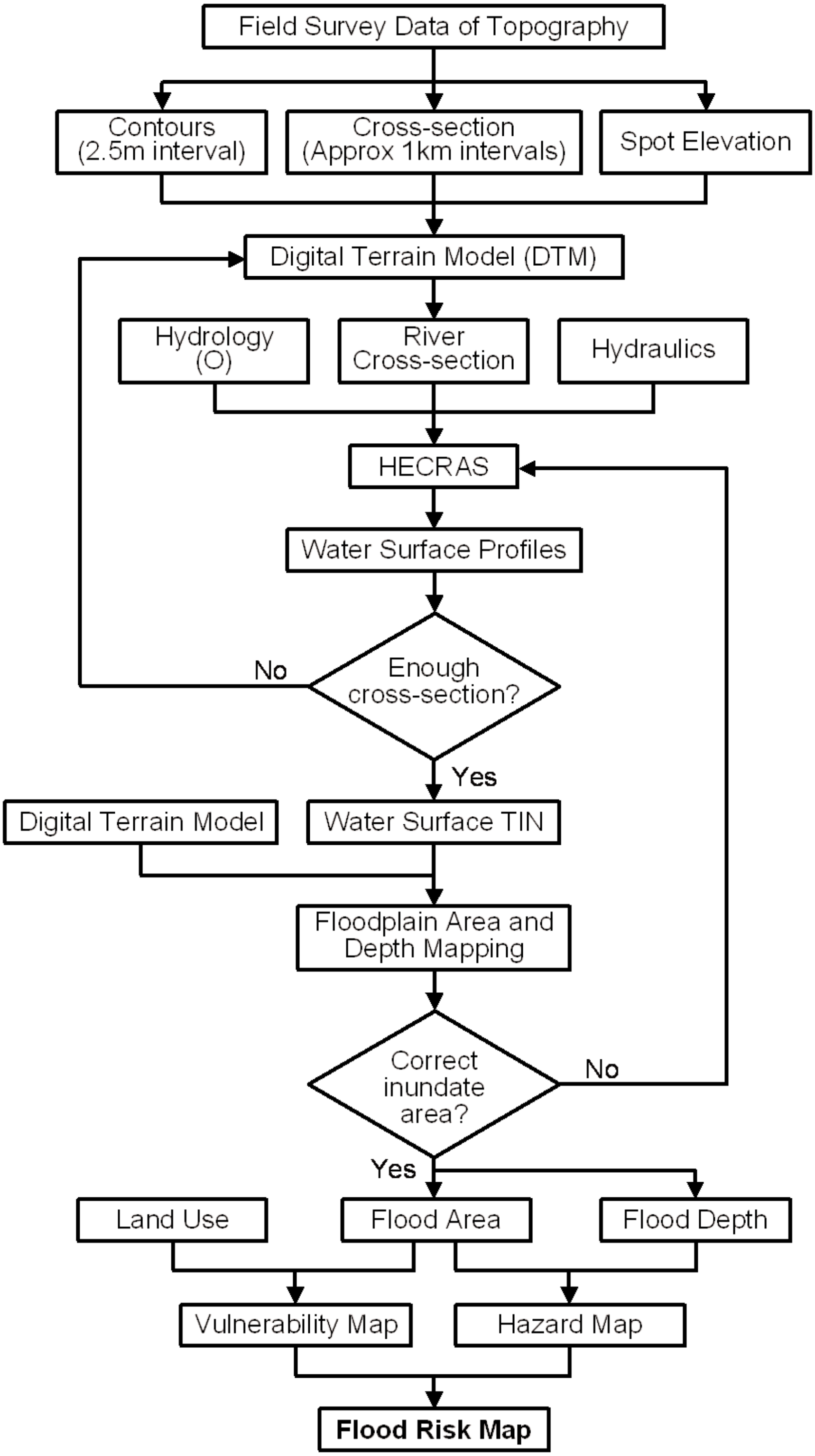

Figure 2.21: **One-dimensional floodplain analysis using HEC-RAS, GIS, and HEC-GeoRAS**

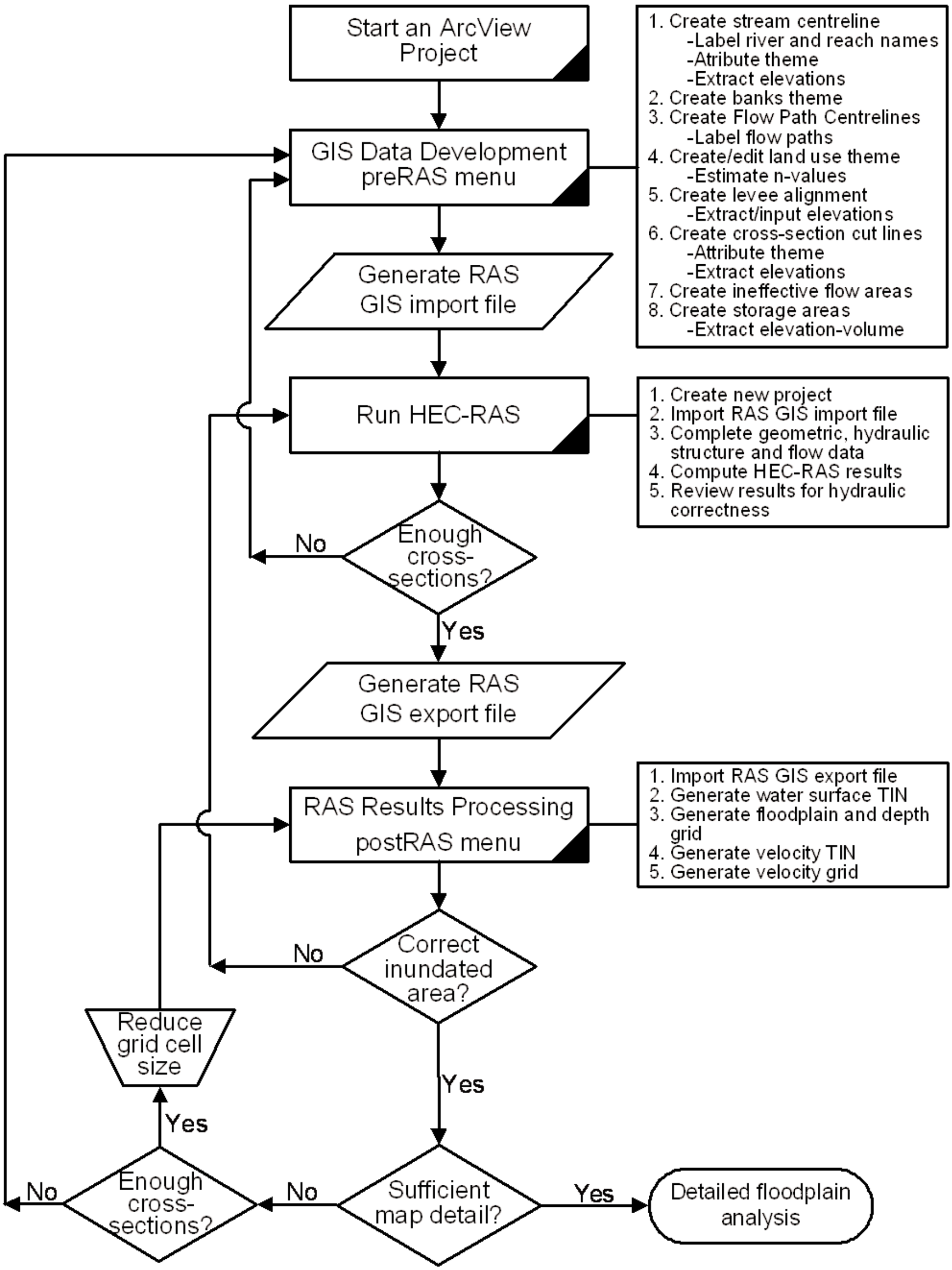

Figure 2.22: **Process flow diagram for using HEC Geo RAS**

and bank stations. Manning's 'n' coefficients are input. Steady flows were entered for various return periods. As no downstream boundary conditions in the form of rating curve or observed water level were available, normal depth was used. HEC-RAS was executed for the sub-critical flow profile, output data were exported into ArcView GIS, and finally the inundation hazard map was prepared.

