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Preparing for Flood Disaster

Mapping and Assessing Hazard in the Ratu Watershed, Nepal

Hindu Kush-Himalayan friend

Narendra R. Khanal
Mandira Shrestha
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About the Organisations

The **International Centre for Integrated Mountain Development** (ICIMOD) is an independent 'Mountain Learning and Knowledge Centre' serving the eight countries of the Hindu Kush-Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and the global mountain community. Founded in 1983, ICIMOD is based in Kathmandu, Nepal, and brings together a partnership of regional member countries, partner institutions, and donors with a commitment for development action to secure a better future for the people and environment of the extended Himalayan region. ICIMOD's activities are supported by its core programme donors: the governments of Austria, Denmark, Germany, Netherlands, Norway, Switzerland, and its regional member countries, along with over thirty project co–financing donors. The primary objective of the Centre is to promote the development of an economically and environmentally sound mountain ecosystem and to improve the living standards of mountain populations.

The **International Hydrological Programme** (IHP) is UNESCO's cooperative programme in water research, water resources management, education, and capacity-building, and the only broadly-based science programme of the UN system in this area. In existence for over 30 years now, IHP is committed to developing the science of hydrology at the service of society. Its primary aim is to draw together scientists worldwide in order to establish the scientific and technological bases for the rational management of water resources with respect to water quantity and quality.

The **Hindu Kush-Himalayan Flow Regimes from International Experimental and Network Data project** (HKH-FRIEND), is a regional network for hydrological research and data exchange. It is one of the eight research groups in the International FRIEND Project under UNESCO's International Hydrological Programme (IHP). The project evolved through a series of regional consultations initiated jointly by UNESCO, ICIMOD, and regional countries since 1989 and was formally established in 1996. ICIMOD has provided the Secretariat for HKH-FRIEND since its inception and also houses its Regional Hydrological Data Centre (RHDC). HKH-FRIEND works through collaboration and partnerships – national, regional, and international – and has received financial support from UNESCO/IHP; the German IHP/OHP National Committee; World Meteorological Organization (WMO); Federal Institute of Hydrology, Germany; Department for International Development (DFID) and Centre for Ecology and Hydrology (CEH), UK; and ICIMOD.

The data and information exchange will facilitate research on the hydrology and water resources of the Hindu Kush-Himalayan region and contribute towards improved management of water resources, such as flood forecasting, climate change impacts on water resources, hydropower development, and assessment of fresh water resources, and contribute towards sustainable development of water resources for poverty alleviation in the region.

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Photo credit: Women involved in flood disaster preparedness in the Ratu Khola
– *Mandira Shrestha*

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Foreword

The devastating impacts of floods on local Himalayan communities as well as downstream residents has been an enduring concern for both ICIMOD and UNESCO as well as our partners. Riverine and flashfloods cause more damage to lives, livelihoods, and infrastructure annually than any other natural calamities in the Himalayan region. This has led both ICIMOD and UNESCO to encourage regional collaboration in the study and sharing of mitigation measures on floods as well as river systems and the interaction between the mountain and plains that these rivers induce. One of the platforms that we have created to forge regional cooperation in the region is the HKH FRIEND. Since its inception in March 1996, HKH-FRIEND has been contributing to improve the understanding of the regional water resources and their behaviours in the HKH region.

The advancement in computer-aided and space-based technology such as geographic information systems (GIS) and remote sensing (RS) has proved very useful in studying and mapping the flood-hazards and developing measures that can be useful to the local communities as well.

This study documents the use of flood-hazard mapping as a way of helping communities to devise plans that would help them develop warning and response systems. This allows communities to prepare a management plan that will boost their resilience to mitigate damages and salvage their livelihoods to the extent possible. This is especially critical for the women and poor within these communities who are the ones to suffer the greatest and the ones with the least ability to recover their meager assts.

This study and flood-hazard mapping of the Ratu Khola watershed in Nepal seeks to encourage others to undertake similar work. The results obtained were of direct use to the communities concerned. More importantly, they illustrate an approach that can be used more widely.

This study has been published at a time when the HKH FRIEND has been put through an evaluation and efforts are underway to revamp and reorganise this regional set up.

ICIMOD and UNESCO-New Delhi were pleased to work together in this important project. We hope the study will not only save lives and livelihoods in Ratu Khola but also provide a basis for replication throughout the Himalayan region.

J. Gabriel Campbell
Director General
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We would like to thank Bhanu Neupane, Regional Programme Specialist of UNESCO, for his comments and support. We would also like to express our sincere gratitude to Suresh Raj Chalise and Richard Heggen, who accompanied us in the field study and provided valuable guidance and suggestions. Thanks are also due to Mr. Pradeep Man Dangol of ICIMOD who helped in various capacities in the accomplishment of this study, and Xu Jianchu whose encouragment and guidance helped to make this publication possible. The valuable inputs of the Publications Unit is gratefully acknowledged, especially Greta M. Rana, Consultant Editor, Joyce M. Mendez, who oversaw preparation of the publication, Dharma R. Maharjan, who did the design and layout, and Asha K. Thaku, who helped modify many of the figures and maps. Last but not least, our heartfelt gratitude goes to all the local people who participated in the group discussions and provided us with valuable insights and information.

The Study Team

Executive Summary

Flood hazards, their impact, and the resilience of communities have been assessed here on three spatial scales – national at macro-level, watershed at meso-level, and village development committee/municipality at micro-level. At national level, the impacts from different environmental hazards have been assessed, whereas at watershed level the focus was on hazard, risk, and vulnerability mapping. The Ratu Watershed in the Central Terai (Mahottari and Dhanusa districts) was selected for mapping. At micro-level, the focus was on enhancing the resilience of local people to cope with and recover from flood hazard. Rajbas in the upstream area and Jaleshwar municipality in the downstream area were selected for micro-level activities. The study was coordinated by the International Centre for Integrated Mountain Development (ICIMOD) with support from the United Nations Education, Scientific and Cultural Organization (UNESCO), New Delhi, India.

Floods occur repeatedly in Nepal and cause tremendous losses in terms of property and life, particularly in the lowland areas of the country. Hence, they constitute the main hazard. Floods that cause substantial devastation in Nepal are triggered by five different mechanisms: continuous rainfall and cloudbursts, glacial lake outbursts, landslide dam outbursts, failure of infrastructure, and sheet flooding or inundation as a result of excessive rain, bank overflow, or obstruction to the flow from infrastructural development. Nearly 77% of the total losses caused by water-induced disasters – floods, landslides, and avalanches – occur in the Terai region where the main water-induced disasters are floods. An extremely rugged, diverse, and dynamic mountain landscape; the fact that the country is landlocked; inaccessibility; dispersed human settlements; and a high rate of territorial mobility among the population are the main causes of extreme physical and locational vulnerability to floods and landslide disasters. Moreover, socio-economic conditions characterised by a poor human development profile, low level of economic growth, mass poverty, and a great disparity in the distribution of productive assets and income, in addition to inadequate provision of services and lack of political stability, commitment, and accountability, increase the vulnerability to natural disasters and constrain appropriate response and augmentation of resilience to disasters.

Flood-hazard, risk, and vulnerability mapping in the Ratu Watershed was carried out through three different approaches: a geomorphic approach using a geographical information system (GIS) and remote sensing (RS), measurement of rainfall-runoff processes using the Hydrological Engineering Corporation's River System Analysis (HEC-RAS) model, and social flood hazard mapping based on local experiences. The main sources of information were maps, aerial photographs, selected imagery, household survey and group discussions, field observations, and published and unpublished documents. GIS-based softwares, such as ArcView, the Integrated Land and Water Information System (ILWIS), and the Hydrological Engineering Corporation's River System Analysis [U.S.Army Corps] (HEC-RAS and HEC-GeoRas) were used for data processing and analysis.

Flood risk and vulnerability maps prepared for the Ratu Watershed show that nearly 18% of the area is in the high-risk category. Inundation-hazard maps show that a large part of the area in the south, near the Nepal-India border, is subject to extensive inundation even by floods in the two-year return category. A comparison of hazard maps prepared based on the three different approaches shows that GIS and RS are useful for mapping the flood hazard, risk, and vulnerability of a large area at watershed level.

Flooding, cutting of river banks, and shifting channels, are the most frequently occurring water-induced disasters in the lowland area of the Ratu Watershed. On average, nearly 8% of the total annual household income is lost as a result of floods. Nearly 61% of the households in the watershed are exposed to flood hazards, among them, 21% of the households are situated in high-hazard areas.

The risk of flooding and its associated processes, such as a rise in the river bed, cutting of river banks, and shifting channels, in the Ratu Watershed is great. Moreover, the risk of inundation has increased over recent years because of added infrastructure such as roads and bridges. This is the case not only in Nepal but also in the nearby border area in India.

Responses to flood hazards are confined to rescue and relief during flooding and some mitigation measures such as construction of dams, spurs, retaining walls, plantation, and drainage management. These activities are insufficient, on the one hand, and, on the other, there are no activities or programmes on flood preparedness. People in the locality realise the importance of incorporating components of watershed conservation and drainage management through proper land-use guidelines, income-generating activities, community-based early warning systems, and awareness creation in plans for watershed conservation. They also realise the need for a local institutional network to design and implement such activities.

An attempt was made to develop a community-based early warning system and identify safe evacuation routes and areas safe for shelter in order to improve the local capacity to respond and manage flood hazards during the second phase of the project. In this context, people were trained to read and record precipitation and discharge in upstream areas; and discussions took place on the use of maps of safe evacuation routes and shelters in downstream areas. The benefits of these efforts have yet to be realised through organising and networking to establish an early warning system and by creating awareness.

This publication is a summary of a detailed study on flood-risk and vulnerability mapping of the Ratu Khola using GIS methods. It is divided into four chapters. Chapter One describes the biophysical and socioeconomic characteristics of Nepal, discusses the types, frequency, and magnitude of losses from different types of natural disaster and their spatial concentration with special reference to flood disasters, and assesses the vulnerability to flood hazards in the country. Chapter Two describes flood-hazard and risk mapping in the Ratu Watershed. This chapter provides details of the project area and the methodology for and results of hazard, risk, and vulnerability mapping. Chapter Three gives an account of the assessment carried out on response and resilience in the context of hazard, risk, and vulnerability in the Ratu Watershed. Chapter Four covers the main findings, conclusions, and recommendations.

Acronyms and Abbreviations

AV-RAS	Arc View Extension for River Analysis System
DPI	dots per inch
DTM	digital terrain model
DWIDP	Department of Water Induced Disaster Prevention
FCC	false colour composite
HEC-RAS	Hydrological Engineering Corporation, River System Analysis, US Army Corps
IHP	International Hydrological Programme
ILWIS	Integrated Land and Water Information System
LRMP	Land Resources Mapping Project
JICA	Japan International Cooperation Agency
MBT	Main Boundary Thrust
MCT	Main Central Thrust
RGB	red green blue
RMS	root mean square
TM	thematic mapper
TIN	triangular irregular network
UNDRO	United Nation's Disaster Relief Organization
WECS	Water and Energy Commission Secretariat
WMO	World Meteorological Organization
3D	three-dimensional

Currency Equivalent

US $ 1 = NRs 73.69 (as of 10 September 2006)

Chapter 1

Flood Hazard, Risk and Vulnerability in Nepal: the Physical and Socioeconomic Environment

Ratu Khola downstream of Jaleshwar

Introduction

Floods causing loss of life and property are an annual phenomenon in Nepal. A combination of highly concentrated monsoon precipitation, high relief, steep mountain topography, and deep and narrow river valleys with frequent mass-wasting phenomena renders the country susceptible to flood hazards and disasters. Each year many people are killed and made homeless by floods. Private and public property and expensive and often vital infrastructure are damaged. As a consequence, the overall development of the country has been severely affected by repeated flooding.

In the context of recent global warming phenomena, a consequent increase in the intensity of extreme precipitation events, and the dynamics of glacial lakes in high mountain areas, the probability of potentially damaging floods occurring is likely to increase. The risk that is the expected degree of loss from flood hazard is also likely to increase. The encroachment of areas susceptible to floods to establish human settlements and to carry out infrastructural development in the recent past has increased the exposure of these areas to flood hazards. In the past, before the eradication of malaria in 1956, almost all the river valleys, including areas of the Dun or Inner Terai where the threat of floods is high, were prone to malaria. People used to shuttle between the mountain ridges during the summer monsoon and the lowland areas during winter in order to avoid malaria. This also helped to avoid or reduce the impact of floods. After the eradication of malaria, investment in development of human settlements, other infrastructure, and agriculture in lowland areas increased tremendously and, consequently, so did exposure to flood hazards.

Vulnerability to flood disasters is great. Nepal is a least-developed, landlocked, and mountainous country with limited access to socioeconomic infrastructure and service facilities. Inaccessibility, a low level of human development, and mass poverty are prominent reasons for the poor capacity to anticipate, cope with, resist, and recover from and adapt to different types of hazards, floods being among them. In addition, a high population growth rate, among other factors, has led to increasing poverty. As a result, vulnerability to flood hazards is likely to increase unless effective flood mitigation and management activities are implemented. An understanding of the types, frequency, and magnitude of flood events causing harm to life and property; the extent of loss and damage from such events; and their spatial concentration is necessary in order to develop appropriate mitigation and management strategies to reduce risk and vulnerability to flood hazards.

Physical and Socioeconomic Environment of Nepal

Nepal lies in the middle of the Hindu Kush-Himalayan region. Geographically it is located between 80° 4’ to 88° 12’ east longitude and 26° 22’ to 30° 27’ north latitude, covering an area of 147,181 sq. km. The country is divided into 75 administrative districts classified into three ecological regions – the Mountains, the Hills, and the Terai (Figure 1.1). The topography is extremely rugged with elevations ranging from 60m in the south to 8,848m in the north within a short distance of about 160 km. Different mountain chains extend from east to west. In physiographical terms, the country can be divided into five regions, viz., the Terai in the south, the Siwaliks (Churia), the Middle Mountains, the High Mountains, and the High Himal (Figures 1.2 and 1.3) (LRMP 1986a).

Figure 1.1: **Nepal administrative divisions and ecological regions**

The Terai is the northern extension of the Indo-Gangetic Plain. It covers about 13% of the country's land area with altitudes ranging from 60-300m. The area consists of three major landforms: Upper Piedmont, Lower Piedmont, and the Active Alluvial Plain. The Upper Piedmont is formed of a coalescence of fans made of coarse river deposits lying adjacent to the Siwaliks. The slope of the terrain is relatively steep (1-20°) compared to lower areas of the Terai. Bank erosion, channel shifting, and debris torrents are common. The Lower Piedmont is characterised by pebbly and sandy sediments with a few layers of clay. Spring lines, natural ponds, marshy land, and river meandering are common features. The water table is higher than in the Upper Piedmont. River shifting, bank scouring, and sheet flooding are common here. The Alluvial Plain is a typical Gangetic Plain. It is composed mainly of finer sediments comprising sand, silt, and clay. The water table is generally below four metres. Occasional to severe flooding is common. During heavy monsoons most areas remain inundated or wet for many days.

The Siwaliks or the Sub Himalayas constitute a 10-30 km wide foothill belt which includes the Inner Terai (Doon valleys). This area accounts for about 12% of the total area of Nepal. The Siwaliks have a relative relief of less than 1,000m; the slopes are generally steep with shallow soils. The Siwaliks can be stratified into

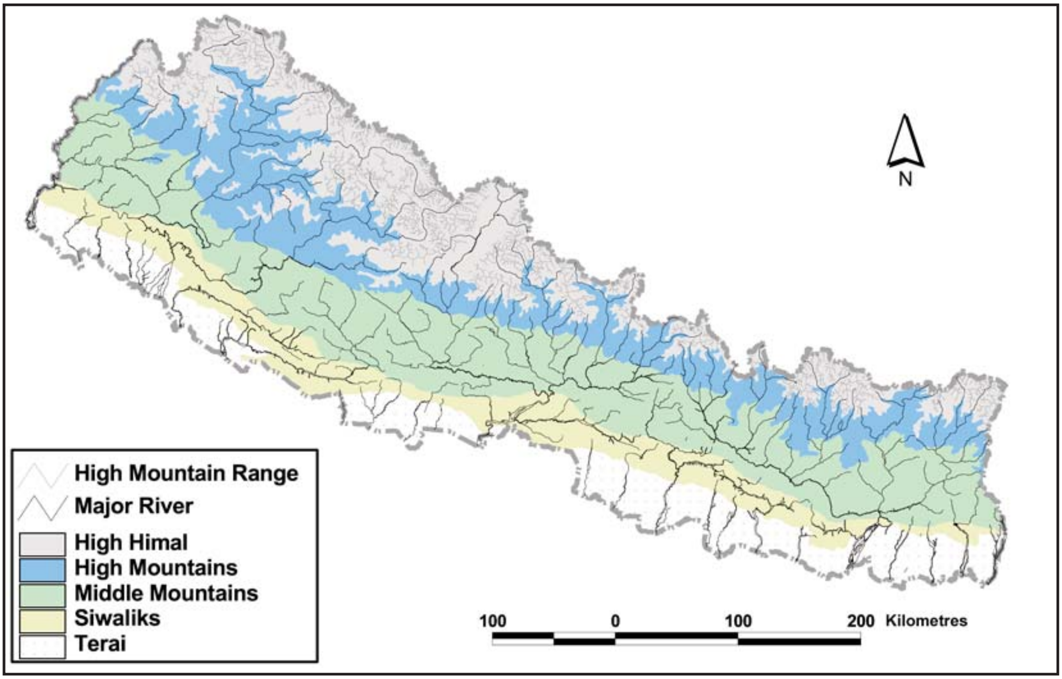

Figure 1.2: **Nepal physiographic regions and drainage network** Source: DWIDP

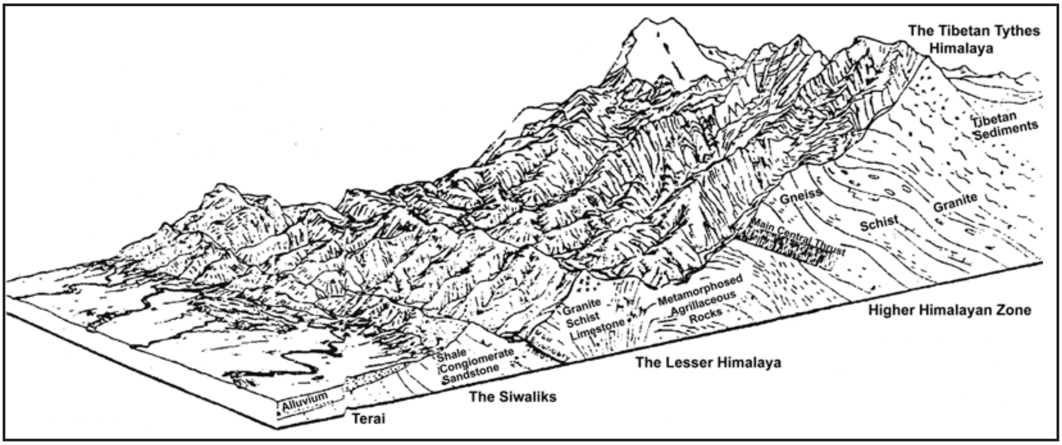

Figure 1.3: **Physiographic regions vis-à-vis major geological formations of the Nepal Himalaya**
Source: DWIDP

three formations: the Lower Siwaliks, the Middle Siwaliks, and the Upper Siwaliks. The Lower Siwaliks consist of hard sandstone with conglomerates containing pebbles of clay and shale, whereas the Upper Siwaliks are composed of coarse conglomerates, sands, grits, and clay. Rivers are extremely flashy; large coarse sediment deposits in a dry river make up a large proportion of the river system. These rivers are extremely unstable and cause immense damage to lives and property every year.