Social flood-hazard mapping involving local stakeholders

Local stakeholders were requested to delineate areas with high, medium, and low flood hazard probabilities on topographical maps (1:25,000) based on their experiences. This was solicited during group discussions in each VDC in the Ratu Watershed. These maps were digitised and finally a flood-hazard map of the Ratu Watershed was prepared.

Results

The results of flood-hazard, risk, and vulnerability mapping work in the Ratu Watershed using the three different approaches are presented in the following section.

Flood hazard, risk, and vulnerability maps using a geomorphological approach

Hazard mapping

A series of maps delineating different features of the terrain with different levels of susceptibility to flood hazards was prepared. These maps were combined and a final map of flood hazards was prepared. Such terrain features and their association with flood hazards are described below.

Flood plains frequently affected by floods

Areas frequently affected by floods were mapped based on interpretation of aerial photos and satellite images from different periods and are presented in Figures 2.23-2.25.

A terrain unit map depicting geomorphic features with different levels of flood susceptibility, such as river channels, fans, floodplains, terraces, and hill slopes amongst others, was prepared by interpreting aerial photographs (Figure 2.26.) These geomorphic features signify the different degrees of flood hazards. Floodplains in the Patu, Kalapani, Bahunmara, and Rajbas areas in the northern part of the watershed are subject to occasional flooding.

In the depositional zone, floodplains with three distinct topographic heights – the lower, the middle, and the upper – were identified. These floodplains generally begin from the point of spring lines or re-emergence of the perennial channels. The lower floodplains lie in the vicinity of river channels. The lower floodplain has an area of about 31.1 sq. km. This zone is subjected to normal flooding. In the middle Terai, the maximum width of the lower floodplain is about 800 metres, and in the southernmost part of the basin it is up to 1,390m. The outer margin of the floodplains is generally cultivated or under grass cover. This zone is mostly