The Middle Mountains, also known as the Lesser Himalaya, cover about 30% of the total area of Nepal. The total width ranges from 60-80 km. These mountains are made up mostly of non-fossiliferous sedimentary and meta-sedimentary rocks such as shale, sandstone, conglomerates, slate, phyllite, schist, quartzite, limestone, dolomite, and others. Two distinct geomorphic units can be identified in the Lesser Himalaya: the Mahabharat Range and the Midland. The Mahabharat Range (lekh) rises fairly abruptly from the Siwaliks to elevations between 1,500 and 3,000 metres above mean sea level (masl). The terrain is rugged with sharp crests and steep slopes. This range also forms the first effective barrier to the monsoon clouds entering the Himalaya and has a considerable influence on the country's rainfall distribution. Due to its steep terrain and rain-bearing flanks, the south-facing slopes of the Mahabharat Lekh are highly prone to landslides, debris flows, and floods. The Midland consists of subdued hills, wide river valleys, and tectonic basins. This zone has an average width of 60 km and the relief ranges from about 1,000-1,500m from the valley bottom to the hilltops. Due to the gentle topography, wide valleys, and warm temperate climate, this zone is densely populated and nearly 40% of the total population of Nepal lives here.

The High Mountains (the Fore-Himalaya or temperate lekh or Higher Himalaya), composed of gneiss, quartzite, and mica schist, cover about 20% of the total area of Nepal. Altitudes range from 2,000 to 4,000m. Topographically, this mountain range has extremely rugged terrain with steep slopes and deeply cut valleys.

The Tibetan-Tethys Himalaya

The Tibetan-Tethys Himalaya or High Himal in the north is composed of gneiss, schist, limestone, and Tethys sediments. It occupies nearly 24% of the total area. The Himal represents four distinct landscape units: the Great Himalaya, trans-Himalayan valleys (Bhot), Tibetan marginal lands, and the Tibetan Plateau (LRMP 1986a; Gurung 2004; Upreti 2001). A large proportion of the Great Himalaya is covered by rock and ice. Snow avalanches, rockfalls, and gully erosion are common geomorphic hazards.

The climate at macro-level is dominated by the summer monsoon and topography plays an important role in creating meso- and micro-level differences (Chalise 2001). Hence, there are pronounced temporal and spatial variations in precipitation. The average area-weighted annual precipitation for Nepal is about 1,630 mm. More than 80% of the total annual precipitation occurs during the summer months (June-September). In extreme cases up to 37% of the mean annual precipitation occurs within 24 hours Spatially, mean annual precipitation ranges from only 163 mm in Lomangthang (Mustang) located in the trans-Himalayan zone north of the Higher Himalayan ranges, to more than 5,000 mm in Lumle (near Pokhara) located in the southern part of the Higher Himalayan ranges. A few isolated pockets of dense precipitation are located in different parts of the country. High intensity precipitation is a characteristic micro-climatic feature which is responsible for the repeated occurrence of devastating floods (Figure 1.4). For example, rainfall exceeding 300 mm within 24 hours, which generally disturbs both hill slope and river channel equilibrium on a regional scale, occurs frequently. Precipitation as high as 540 mm in 24 hours with a peak intensity of 70 mm per hour occurred on July 20, 1993 in Central Nepal, causing a big flood disaster. Several hundred people were swept away and much infrastructure and property damaged (Dhital et al. 1993). A preliminary analysis

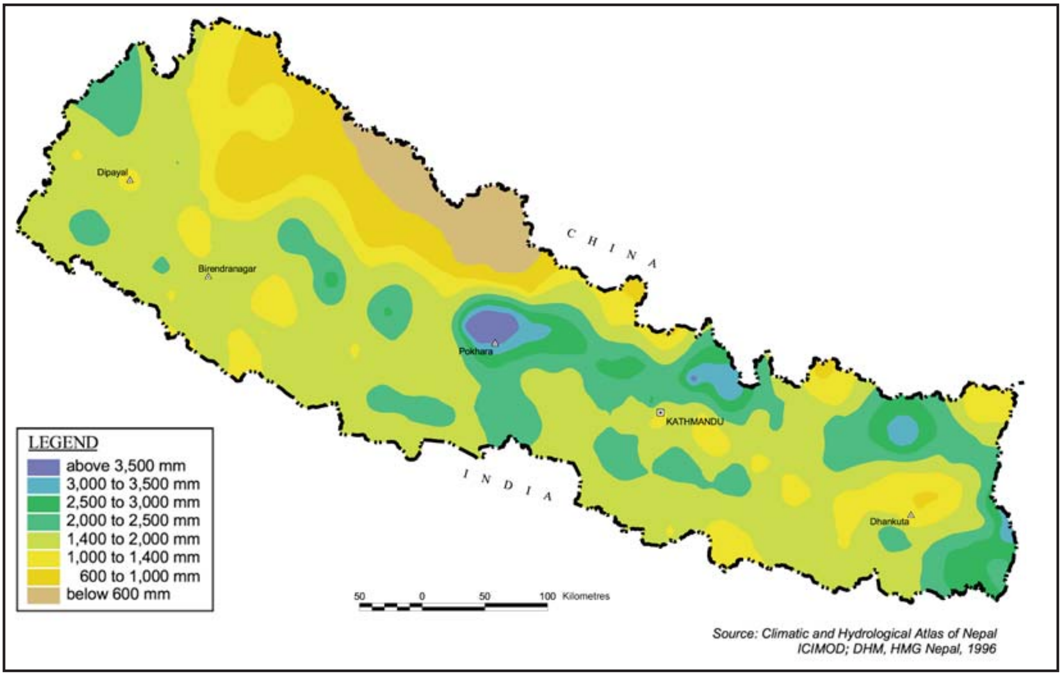

Figure 1.4: **Nepal distribution of mean annual rainfall**

of the frequency of extreme precipitation, with rainfall exceeding 100 mm within 24 hours, occurring between 1971-1990 in the country, indicated an increasing trend in such events in recent years (Chalise and Khanal 2001). This shows that the probability of occurrence of flood hazards has increased.

Nepal has a dense network of more than 6,000 rivers. Some of these rivers originate in the relatively drier Tibetan Plateau in the People's Republic of China to the north. These rivers are antecedent and have crossed high mountain ranges forming deep gorges and narrow river valleys. The total average annual runoff from these river systems is estimated at about 225 billion cubic metres. The rivers are characterised by high water and sediment discharge during summer. In the hydrological cycle, about 64% of all rainfall immediately drains as surface runoff. Inter annual variation in discharge is also very high. Based on temporal variation in water discharge these rivers can be divided into three types: snow-fed perennial rivers originating in the High Himal with low seasonal fluctuation in discharge; groundwater-fed intermittent rivers originating in the High Mountains and the Middle Hills with wide seasonal fluctuation; and ephemeral or flashy rivers with very high width-depth originating from the Siwalik (Churia) hills in the south. River channels in the Inner Terai and the Terai regions are extremely unstable and various forms of channel shifting, such as avulsion, chute-off, neck-off, and meander shift, are common.

According to the Population Census of 2001, Nepal had a total population of 23.15 million. Nearly 7.3% of the population lives in the northern Mountain Region, 44.3% in the Middle Hills, and 48.4% in the Terai region (CBS 2002). Population density ranges from 33 persons per sq. km in the Mountain Region to 167 persons per sq. km in the Middle Hills, and 330 persons per sq. km in the

Terai Region. The annual growth rate in population remained 2.25% between 1991 and 2001. It is comparatively high (2.62%) in the Terai region. Family size is rather large (5.4 persons) and the joint family system is common in many rural areas. There is wide cultural diversity with more than 100 ethnic/caste groups having their own distinct language and culture. The overall literacy rate for the population six years and above is still low at 54.1%; 65.5% for males and 42.8% for females.

Agriculture is the main source of income for the majority of people. More than 80% of the workforce is engaged in agriculture. However, agriculture is still subsistence-oriented and characterised by low input use and low productivity. Employment in agriculture is mostly seasonal and many people (50%) are underemployed. Nearly 8% of the total labour force is unemployed. Poverty is widespread with around 38% of the population living below the poverty line. More than one-third of all households have temporary (kachhi) houses constructed with non-durable materials like wooden matting, bamboo, straw/thatch, and mud which are highly susceptible to flooding. Sanitation is another important concern in rural areas. Only 47% of households have toilet facilities. Households with modern means of communication such as radio and television, are few: 53.1% and 23.5%, respectively. Access to social services, such as schools, health centres, and modern means of transport, is very limited. It takes several days to reach the road from many rural settlements.

Types, Magnitude, and Frequency of Natural Disasters in Nepal

The most frequent hazards causing tremendous losses in lives and property are floods, landslides, avalanches, hailstorms, windstorms, lightning, earthquakes, fire, and epidemics. On average, natural disasters take a toll of 951 lives and damage property worth NRs 1,242 million every year (Table 1.1). The actual figure is thought to be higher because the available statistics do not cover every disaster, particularly those in remote mountain areas, and do not include drought, frost, soil erosion, bank erosion, and so forth; and the impact of these are not immediate but over time they cost a great deal. In addition, most disaster reporting is biased towards human casualties.

Table 1.1: Average annual loss of life and property from natural disasters, 1983-2005

Types of Disaster	Loss of life		Families affected		Loss of property	
	No.	%	No.	%	million Rs	%
Floods, landslides and avalanches	309	32.5	27,654	69.7	749.58	60.3
Hailstorms, windstorms and thunderbolts	34	3.5	4,845	12.2	40.86	3.3
Earthquakes	32	3.3	2,979	7.5	228.54	18.4
Fire	52	5.5	3,192	8.0	223.45	18.0
Epidemics	524	55.2	982	2.5	0.00	0.0
Total	**951**	**100.0**	**39652**	**100**	**1242**	**100**

Source: compiled from *The Annual Disaster Review* (different issues), DWIDP

Of the different types of disaster, the overall impact caused by floods, landslides, and avalanches is most severe. Between 1983 and 2005, an average of 309 people died annually, which is lower only than the deaths caused by epidemics, i.e., 524 lives per year (Table 1.1). The loss of life from floods, landslides, and avalanches is about 32% of the total deaths (Figure 1.5).

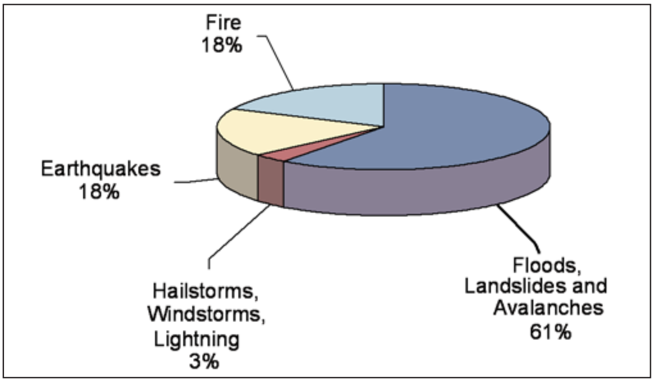

Figure 1.5: **Loss of life from different natural disasters in Nepal, 1983-2005**

Similarly, every year on average, more than 27,654 families are affected by these hazards. They represent about 70% of the total families affected by all types of natural disaster in Nepal (Figure 1.6). The average number of families affected annually by earthquakes and fire is more or less equal (8% of the total families affected by all types of disaster). Many families are also affected by hailstorms, windstorms, and lightning. They account for about 12% of the total families affected by all types of disaster.

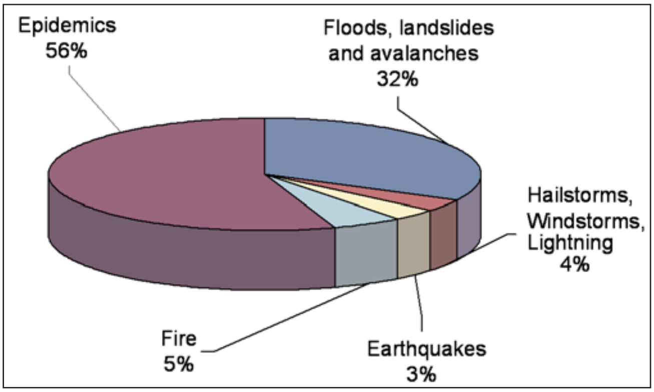

Figure 1.6: **Families affected by different natural disasters in Nepal, 1983-2005**

Annually, property worth more than NRs 749.58 million is lost from floods, landslides, and avalanches. Loss of property from all these types of disaster combined accounts for about 61% of all types of natural disaster in Nepal (Figure 1.7). Although the loss of life and property from earthquakes in a particular year remains quite high, the average loss over the long term is greater from floods and landslides. Nearly 18% of the total amount of property lost is from fire, which is more or less equal to the losses from earthquakes.

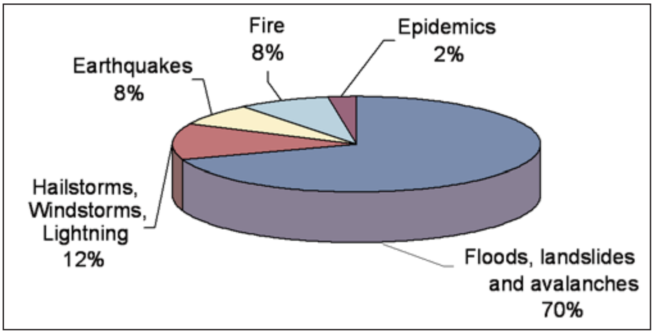

Figure 1.7: **Estimated amount of property lost, 1983-2005**

Floods

In Nepal, devastating floods are triggered by different mechanisms which can be classified into five major types: i) continuous rainfall and cloudburst, ii) glacial lake outburst floods (GLOFs), iii) landslide dam outburst floods (LDOFs), iv) floods triggered by the failure of infrastructure, and v) sheet flooding or inundation in lowland areas due to an obstruction imposed against the flow (Dixit 2003; Khanal 2005).

Continuous rainfall and cloudburst

Floods are common throughout the country in the latter stages of the summer monsoon when the land is saturated and surface runoff increases. Extremely high intensity precipitation in mountain areas cause landslides on mountain slopes and debris flows and floods along the river valleys. Extreme precipitation events between 1948 and 1955 caused landslides and debris flows in mountain areas and, consequently, destructive floods on many rivers in lowland areas. The highest flood recorded occurred on the Kosi River in 1954 and was the result of widespread rainfall in its mountain catchment area (Dixit 2003). Livelihood options for many families in mountain areas were threatened. As a response, the government began resettlement programmes in the Inner Terai and Terai regions in 1956 for severely affected families. At the same time, spontaneous large-scale migration from the mountains to the Terai and from ridge to river valleys took place immediately after these events and concomitant implementation of a malaria eradication programme in the lowland areas (Khanal 2004).

In recent years, between 1981 and 1998, three events of extreme precipitation with extensive damage have been reported (Chalise and Khanal 2002). Devastating floods associated with high intensity precipitation and consequent landslide and debris flow activities in the mountain terrain occurred in Lele (Lalitpur district) on September 30, 1981; in Kulekhani-Sindhuli area on July 19-20, 1993; and in Syangja district on August 27, 1998. In the 1993 event, the loss of life and property was not confined to the mountain areas where high-intensity precipitation had taken place; hundreds of people were also swept away in downstream areas as far away as Rautahat and Sarlahi districts in the Terai.

Glacial lake outburst floods (GLOFs)

Glacial lakes are common in the High Himal area of Nepal. A recent study shows that there are 3,252 glacial lakes in Nepal (Mool et al. 2001). Altogether 21 GLOF events were identified, of which 13 occurred in 34 years between 1964 and 1998. Out of 21 GLOFs identified, nine occurred in the Tibet Autonomous Region (China) affecting downstream areas along transboundary rivers like the Sunkoshi, Arun, and Trisuli in Nepal. A GLOF in 1981 damaged a hydropower plant and many houses along the Sunkoshi River and a similar event in 1985 swept away three persons, one hydropower plant, 14 bridges, and 35 houses along the Dudhkoshi River. Nearly 26 glacial lakes are identified as potentially dangerous and much of the infrastructure along the rivers originating from these lakes is at immediate risk.

Landslide dam outburst floods (LDOFs)

Formation of temporary lakes due to landslide damming is a common phenomenon in high mountain areas where there are very narrow river channels and steep mountain slopes. Eleven disastrous floods caused by breaching of landslide dams have been reported in Nepal between 1967 and 1989 (Khanal 1996). Budhigandaki River near Lukubesi in 1968, Sunkoshi River near Barhabise in 1982, Balephi Khola in Sindhupalchok in 1982, and Gyangphedi Khola in Nuwakot in 1986 were dammed by landslides and resultant outburst floods swept away many people and damaged infrastructure, including human settlements.

Floods triggered by infrastructural failure

Floods triggered as a result of poor infrastructural design are also common in Nepal. Eight floods from such causes have been reported. Failure of checkdams and embankments in Butwal in 1981 led to 41 people, 120 houses, and one bridge being swept away. Similarly, 26 people and 880 houses were swept away by a flood triggered by the failure of a checkdam on the Rapti River in Chitwan in 1990. In 1993, the Bagmati River was dammed for a few hours because of blocking by tree logs at the Bagmati barrage and an outburst flood swept away 816 people in Rautahat and Sarlahi districts. Larcha River was dammed by a boulder at the bridge over the highway in 1996 and an outburst flood swept away 54 persons and damaged 22 houses.

Sheet flooding

Sheet flooding or inundations are common during the summer monsoon in lowland areas in the southern Terai region. The risk of such hazards has been increasing in recent years as a result of increasing development of infrastructure such as roads, culverts, and checkdams, and consequent obstruction in the natural flow of surface runoff. Moreover, unilateral construction of roads perpendicular to natural flow without sufficient drainage and construction of barrages, dams, afflux bunds, and dykes on the rivers near the border area between India and Nepal have also exacerbated flooding in Nepal (Bhusal 2004). More than 10 cases of such infrastructure-induced flood disasters have been reported near the border area.