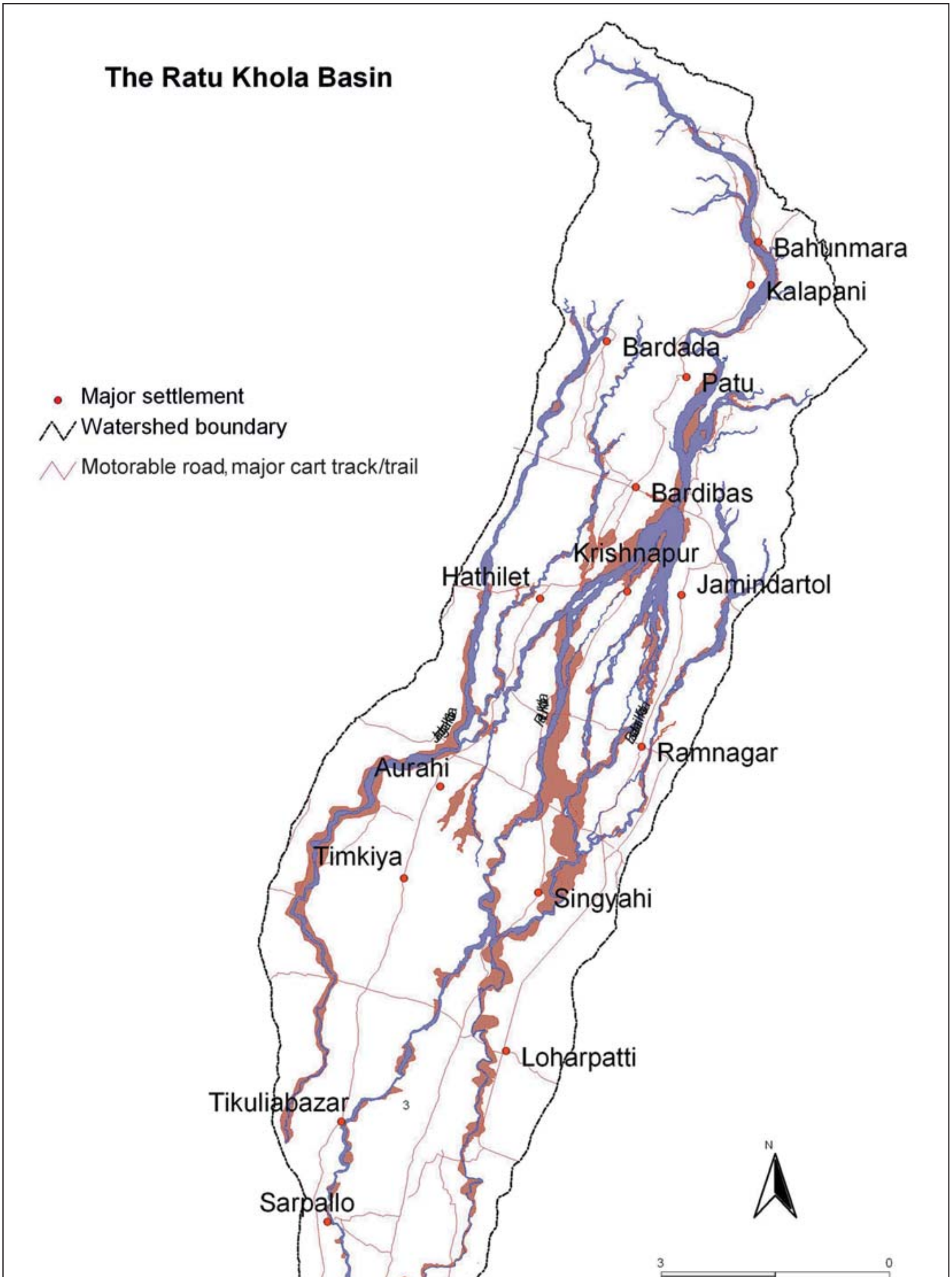

Figure 2.23: **Flood-affected areas, 1978/79 aerial photos**

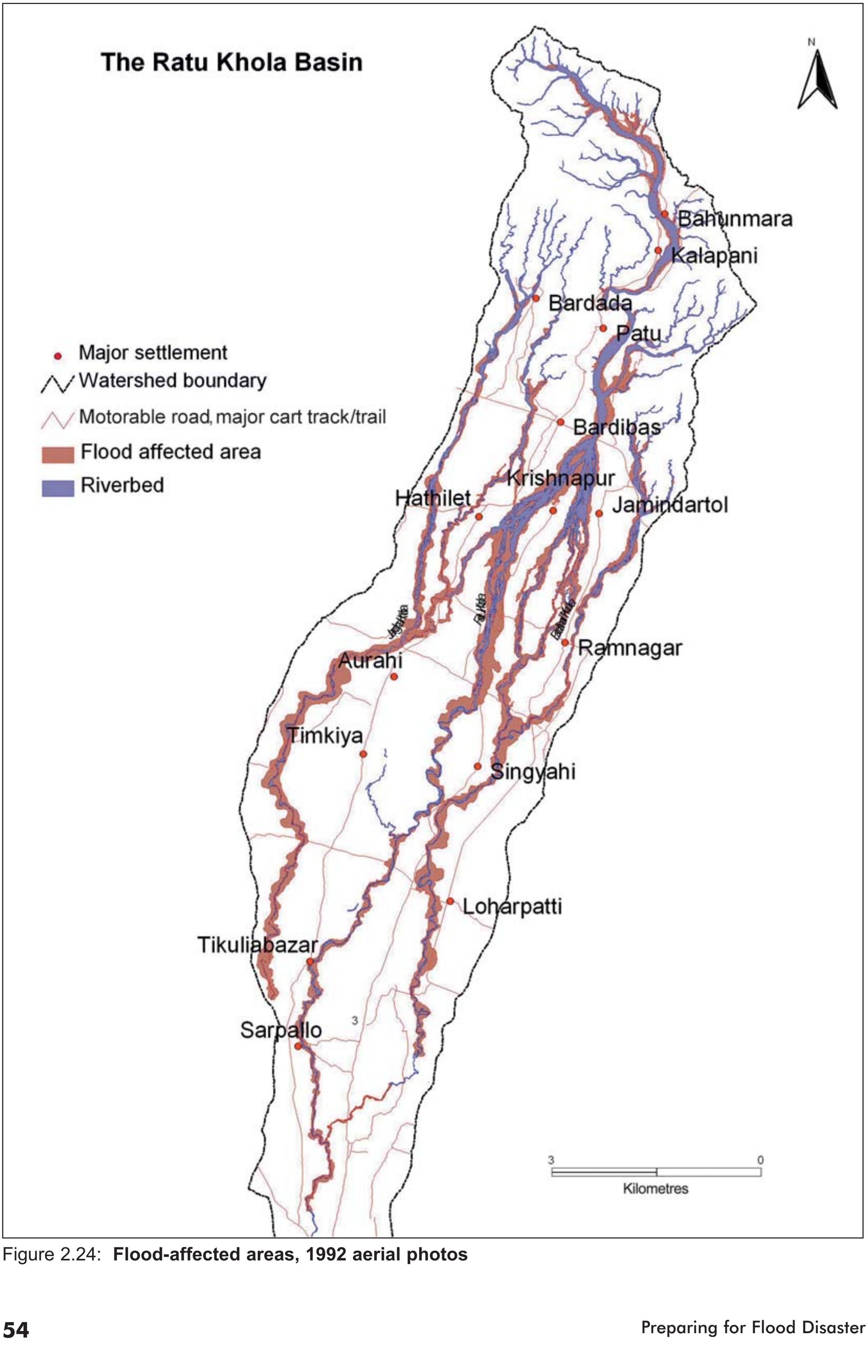

Figure 2.24: **Flood-affected areas, 1992 aerial photos**

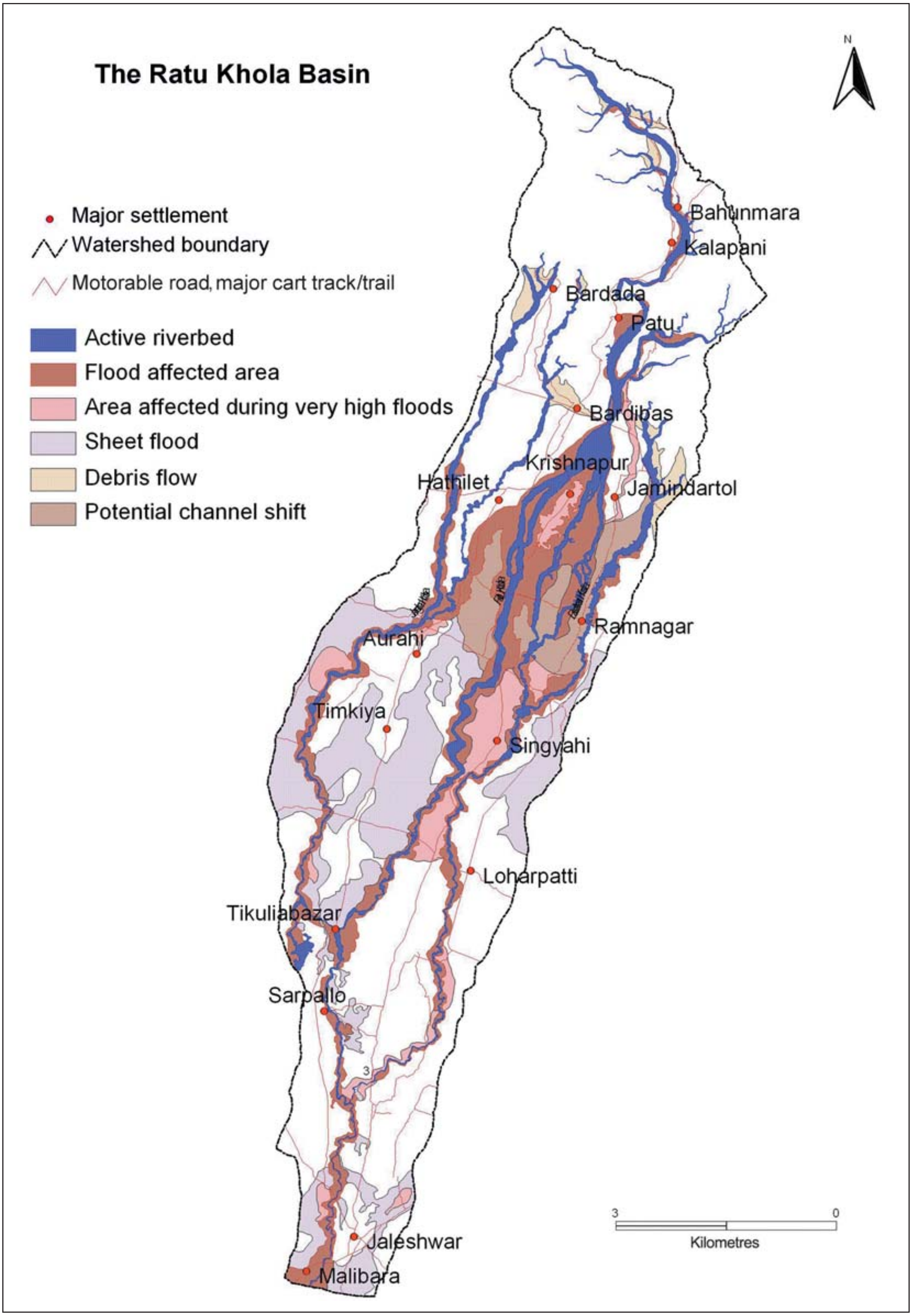

Figure 2.25: **Flood-affected areas, 1999 Landsat TM imagery**

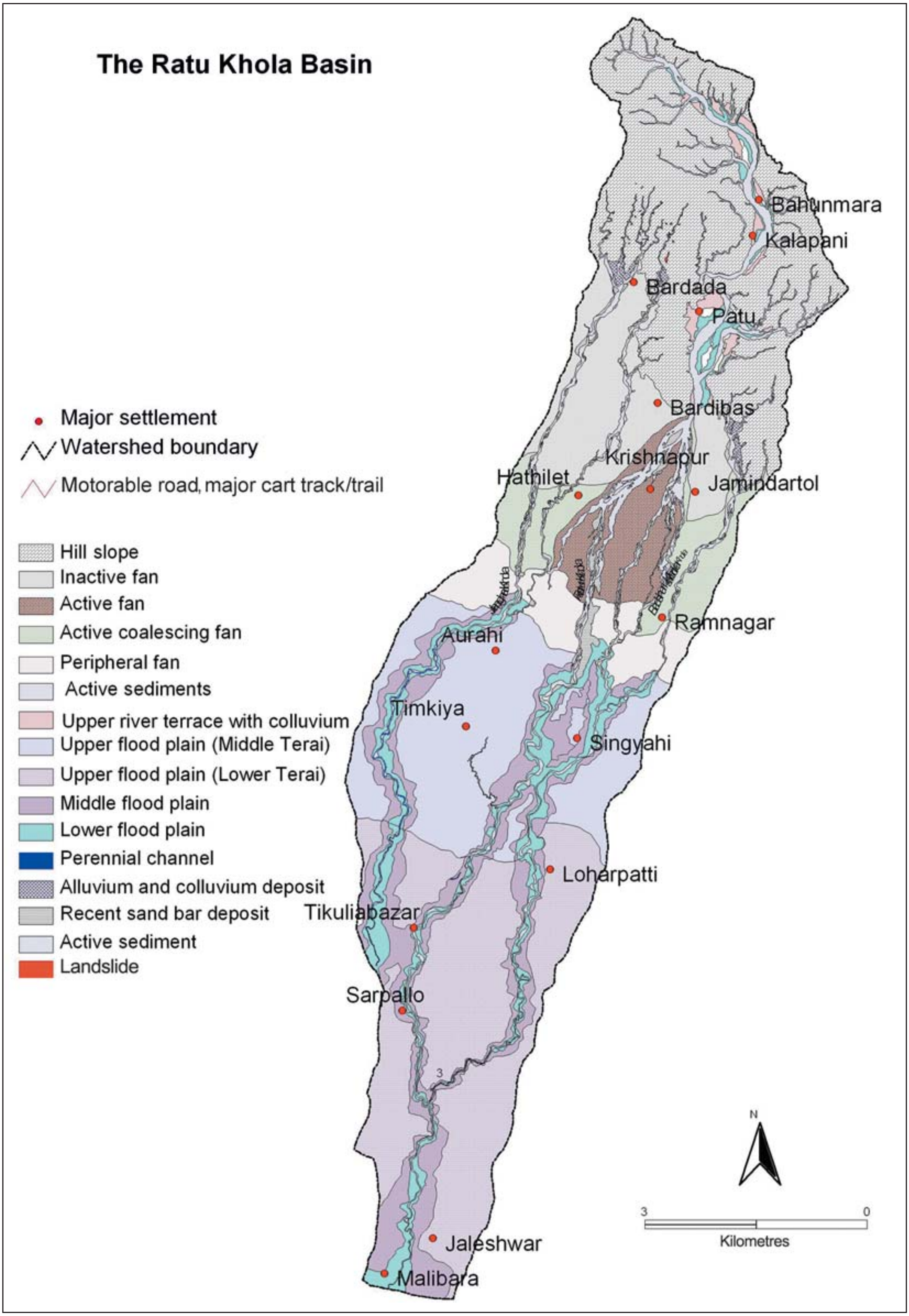

Figure 2.26: **Terrain unit map**

avoided for human settlement development. According to the topographical maps, only 174 (1.7%) building units are located in this area. About nine built-up areas are located in this floodplain: Suryahi, Malibara, Singhyahi, Gonarpura, Kolhuwa, Baidiyatol, Sripur Kalibara, and Kathundhar.

The middle floodplain is generally recognised by adjacent terraces with less bright tones and finer textures indicating finer and relatively stable sediments. This zone intersperses with the upper floodplain characterising the zone of depression left by the old channel. During high discharge, water overflows through these depressions. The zone has more extensive areas of river meandering.

The upper floodplain is generally the old riverbed areas and is represented by higher relief and stable alluvium with fine silt content. The zone is a site for settlements and may be affected by the channel shift due to a rise in the existing bed level upstream. This part is subjected to occasional sheet-flooding originating from the upper catchments of the channels in or across the basin.

River channels

One of the most flooded land units is the river channel. River channels in this area are wide and remain dry during winter and subject to frequent flooding during the monsoon. Several old channels of the recent or distant past are susceptible to occasional flooding (Figure 2.27). Another common process associated with flood hazards in the watershed is inter-basin transfer of water due to channel shifting.