Information on losses from the different types of flood hazards mentioned above is not available. The information available is in combination with floods, landslides, and avalanches at district level. Table 1.2 shows the losses from floods, landslides, and avalanches in combination between 1983 and 2005. Annual deaths from floods, landslides, and avalanches in the recorded history of 23 years ranged from 49 to 1,336, with an annual average of 309 persons. Similarly, the number of persons injured ranged from 4 to 265 with an annual average of 68 persons. Another important element of loss is livestock. Figures ranged from 36 to 25,425 with an annual average of 2,161 livestock lost. Damage to houses ranged from 88 to 33,721 with an average of 7,241 houses destroyed annually. Similarly, the number of families affected by these hazards ranged from 545 to 128,540 with an annual average of 27,654 families. The estimated area affected ranged from 135 ha to 41,867 ha with an annual average of 3,914 ha. Data on the loss of infrastructure are scant; there has been no record for many years. However, earlier data show that the amount of infrastructure damaged by floods and landslides ranged from 25 to 869 structures with an average of 86 per annum. Estimated loss of property within this period ranged from NRs 10.78

Table 1.2: **Losses from floods, landslides, and avalanches, 1983-2005**

Year	Deaths (No.)	Injured (No.)	Livestock lost (No.)	Houses destroyed (No.)	Families Affected (No.)	Land Affected (ha)	Infrastructure damaged (No.)	Estimated losses (In million NRs)
1983	293	NA	248	NA	NA	NA	NA	240.00
1984	363	NA	3114	7566	NA	1242.00	869	37.00
1985	420	NA	3058	4620	NA	1355.00	173	58.10
1986	315	NA	1886	3035	NA	1315.00	436	15.85
1987	391	162	1434	33721	96151	18858.00	421	2000.00
1988	342	197	873	2481	4197	NA	NA	1087.00
1989	700	4	2979	6203	NA	NA	NA	2528.61
1990	307	26	314	3060	5165	1132.00	NA	44.00
1991	93	12	36	817	1621	283.00	25	21.20
1992	71	17	179	88	545	135.00	44	10.78
1993	1336	163	25425	17113	85254	5584.00	NA	4904.00
1994	49	34	284	569	3697	392.00	NA	59.00
1995	246	58	1535	5162	128540	41867.28	NA	1419.00
1996	262	73	1548	28432	37096	6063.40	NA	1186.00
1997	87	69	317	1814	5833	NA	NA	102.00
1998	273	80	982	13990	33549	326.89	NA	969.00
1999	214	92	331	2543	9769	182.40	NA	365.00
2000	173	100	822	5417	15617	888.90	NA	932.00
2001	196	88	377	3934	7901	NA	NA	251.10
2002	441	265	2024	18181	39309	10077.50	NA	418.91
2003	232	76	865	3017	7167	NA	NA	234.78
2004	131	24	495	3684	14238	321.82	NA	219.28
2005	162	34	588	1103	2130	NA	NA	137.81
Average*	309	83	2161	7570	27654	5627	328	750

* Average for years for which data are available (values would be lower if there was no loss in the years for which no data is available)

NA = no data available; Note: Figures rounded to the nearest whole number

Source: Compiled from the *Annual Disaster Review*, different series published by DWIDP million to 4,904 million with an average of 750 million annually. On average, the losses from floods and landslides are almost 0.6% of the GDP at current prices (2006), 3% of the total budget, 4.7% of total development expenditure, and 14.9% of foreign loans.

The estimated loss of life and property between 1983 and 2005 is shown in Figure 1.8. The loss fluctuated year by year and there is no clear trend. In one particularly bad year (1993), deaths of 1,336 persons were recorded, and the country's economy was badly ravaged. The estimated loss was equal to approximately 3% of the GDP, 23% of development expenditure, Losses unaccounted for from disruption in transportation, power and water supplies, and normal business were also discouraging. The government has to spend large amounts of money every year in relief and reconstruction activities. On average 12.9% of the development expenditure of Nepal and 5.39% of its real GDP are spent on disaster response and recovery activities every year (Li and Behrens 2002).

Since there are no separate statistics recorded for flood disasters in Nepal, the extent of flood disasters in the country can be inferred from the loss of life and property in the Terai districts where the impact of landslides and avalanches is almost absent. Table 1.3 shows the losses from floods, landslides, and avalanches by ecological regions in Nepal between 1992 and 2001. Though the loss of human lives from floods in the Terai is not as high as those in other ecological regions of Nepal, the damage to and loss of property are significantly high. The amount of damage and loss of property caused by floods in the Terai is 77% of the total loss due to floods, landslides, and avalanches combined from 1992-2001. During this period, the loss of housing, livestock, and farmland in the Terai was about 85, 71, and 69% of the total, respectively. Similarly, the number of families affected by floods was 70% of the total. It is difficult to quantify the losses and damage caused by floods or landslides separately in the Hill and the Mountain districts; the impact of floods, even in these districts, is significant. Hence the statistics indicate that the scale of disasters from flood hazards is very high. Coupled with rapid population growth and a high incidence of poverty and

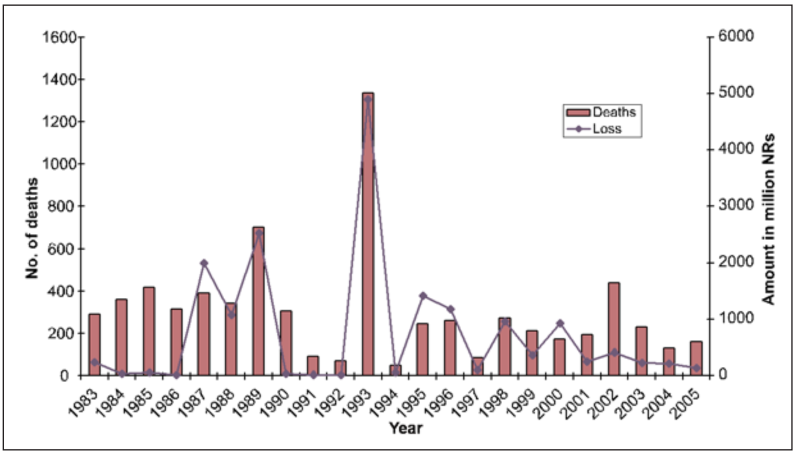

Figure 1.8: **Annual loss of life and property from landslides, floods, and avalanches**

Table 1.3: **Losses from floods and landslides by ecological region, 1992-2001**									
Ecological region	Loss of lives (No.)	Persons injured (No.)	Houses destroyed partly (No.)	Houses destroyed completely (No.)	Cattle sheds destroyed (No.)	Families Affected (No.)	Loss of farmland (ha)	Loss of livestock (No.)	Amount lost (million (Rs)
Hills	1,488	413	7,941	12,510	1,380	80,475	37,283	7,214	4,053
Mountains	323	103	373	1,346	104	10,072	32,45	1,742	466
Terai	1,002	117	47,887	44,292	1,248	221,232	878,70	22,233	15,443
Total	**2,813**	**633**	**56,201**	**58,148**	**2,732**	**311,779**	**128,399**	**31,189**	**19,962**

Note: Total figures are rounded to the nearest whole number
Source: Compiled from *Annual Disaster Review*, different series published by DWIDP

landless and marginal farmers, the vulnerability in the Terai is high. Figure 1.9 shows the frequency of floods and landslides by district, and the annual number of deaths, families affected, and estimated losses from floods and landslides. Although the loss of life is comparatively low in the Terai districts where floods are the major natural disasters, the extent of impact in terms of the number of families affected and loss estimated is very high. Districts located in the central Terai, such as Rautahat, Sarlahi, Mahottari, and Dhanusa, are seriously affected by floods. A comparison made by Khanal (2005) of the loss and damage between 1970 and 1993-2002 shows that the central and eastern Terai have been experiencing increasing losses from water-induced disasters in the years after 1992. Again in the central Terai, Rautahat, Sarlahi, Mahottari, Dhanusa, and Sindhuli districts have been repeatedly and seriously affected by floods.

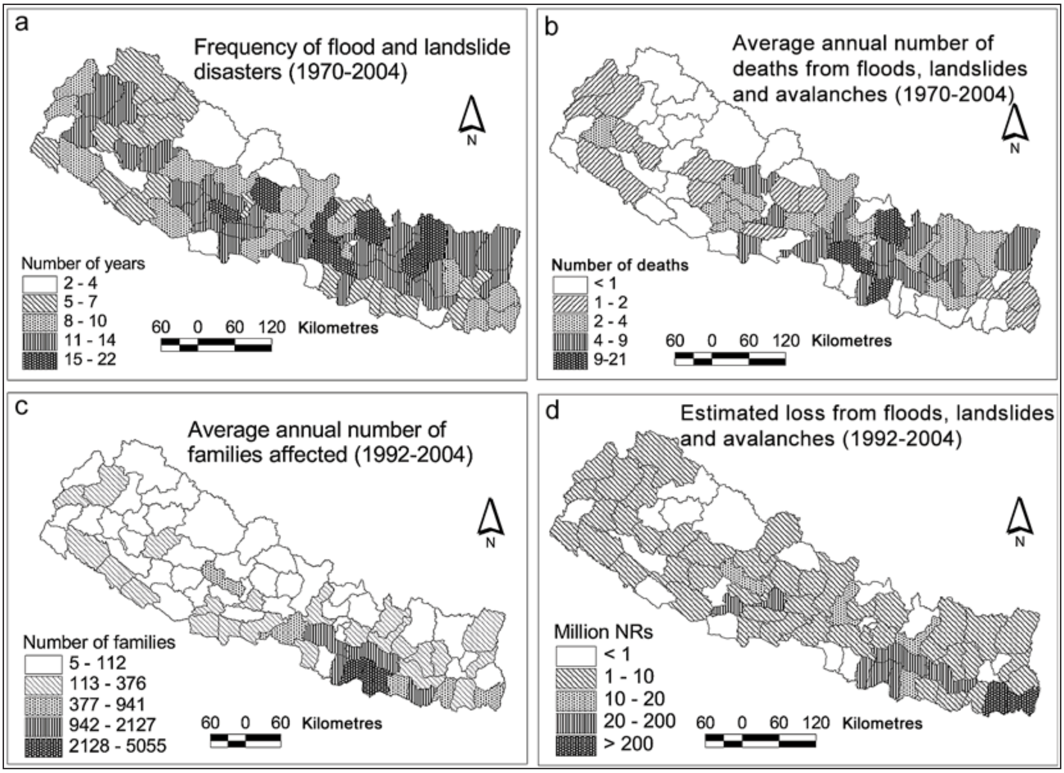

Figure 1.9: **Frequency of flood and landslide hazards and impact by district** Source: DWIDP

Vulnerabilty

Various definitions of vulnerability have been provided in the context of natural hazards and climate change (Varnes 1984; Blaikie et al. 1994; Twigg 1998; Kumar 1999; Kasperson 2001). From these definitions, vulnerability can be viewed from the perspective of the physical, spatial or locational, and socioeconomic characteristics of a region. Physical vulnerability could be referred to as a set of physical conditions or phenomena, such as geology, topography, climate, land use and land cover, and so forth, which renders a place and the people living there susceptible to disaster. The technical capacity of the built-up environment to handle the impact of a natural hazard is also a factor of physical vulnerability. Spatial vulnerability is closely related to physical vulnerability. The degree of danger or threat and the levels of exposure and resilience to threat are closely associated with location. Hence, spatial vulnerability is a function of location, exposure to hazards, and the physical performance of a structure, whereas socioeconomic vulnerability refers to the socioeconomic and political conditions in which people exposed to disaster are living. These vulnerabilities at national level are briefly discussed below.

Physical and spatial vulnerability

Different factors are responsible for physical and spatial vulnerability to flood hazards in Nepal. These factors are discussed below.

Extremely dynamic landscape

Nepal is situated in a high-energy environment because of its rugged relief, steep mountain slopes, active tectonics, highly concentrated precipitation, and intense human activities in landscapes associated with high growth and density of human and livestock populations, along with a subsistence agricultural economy. As a result, the rate and magnitude of occurrence and operation of geomorphic processes are high. Landslides, erosion, debris torrents in the hills, and rises in bed level due to excessive sediment loads in the rivers and the shifting of river channels in the Terai are typical geomorphic processes during the summer rainy season. Both accumulation of snow as a result of the availability of moisture in the atmosphere, and melting due to high temperatures, take place simultaneously during summer. Snow avalanches, intense glacial erosion, and formation and outburst of glacial lakes are common phenomena in the High Himal area. In periglacial areas, freezing and thawing of ground surfaces are common processes resulting in increased physical weathering and rupturing and dislocating of rock blocks leading to rockfall. These processes are responsible for the production of huge amounts of transported hill-slope materials and increased sediment loads in rivers. The highest global rate of sediment production has been reported for Himalayan river basins such as the Kosi, Narayani, and Karnali (2,000-5,000 tonnes km^{-2} $year^{-1}$). Similarly, rivers originating in the Siwaliks adjacent to the Terai region, such as the Tinau, Rapti, Bagmati, Kamala, and Lothar, carry disproportionately huge sediment loads. Immense fans formed by Himalayan rivers in the foothills indicate a high degree of sediment production and transport in upstream areas due to intense mass-wasting. The frequent seismic events and excessive rainfall make the terrain susceptible to erosion, landslides, debris flows, channel shifting, and sedimentation, and these are responsible for excessive sediment loads in the rivers. This increases water levels in the rivers and risk and vulnerability to floods.

Inaccessibility

Access to infrastructural services such as transportation, communications, health, marketing, and other extension services like education, skills development, and so on, plays an important role in all stages of flood-hazard mitigation and management: pre-disaster preparedness, during disaster evacuation and relief activities, and post-disaster rehabilitation and recovery. Nepal, being a landlocked country bordered by China in the north and India in the south, east, and west, does not have easy access to other countries via land and water transportation. This has created problems in the timely flow of goods and services, and the ability to take advantage of cheaper means of transportation. Moreover, Nepal's rugged topography has constrained the development of service infrastructure. Many areas are not yet connected by any modern means of transportation. The development of water and railway transportation in the country is insignificant. Even the road network is very poor. As of 2003 there was a total road length of 16,835 km out of which 28% was black topped, 27% gravelled, and 45% earthen (CBS 2005). The country's road density is only 11.4 km for an area of 100 sq. km and 7.2 km for every 1,000 people. However, its development is not uniform in all regions. Out of 75 administrative districts, 16 districts located in the mountain region are not connected by any type of road. Though the density of roads in terms of area in the Terai districts, which are highly prone to flood hazards, is comparatively high, a large proportion of roads are earthen and most of them are closed during the rainy season when flooding occurs. Improvements in accessibility through developing the road network is an essential prerequisite to reducing vulnerability to different types of hazard. Notwithstanding the absence of proper design, lack of road maintenance has increased vulnerability to landslides and floods. Poorly designed roads without regular maintenance have created serious problems in the form of landslides and erosion in mountain areas, and insufficient drainage along the roads has exacerbated inundation in the Terai.

Declining access to physical assets

Agriculture is the main economic activity in Nepal. Access to physical assets, particularly land and land-based resources, has declined and continues to decline with population growth. The quality of resources has been deteriorating. The result has been encroachment on marginal lands prone to soil erosion, landslides, and floods. The land capability survey (LRMP 1986) shows that about 67% of the land is unsuited to cultivation and human settlement due to different biophysical conditions. Geographical information systems (GIS) overlay analysis of the land utilisation and land capability map prepared by the Land Resources Mapping Project (1986) and carried out by Kenting Earth Sciences and the Government of Nepal indicates that about 30% of all hill slope cultivation is carried out on unsuitable land, increasing vulnerability to erosion, landslides, and debris flows. About 21% of lowland cultivation lies in flood-prone areas.

Widely-dispersed human settlements and migration

Human settlements in mountain areas are widely dispersed and small in size. In the past, security issues from the perspective of avoidance of wars and diseases, as well as access to food, water, and energy, were considered important factors in the development of human settlements. Hence, many permanent settlements, particularly in mountain areas, were developed on stable mountain slopes to avoid the malaria in lowland areas. The size of settlements was determined by the capacity of physical assets in the surrounding area to fulfil the needs of the encapsulated settlement and its population. However, the rapid growth in population and increasing pressure on available resources, on the one hand, and eradication of malaria from lowland areas, on the other, led to the emergence and expansion of human settlements in lower river valleys in the mountains, the Inner Terai, and the Terai. Both immigration from outside the country and in-migration in the Nepal Terai from the hills and mountains remained high since the 1950s. Evidence of this can be seen from the increase in population in the Terai from 35.2% in 1952/54 to 36.4% in 1961, 37.6% in 1971, 43.6% in 1981, 46.7% in 1991, and 48.4% in 2001 (Pantha and Sharma 2003).

The rapid rate of population growth has led people to encroach on even marginal areas susceptible to flood hazards. Moreover, people who moved to new places with experience of different environmental conditions and processes in their place of origin are less experienced in the type, frequency, and magnitude of floods in their new destinations and thus, less capable of anticipating flood hazards and invest unknowingly in hazard-prone areas. Along with the emergence and expansion of settlements, other infrastructure also developed in nearby areas. In the absence of building codes and proper technical standards for built-up environments, the risk of and vulnerability to floods have been increasing.

Socioeconomic vulnerability

The scale and magnitude of impacts of natural hazards are not only determined by physical vulnerability, they are derived from a combination of both physical and socioeconomic vulnerability. Socioeconomic vulnerability is the extent to which an individual, community, subgroup, structure, or geographical area is likely to be damaged or disrupted by a disaster. In the words of Blaikie et al. (1994) vulnerability is the characteristic of a people or group in terms of its capacity to anticipate, cope with, resist, and recover from the impact of a natural disaster. Hence, it refers to coping capacity/actions and resilience of the people, society, and institutions of a nation. A brief overview of socioeconomic vulnerability is discussed in the following sections.

The coping capacity for and social resilience to natural disasters assessed in terms of some key socioeconomic and infrastructural indicators presented in Table 1.4 indicate that these are among the low and lowest levels in the South Asian region. The causes of poor coping capacity are as follows.

Low human development index

Nepal's overall human development index ranking (based on 2000 data) is 142 out of 173, lower than all our Asian neighbours except Bangladesh. Poverty has

Table 1.4: **Socioeconomic indicators of Nepal and other countries in South Asia**

Country	Nepal	India	Bangla-desh	Pakistan	South Asia
Total population (millions)	23	997.5	131.1	138.1	1.4 billion
Population density (persons km^{-2})	148	335.5	997	179	283
Annual population growth (%)	2.4	1.8	1.7	2.4	1.9
National poverty rate (% of population)	42	35	35.6	34	
Life expectancy at birth (years)	58.9	61.4	61.2	63	62.4
Malnutrition prevalence (% of children under 5)	46.9	47	61.3		48.7
Urban population (% of total)	11.9	28.1	24.5	37	28.4
Illiteracy rate, adult male (% of males 15+)	40.4	32.3	47.7	42.5	33.9
Illiteracy rate, adult female (% of females 15+)	76	55.6	70.1	72.1	57.3
Improved water sources (% of total population with access)	81		97	88	87.2
Improved sanitation facilities, urban (% of urban population with access)	75		82	94	76
Energy use per capita (kg of oil equivalent)	357.9		139.3	443.9	440.6
Electricity use per capita (kWh)	47.1	379.2	89	321.2	337
GNI per capita, Atlas method (current US$)	240	440	370	440	440
Annual GDP growth (%)	6.5	7.1	5.9	4.4	4.2
Inflation, GDP deflator (annual %)	4.3		1.9	3.7	4.1
Agricultural productivity per agricultural worker (1995 $)	189	395	247	626	306
Agriculture, value added (% of GDP)	40.3	26.2	24.6	26.3	25.1
Industry, value added (% of GDP)	22.4	26	24.4	22.8	26.2
Services, etc., value added (% of GDP)	37.4	47.8	51	50.9	48.8
Exports of goods and services (% of GDP)	23.7	12	14	15.5	15.1
Imports of goods and services (% of GDP)	32	15.1	19.2	19.1	18.3
Gross capital formation (% of GDP)	24.3	24.3	23	15.6	22.9
Current revenue, excluding grants (% of GDP)	10.6	11.9	9.3	16.7	13.7
Fixed lines and mobile telephones (per 1000 people)	11.9	26.5	5	24.1	30.7
Paved roads (% of total)	30.8	45.7	9.5	43	36.9

Note: GDP= gross domestic product; GNI=gross national income; kWh=kilowatt hours
Source: World Bank Report 2002

been the major cause (and effect) of poor human development. About 40% of the population of 23.7 million live below the national poverty line of NRs 4,400 ($77) per capita per annum. Poverty is primarily rural, with urban poverty rates about half the national average. The incidence of poverty in the mid-western and far western development regions greatly exceeds the national average, as does the rate in mountain districts.