Several old channel courses detected in aerial photographs show that the Ratu Khola system has accommodated the water flow from Jangha Khola in the west and from Bighi Khola in the east in several instances in the past. Similarly, the traces of the old riverbed of the Jangha Khola and Marha Khola show that they formed common drainage in the lower catchments in the past. Recently, since 1998, Jangha River has diverted from its original path to join the Ratu Khola system. Due to these changes in the river course there has been a fluctuation in the basin area contributing water to the lower catchments. Water overflowing the banks during heavy monsoon rain over extensive parts of the lowermost catchment of the Ratu Khola can be attributed to water flowing in from the Jangha Khola to the Ratu Khola near Sarpallo. An interesting feature to note is that this old channel bed seems to be avoided for settlements as these areas are subjected to flooding or are damp for most part of the year. GIS overlay analysis shows that, in most cases, settlements are located along the banks of these channels.

Gently sloping land with traces of fresh sediment from sheet flooding

Gently sloping lands are frequently affected by sheet flooding which is moving rain-borne or water overflow from banks that is not concentrated into defined channels. In the aerial photo and imagery, areas with moderate to thin light grey tones, indicating fresh sediments brought and deposited by running water, were identified and mapped (Figure 2.25). Sheet flooding has been the cause of inter basin flow of water between the Jangha and Maraha kholas in the west, and Jangha and Ratu, and Bighi Khola and Ratu in the east. The cause of the flooding in the Jaleshwar municipality area is sheet flow from the Bighi Khola which is

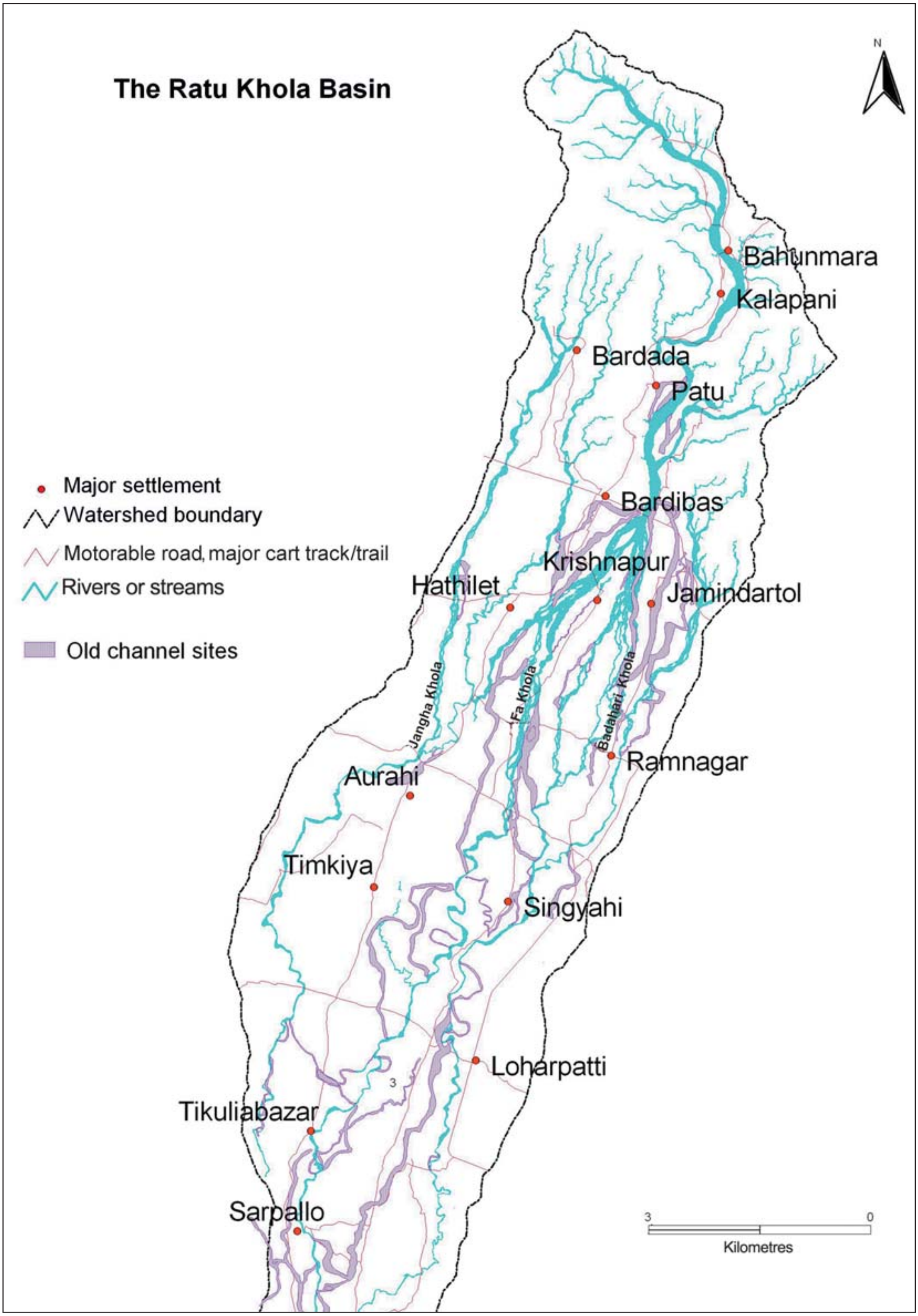

Figure 2.27: **Old river channel courses**

outside the Ratu Khola Basin. Sheet flooding is often attributed to the intervention of infrastructure such as motorable roads, culverts, bridges, and so on, in the natural drainage system. Sheet flooding is also common near the meander bends (convex nooks) of the channels. Overflow from the banks of small, localised streams is another cause for sheet flooding in this area.