Poor economic growth

The economic growth has been less than 4% on an annual basis and is characterised by low agricultural growth, growth that is urban biased, and poor distributive capacity. In the FY2002, the gross domestic product (GDP) per capita was only $231, making Nepal one of the poorest countries in Asia. Government revenue and gross domestic savings have remained at only 8 and 11% on average of the GDP during the last decade. Low levels of revenue and savings limit the allocation of resources to social priority sectors, and thereby limit the capacity to cope with natural disasters

Disparity in productive assets and income

Out of the total households in the country, nearly 78% are agricultural households, cultivating land of at least 0.013 ha and about 2% are agricultural households without land (CBS 2004). The average size of agricultural land held is 0.83 ha and holding sizes have been decreasing. Small farmers operating less than 0.5 ha of land account for about 45% and they own only 13% of the agricultural land. Nearly 73% of households have less than one ha of land and own only 31% of the area. Similarly, the bottom 20% of households receive only 5.3% of the national income while the top 10% have nearly 54%. Such wide disparity and skewed distribution in productive assets and income result in a poor capacity to cope with disasters.

Heavy dependence on agriculture and its poor production potential

Agriculture is the principal economic sector, but its production has remained stagnant or has only marginally increased: it is poorly diversified and largely dependent on variable monsoons. The value added per unit of agricultural land and agricultural worker is low compared to South Asian levels. Since most farmers are marginal and landless or have very small farms and have limited access to technology or the formal credit sector, roads, and markets, the agricultural returns are very poor (Chettri 1996). Only 44% of the total cultivable land (18% of the land area) is irrigated, and the current irrigation system contributes approximately 33% to the country's current agricultural production. Even if all irrigable lands were irrigated, the total production would increase by only 50% (due to water inputs only) (WECS 2002).

Inadequate service provisions

Access to safe drinking water, and health and sanitation is below South Asian standards. The health service delivery system is inadequate in terms of both quantity and quality of services. There is only one health centre including hospitals and health posts per 186 sq. km, and one health centre has to serve nearly 29,000 people. The ratio of doctors to population is 1:18,000 with a hospital bed ratio of 1:4,000 (CBS 2005). According to the Nepal Living Standards Survey (2003/04), the percentage of households requiring travel times of more than 30 minutes is 33% for health posts, 38% for hospitals, 66% for market centres, 46% for telephone booths, and 66% for paved roads. In rural areas, the mean travel time to reach different facilities is one hour and 16 minutes for health posts/hospitals, 2 hours and 14 minutes for markets, 5 hours and 11 minutes for paved roads, 3 hours and 12 minutes for bus stops, and 2 hours and 13 minutes for telephone booths (CBS 2004a). The adult illiteracy rate for both males and females is high and is higher in females, and overall the highest in South Asia, implying a low level of human resource development. The electricity use per capita is much lower than South Asian levels. This low level of social and physical infrastructure implies low coping/adaptive capacities in the event of disasters.

Increased population pressure

Under conditions of poor economic growth, the increase in the population growth rate has meant an increase in poverty level. The population has increased by 2.25% annually over the last decade, which means the population might well double in the next few decades (CBS 2004). Since 1976, the absolute number of people living below poverty level has doubled to the extent of nine million. Every year, about 200,000 people enter the labour force, and not a small fraction of this is absorbed into the non-agricultural sector. As a result, pressure on farmland and forests has increased. At times, this has led to deforestation, intensifying the use of marginal land, and this has affected the environment adversely. This, in turn, has had devastating effects on the poor as they rely on marginal land (UNDP 2001). Because of increasing poverty and its adverse effect on the environment, the vulnerability to natural disasters is likely to be high in the context of a poor coping capacity.

Ineffective implementation of disaster management strategies, policies, and programmes

Government activities until 1982 were mainly directed towards post-disaster activities, viz., rescue, relief, and rehabilitation, only as voluntary social work (Chettri and Bhattarai 2001; Dixit 2003). The Natural Disaster Relief Act 1982 provided a legislative framework for disaster management in the country (MOL 1982). Several amendments to the Act were made later. In the Act, provision for disaster management committees was made at the national and district levels in order to expedite relief measures in an effective and coordinated manner. Although there was an increase in the logistic and institutional capability for emergency response, it still lacked a broad perspective of disaster and its management. In 1996, the National Action Plan on Disaster Management (MOHA 1996) was introduced to address the manifold issues of disaster such as disaster preparedness, early warning systems, disaster information systems, hazard and risk analysis, vulnerability and adaptation assessment, land-use planning, training, and simulation. The Local Self-Governance Act (MOL 1999) came into existence in 1999. It provided a legislative framework to carry out disaster mitigation activities at the local level by mobilising local communities. The 9th and 10th plans (NPC 2002; 1998) also emphasised prevention, mitigation, and reduction of natural disasters through advanced geological, hydrological, and meteorological technology.

The National Water Plan (2002-2027) prepared by the Water and Energy Commission (WECS 2005) outlined several activities for the mitigation and management of water-induced disasters. These include formulation of policies and programmes for better management of water-induced disasters, implementation of risk and vulnerability mapping and zoning work, preparation and implementation of a floodplains' action plan, development of disaster networking and information systems such as early warning systems, formulation and implementation of community-level disaster preparedness plans, and implementation of relief and rehabilitation activities. It discusses approaches to river basin planning and outlines some activities in this context (WECS 2005).

Many institutions are involved in disaster mitigation and management activities. The Ministry of Home Affairs (MOHA) formulates and implements overall disaster management strategies, policies, and plans. Relief and rehabilitation activities are carried out by the Ministry of Home Affairs, Nepal Red Cross Society, Royal Nepal Army, and local non-government organisations (NGOs). The Department of Water Induced Disaster Prevention (DWIDP) is responsible for managing and mitigating water-induced disasters. Similarly, the Department of Hydrology and Meteorology (DHM), the Department of Soil Conservation and Watershed Management, the Ministry of Local Development, the Ministry of Population and Environment (MOPE), and many NGOs, intergovernmental organisations (IGOs), and international non-government organisations (INGOs) are involved in disaster mitigation and management activities directly or indirectly; but there is poor coordination in implementing activities among these institutions. Besides these institutions, a special Inundation Committee has been formed under the jurisdiction of the Ministry of Water Resources to deal with the problems of inundation caused by infrastructure constructed by India just downstream of Nepal. But this committee has yet to be effective in solving outstanding problems of inundation in border areas.

In spite of these strategies, policies, guidelines, programmes, legislation, and institutional provisions, only a few goals have been achieved. The government's disaster-mitigation efforts until now have been confined to rescue operations and post-disaster activities. The reasons for this may be lack of resources, low technical and institutional capabilities, low level of public awareness, and less effective mechanisms and bad governance. Less effective legislation and action plans clearly imply that the state's disaster coping mechanisms are inefficient.

Mapping and Past Assessment Efforts

Efforts have been made to map flood hazards, risks, and vulnerability, although they are very limited in scope and scale. Attempts are made here to review the work carried out on flood hazard, risk, and vulnerability mapping. After the devastating floods and landslides in 1993 in Kulekhani and its adjacent area, efforts were made to identify and map hazardous sites in that area. Hazardous sites in the Agra, Belkhu, and Malekhu Khola watersheds were mapped (DPTC and CDG 1994). Similarly, hazard maps of severely affected areas from the high intensity precipitation event in 1993 in the Kulekhani area (Miyajima and Thapa 1995) and Sarlahi district (Lama 1995) were prepared. Probabilities of hazards with different ratings were used to delineate areas with different levels of hazard – low, medium, and high in the Kulekhani area. The degree of damage in Sarlahi district and its vicinity was mapped. It highlighted the fact that the rising of river beds was one of the main causes of flooding in Sarlahi district in the Terai.

Hazard maps have been prepared for the Sun Koshi and Bhote Koshi catchments in central Nepal (ITECO 1996). The conclusion of this mapping exercise was that development of human settlements in hazardous areas increases the risk of floods and landslides. Measures to reduce the impact of natural disasters in these catchments have also been suggested.

A map indicating the zone vulnerable to flood hazards along the Khando Khola in the eastern Terai was prepared using GIS methodology (Sharma et al. 2003). Risk zoning was carried out for flood hazards with return periods of 10 and 50 years Similarly, preliminary work for flood-risk mapping along the Tinau Khola (downstream from Butwal) and the Lakhandi Khola in Rupandehi district was carried out by the Department of Hydrology and Meteorology in 1998. A one-dimensional intelligent drive array (IDA) method was used to determine flood levels along river channels and river valley bottoms using seven river cross-sections surveyed for 42.5 km along the river. It highlighted the need to have a sufficient number of cross sections and longitudinal profiles for better mapping and assessment of flood hazards and risks.

The Japan International Cooperation Agency (JICA) and the Department of Irrigation (DoI) (1999ab) prepared a flood-hazard map of Lakhandei Khola based on a field study carried out after the 1993 flood under 'The Study on Flood Mitigation Plan for Selected Rivers in the Terai Plain in Nepal' [sic]. The study also carried out various analyses including a flood-flow analysis using an unsteady flow simulation model. Flood-hazard maps were also prepared based on field investigations and personal interviews. The simulated result shows that, in many sites, the simulated water level goes far beyond the river cross-section and this could not represent the actual flood-water levels. These maps bear no relationship to the hazard level, e.g., the return period of flooding and floodwater depth. It also pointed out the need to prepare new flood hazard maps refining those prepared for the study (JICA/DoI 1999a). The study concluded that the application of numerical modelling tools and GIS can provide effective and efficient means of floodplain analysis and flood-risk assessment. This can facilitate the transition from conventional flood-hazard mapping techniques based on field investigations to a knowledge-based system for a more objective analysis. This can also provide a framework for a decision-support system and facilitate the evaluation of alternative strategies for flood management.