Topographic depressions: marsh and water-logged areas

Areas of local depression are another characteristic geomorphic feature of the alluvial plain. Such depressions characterise marshes, swamps, seasonally waterlogged areas, and oxbow lakes. These depressions are clearly identified in the false colour composites of Landsat Thematic Mapper's (TM's) bands 7, 4, and 1 (see above). The dark bluish tone close to channels in this band combination indicates highly moist areas, which are the damp, swamp, and waterlogged areas. Most depressions represent the bed and active floodplain of past channel courses (Figure 2.28). These areas form the accumulation sites or the flow paths for local drainage. Such depression sites constitute 27 sq. km or 10% of the alluvial plain. The Middle Terai alone accounts for 70% of the area (19 sq. km) with such depressions. These areas are also prone to sheet flooding during the rainy season.

River channel banks

Bank cutting is common in the Ratu Khola and the Jangha Khola. Bank cutting is generally active on the convex loop of the channel meander. The slope map showing the topographic break points on the depositional zone shows potential river-bank cutting adjacent to the channel. Such sites, by and large, are more pronounced in the middle and lower Terai where the slope is very low and the rivers are sinuous (Figure 2.29).

Composite flood-hazard map

A composite flood-hazard map was prepared and is presented in Figure 2.30. The Ratu Watershed was classified into four hazard areas – low, moderate, moderately high, and high on the basis of degree of flood hazard. The area of high hazard accounts for more than one-fourth (26%) of the total watershed area and that of low hazard constitutes 52% of the area (Table 2.5). In general, the basin characteristics suggest high hazard for settlement, agricultural land, and infrastructure, thereby posing a serious threat to sustainable livelihoods.

Table 2.5: **Areas by flood-hazard types**

Hazard type	**Area** in (sq.km)	%
Low	276	52
Moderate	63	12
Moderately high	56	11
High	137	26
Total	**532**	**100**

Risk and vulnerability mapping

Because of time and budgetary constraints, it was not possible to collect detailed information on types, characteristics, and socioeconomic value of all the elements in each polygon of flood hazard mapped in the watershed. However, an attempt was made to quantify the risk based on the information available from topographical maps. The elements include houses, built-up areas, infrastructure, and agricultural land.

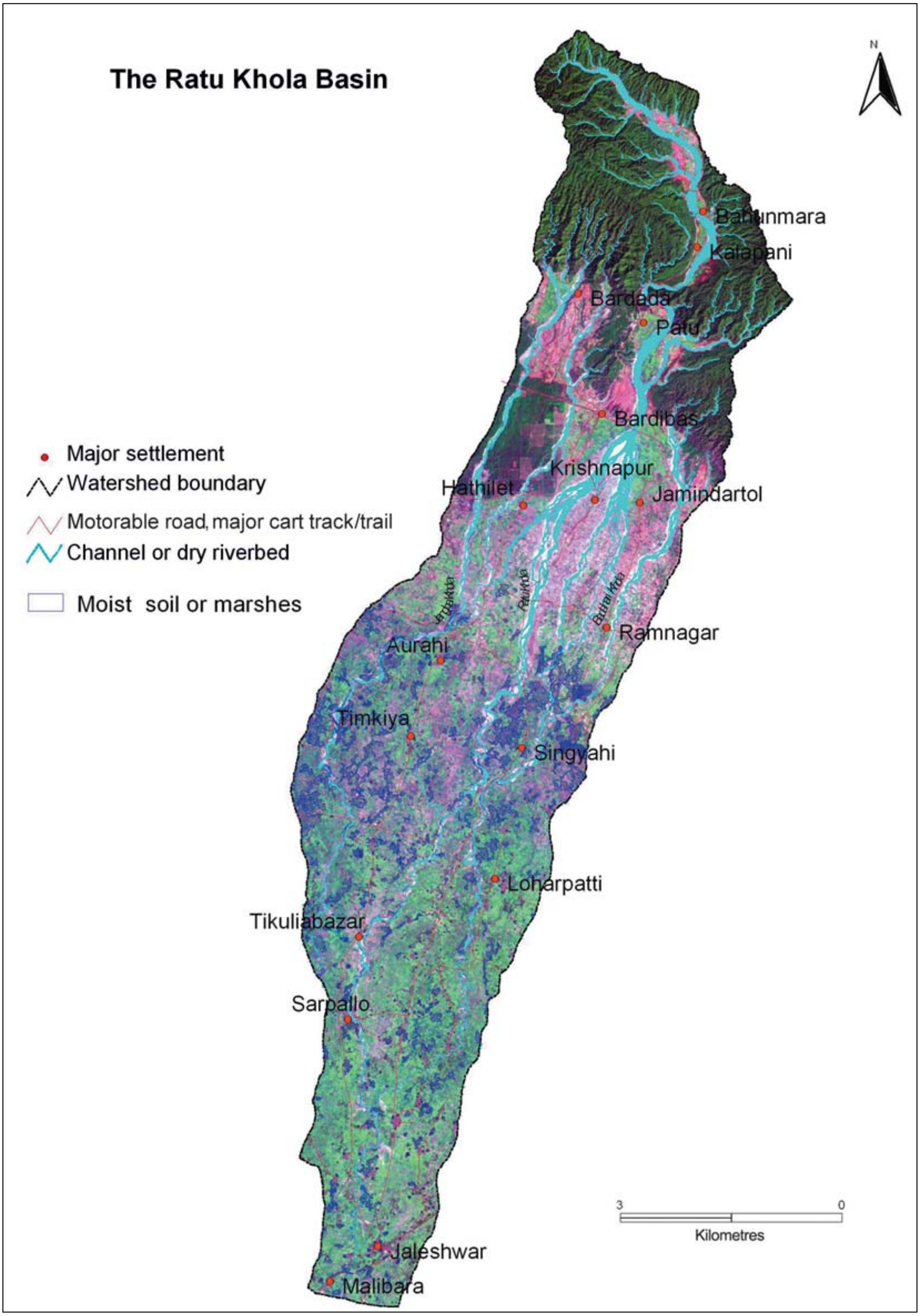

Figure 2.28: **Moist areas and marshes**

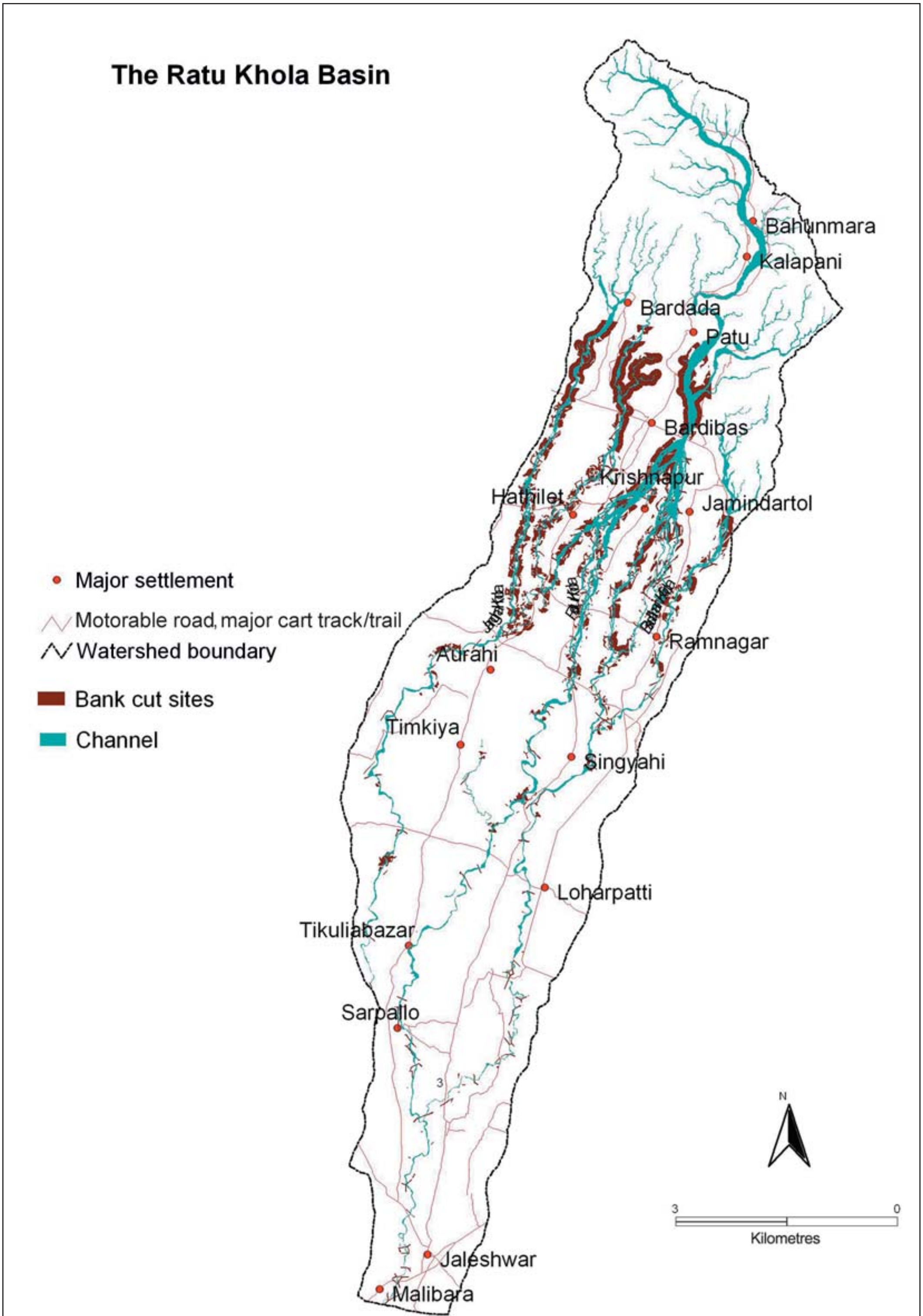

Figure 2.29: **Potential areas of river-bank cutting** (within 200m buffer)

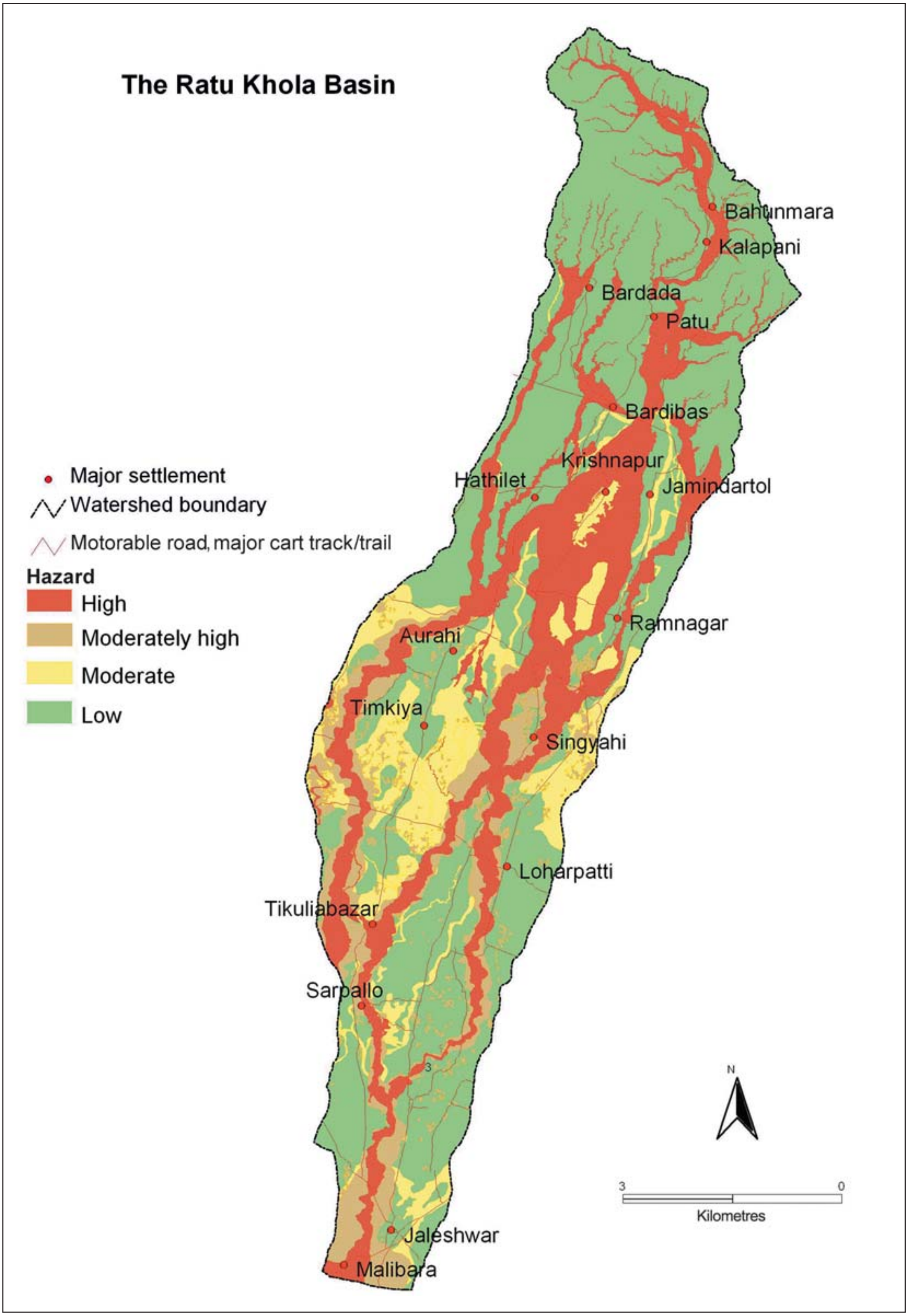

Figure 2.30: **Composite flood-hazard map**

About 17% of house units lie in the high hazard zone, 8% in the moderately high hazard zone, and 60% in the low hazard zone (Figure 2.31). In the high hazard and moderately high hazard zones, 14% and 6% of the area, respectively, is built up. Of the 144 polygons representing built-up areas in the Ratu Khola Basin, 61% are located in the low hazard zone.

Similarly, GIS overlay showed that about 25% (8,853 ha) of the total area of cultivated land (including orchards) lies in the high-hazard zone, and about 15% in the moderately high hazard zone.

As a result of flooding, cultivated land often becomes wasteland, or it takes a long time and is very expensive to reclaim for cultivation. In the middle and lower Terai, however, the damage caused to agricultural land is relatively less severe than that to other valuable infrastructure, as the damage is mostly to standing crops and may cause less damage to the land itself. It is often thought by the local people that the fine silt accumulation during normal flooding adds fertility to the soil. But, quite recently, people have experienced the appearance of coarser materials and decrease in the river depth, causing increased sedimentation problems and river instability. The recent change in the course of the Jangha Khola in Sarpallo region in the lower Terai has converted a large tract of arable land into river bed and wasteland.

Out of a total of 629 points where service infrastructure such as government offices, schools, hospitals, health posts, public buildings, and temples are located in the watershed, about 101 points (16%) lie in the high-hazard zone.

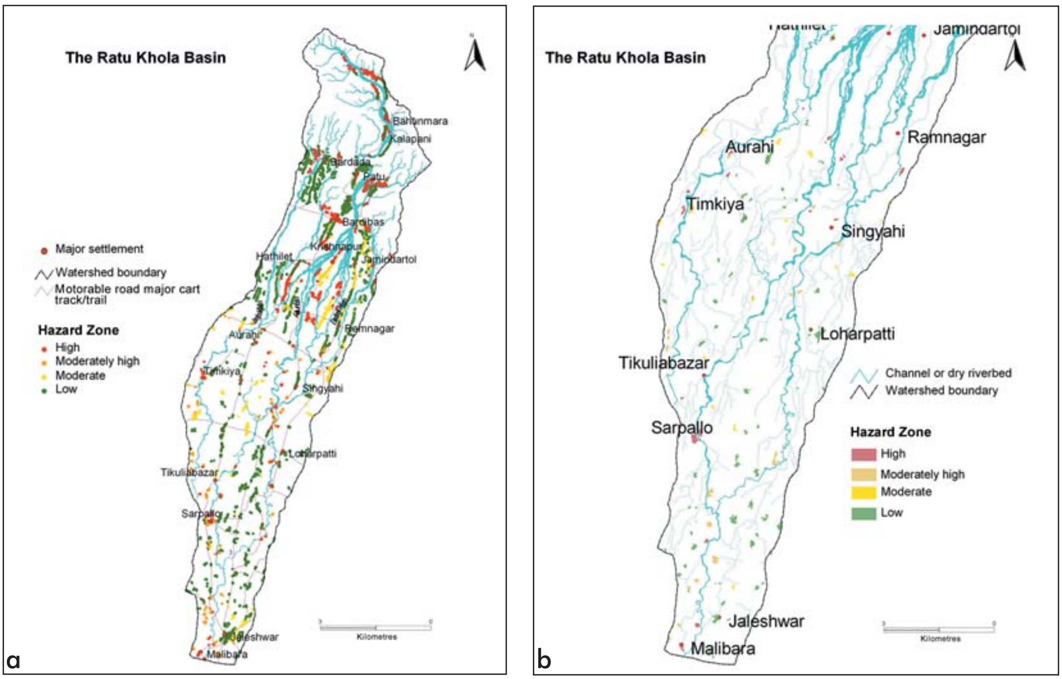

Figure 2.31: **House units (a) and built-up areas (b) at risk from flood hazard**

An attempt was made to assess flood risk induced by the construction of dams, spurs, and embankments of 0.5-1.0m for Ratu Khola on the Indo-Nepal border. DEM analysis shows that an assumed 0.5m or 1m high structure would induce inundation over an area of 9.6 or 16.5 sq. km, respectively. In the former case, about 10 built-up areas and more than 900 ha of cropland would be affected (Figure 2.32). In the latter case about 16 built-up areas and more than 1,500 ha of cultivated land or orchard would be affected. The backwater effect would extend to 5.5 km for both cases.

Flood risk and vulnerability maps of the Ratu Watershed are presented in Figure 2.33. Nearly 18% of the area is at high risk. These areas include the settlement zones in the high and moderately high hazard areas. Agricultural land in the high flood hazard zone can be considered moderate risk zones. This zone comprises about 11% of the basin area. The rest is at low risk.

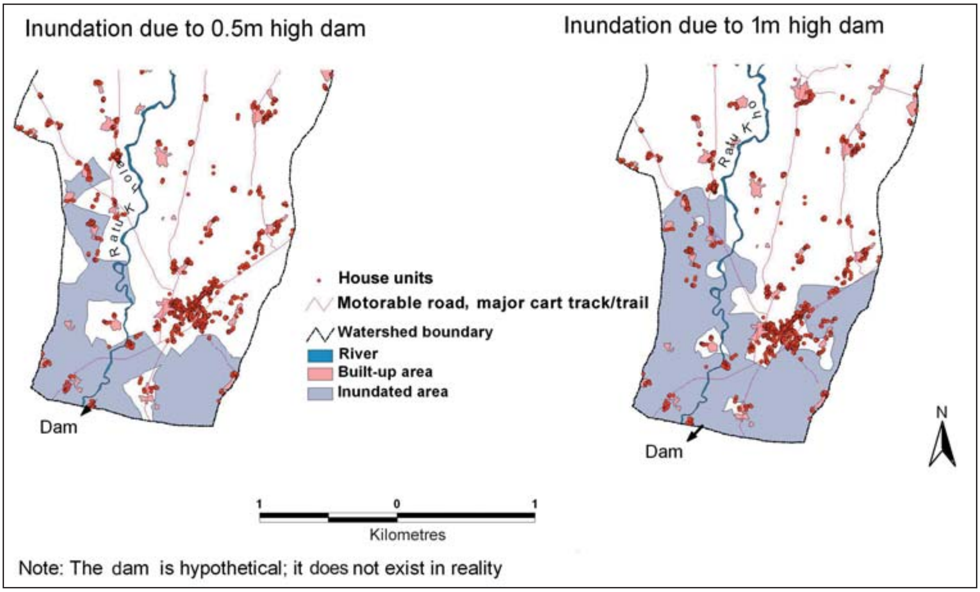

Figure 2.32: **Theoretical inundation due to flow intervention by a structure at the Indo-Nepal border**

Inundation-hazard mapping using the HEC-RAS model

An inundation-hazard map based on HEC-RAS results was prepared for the two- and five-year return flow of both a 50 and 100% discharge on the major channel of the Ratu Khola and is presented in Figures 2.34 and 2.35. The Ratu Khola splits into two channels at the fan head. The east channel is the major channel in terms of water flow. These maps show the inundation is extensive in the lower Terai even in a flood having a two-year return period. The analysis also shows that the extent of inundated area is not significantly different in two- and five-year return period flows. However, the difference in the depth of the flow seems to be significant. Hence, the flood water is accommodated in the same floodplain. Considering the 25-, 50-, and 100-year return period flows, more extensive inundation could be expected causing disaster of a large spatial scale in the lower Terai where drainage is poor and the groundwater level is high.

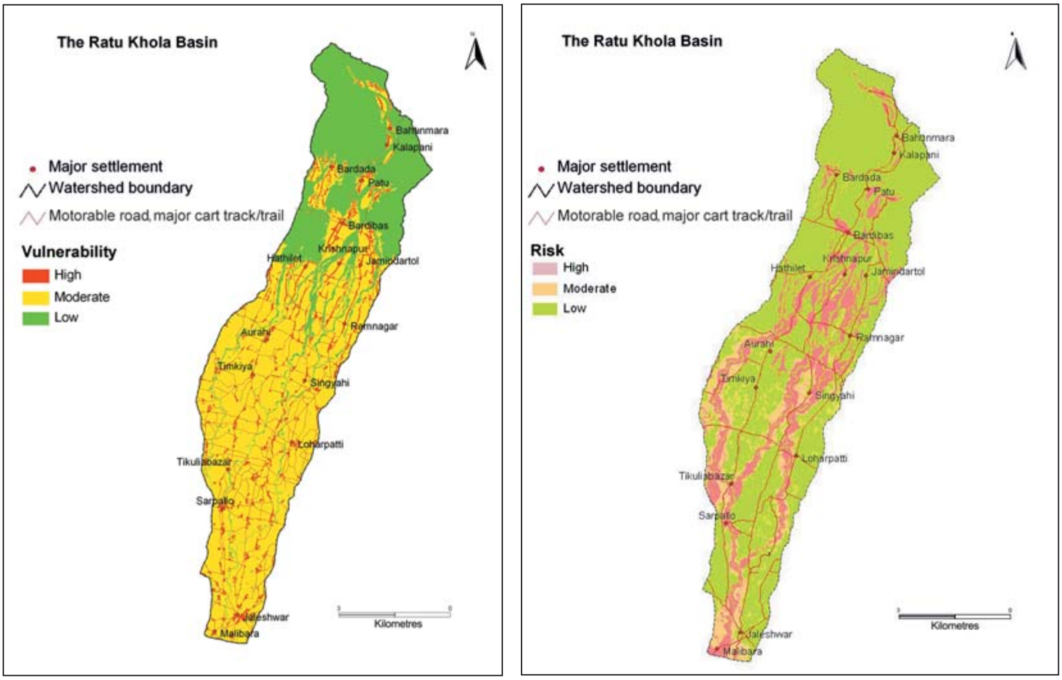

Figure 2.33: **Vulnerability** (left) **and risk maps** (right)

Social flood-hazard mapping by local stakeholders

Flood-hazard maps drawn by local stakeholders with technical help from the research assistants during group discussions in each VDC in the Ratu Watershed were digitised and are presented in Figure 2.36.

Comparative evaluation of flood-hazard maps

Figure 2.36 shows two flood-hazard maps: one prepared by local stakeholders during group discussions and another prepared using GIS and remote sensing with a geomorphic approach. Though the hazard areas seem to be a little exaggerated in the map prepared using GIS and RS, the sites are more or less the same as in the map prepared by the local stakeholders. This shows that GIS and RS can be useful tools for mapping flood hazard, risk, and vulnerability for a large area. Such maps can be improved and validated using local knowledge and experience involving local stakeholders

It is evident that flood-hazard, risk, and vulnerability mapping at pre-feasibility level can be carried out using secondary information from maps, aerial photographs, satellite images, and published and unpublished documents. These maps are useful for developing activities for flood control and management. However, an understanding of the level of socioeconomic vulnerability and the response and resilience of local people is necessary for effective implementation of such activities. It is in this context that an assessment of the flood hazard, risk, vulnerability, and response and resilience has been made in the next chapter.

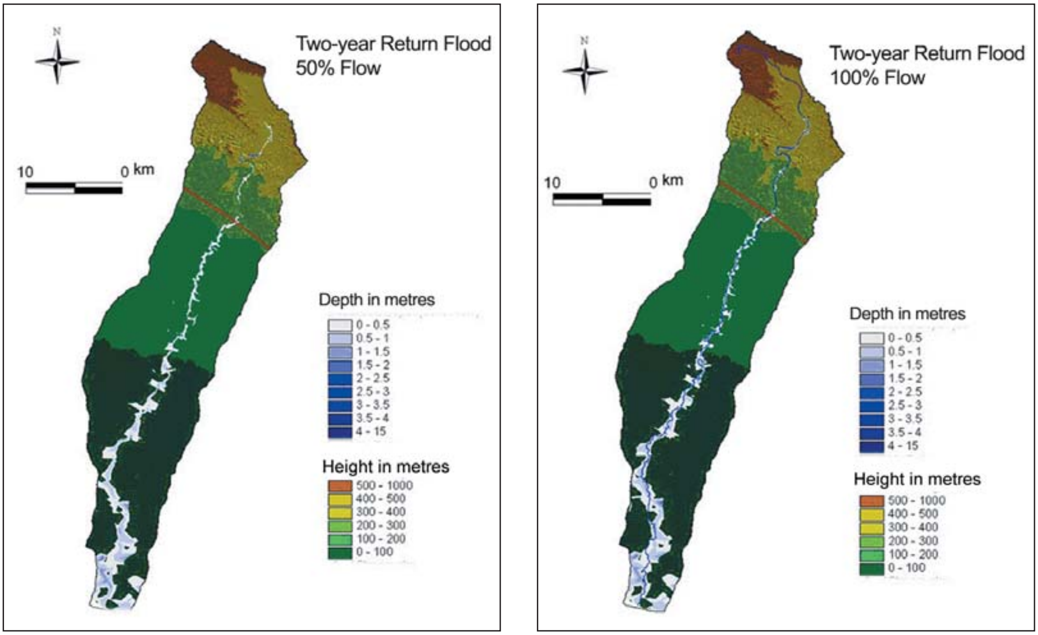

Figure 2.34: **Two-year return flood with 50** (left) **and 100%** (right) **flow**

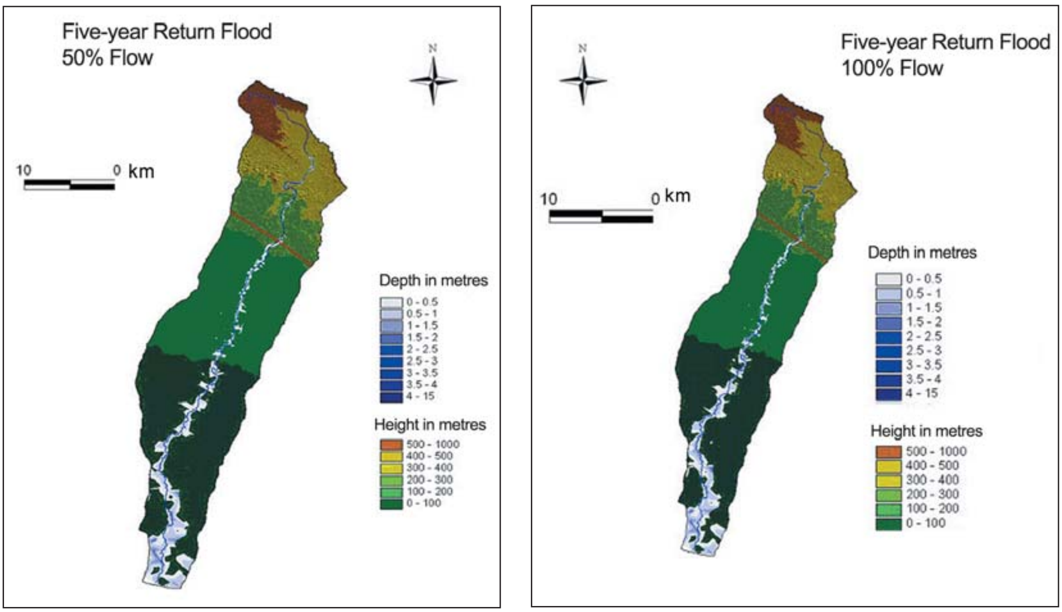

Figure 2.35: **Five-year return flood with 50** (left) **and 100%** (right) **flow**

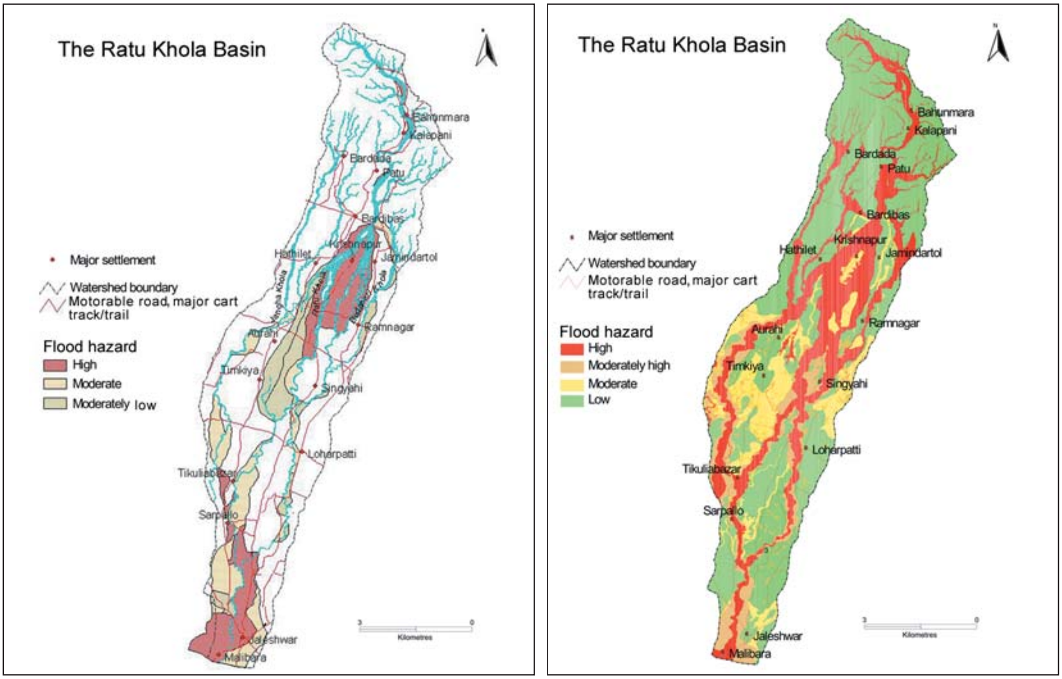

Figure 2.36: **Flood-hazard maps: social** (left) **and geomorphic** (right) **approach**