An attempt was made at floodplain analysis and flood-risk assessment along the Babai Khola, using GIS and numerical modelling tools such as HEC-RAS (Shrestha 2000). Similarly, His Majesty's Government of Nepal (HMG/N), Department of Water Induced Disaster Prevention (DWIDP) and the Mountain Risk Engineering (MRE) Unit of Tribhuvan University (TU) (MRE 2003) prepared water-induced hazard maps of a part of Rupandehi District. A flood-hazard map has been prepared on the basis of field studies and numerical modelling.

The socio-technical aspect of flood-mitigation work in the Ratu Khola has been studied (R.S. Engineering Service 2000). The river basin was categorised into three zones based on vulnerability. Structural and non-structural measures have been recommended.

In 2003, the UNDP Office for Coordination of Humanitarian Affairs (UNDP/OCHA) carried out one mapping and assessment exercise entitled 'Multi-hazard Mapping and Vulnerability Assessment of Chitwan District'. This study attempted to identify settlements located in disaster-prone areas; estimate the number of households and population in those settlements; assess the risk; discuss the major causes of disaster; and prepare maps showing different types and levels of hazard in the district.

In addition to the flood-hazard and risk-mapping work in different parts of the country, several attempts have been made to review and analyse the issues of floods and their mitigation and management in Nepal. Khanal (1997) describes different types of floods frequently occurring in the country and discusses causes behind their increase and augmentation in the risk of flooding. The causes and extent of damage along with programmes recommended for managing floods through rehabilitation and preparedness activities have been reviewed on the basis of the flood events of 1993 in Chitwan, Makwanpur, Rautahat, and Sarlahi districts by the National Planning Commission (NPC 1994). Similarly, Chhetri and Bhattarai (2001) have reviewed some of the past flood and landslide events; highlighted the main factors contributing to increased vulnerability to flood disasters; and discussed flood-disaster management efforts – including policy, legislation, and institutional arrangements. The constraints to effective flood prevention and opportunities for technical exchange and collaborative work are also discussed. Similarly, Dixit (2003) has discussed the nature of frequently occurring floods and their impacts as well as responses in terms of mitigation and management; and he has highlighted the need for new approaches to flood mitigation and risk management.

ICIMOD's Activities

One of the goals of ICIMOD is to decrease the physical vulnerability within watershed and regional river basins and increase the evironmental security of mountain peoples and the downstream poor. The Water, Hazards and Environmental Management (WHEM) Programme of ICIMOD contributes directly to meeting this goal through its various programme activities. The overall goal of WHEM is to share information and knowledge on water, hazard, and ecosystem health, and secure environmental services in the Hindu Kush-Himalayan (HKH) region through regional collaboration. The Programe has three action initiatives, (i) water and floods, (ii) climate change and response, and (iii) environmental services. The activities under water and floods include the identification of measures to mitigate different types of natural hazard, particularly floods; promote skills and methodologies for natural hazard assessment; promote regional cooperation; and improve public awareness about disaster preparedness. In the past, ICIMOD's efforts were mainly concentrated on the publication of technical reviews on different issues related to water, e.g., flood hazard and risk (Carson 1985; Ives 1986; Bruijnzeel and Bremmer 1986). It also started to carry out case studies of extreme landslide and flood events occurring in the HKH region (Dhital et al. 1993; Khanal 1999) and organise workshops and meetings to initiate dialogue on better mitigation and management of flood disasters. ICIMOD, in collaboration with its regional member countries and the UNESCO International Hydrology Programme (UNESCO-IHP), was successful in launching the HKH-FRIEND (Flow Regimes for Experimental Network and Data) Project in 1996. A Regional Hydrological Data Centre (RHDC) has also been established to promote free exchange of data for hydrological research. ICIMOD has also promoted a Regional Flood Initiative in collaboration with the World Meteorological

Organization (WMO) to promote regional cooperation in flood forecasting and sharing of data and information among regional member countries. Its aim is to build trust and confidence amongst the participating countries through regional dialogues and to enable establishment of an operational flood information system providing reliable and timely flood forecasting and information to minimise the loss of lives and property in the Indus Ganges, Bramhaputra and Megne River Basins.

ICIMOD has carried out hazard and risk mapping and community risk and vulnerability assessment activities as a part of the Participatory Disaster Management Programme (NEP/99/014) implemented by UNDP/Nepal (ICIMOD 2002; 2002a). Its aim was to map hazards and risks in seven village development committees (VDCs) and one municipality in four districts of Nepal. Among them, two districts – Chitwan and Barida – lie in the Inner Terai and Terai regions where the main hazard is associated with floods and consequent changes in river channels. The relatively greater exposure of lives, buildings, land, crops, livestock, and infrastructure to water-induced disasters, on the one hand, and the lower overall response and recovery capacity of local people in VDCs located in the Inner Terai and Terai regions compared to VDCs located in the Hills, on the other, clearly indicate an increasing risk of flood hazards in the Inner Terai and Terai regions. It also shows that the application of GIS and remote sensing (RS) technology is very useful for flood-hazard and risk mapping. It concludes that such hazard and risk maps provide a basis for formulating different intervention strategies and programmes to reduce the adverse impacts of flood disasters

It was in this context that the study described in this publication was proposed with the objectives of preparing flood-hazard, risk, and vulnerability maps and assessments at watershed level with the active participation of local people. Keeping in mind the increasing loss of property from floods and other water-induced disasters in the central Terai region, Ratu Khola and its basin located in Mahottari and Dhanusa districts, were selected for flood-hazard, risk, and vulnerability mapping and assessment.

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

This study was carried out by the International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal, with support from the United Nations Education, Scientific and Cultural Organisation (UNESCO), New Delhi, India.

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.

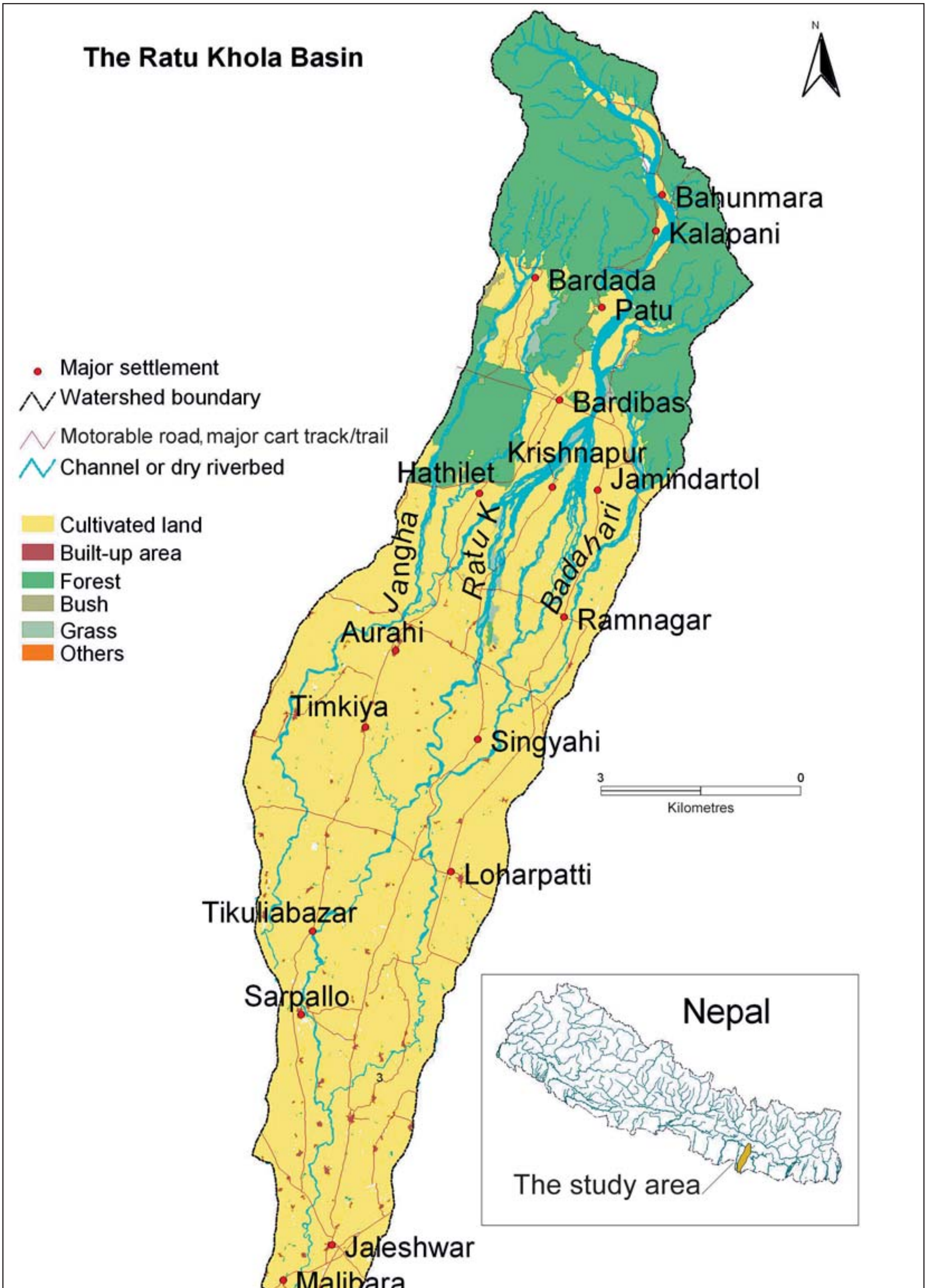

Figure 2.1: **Map of the study area**

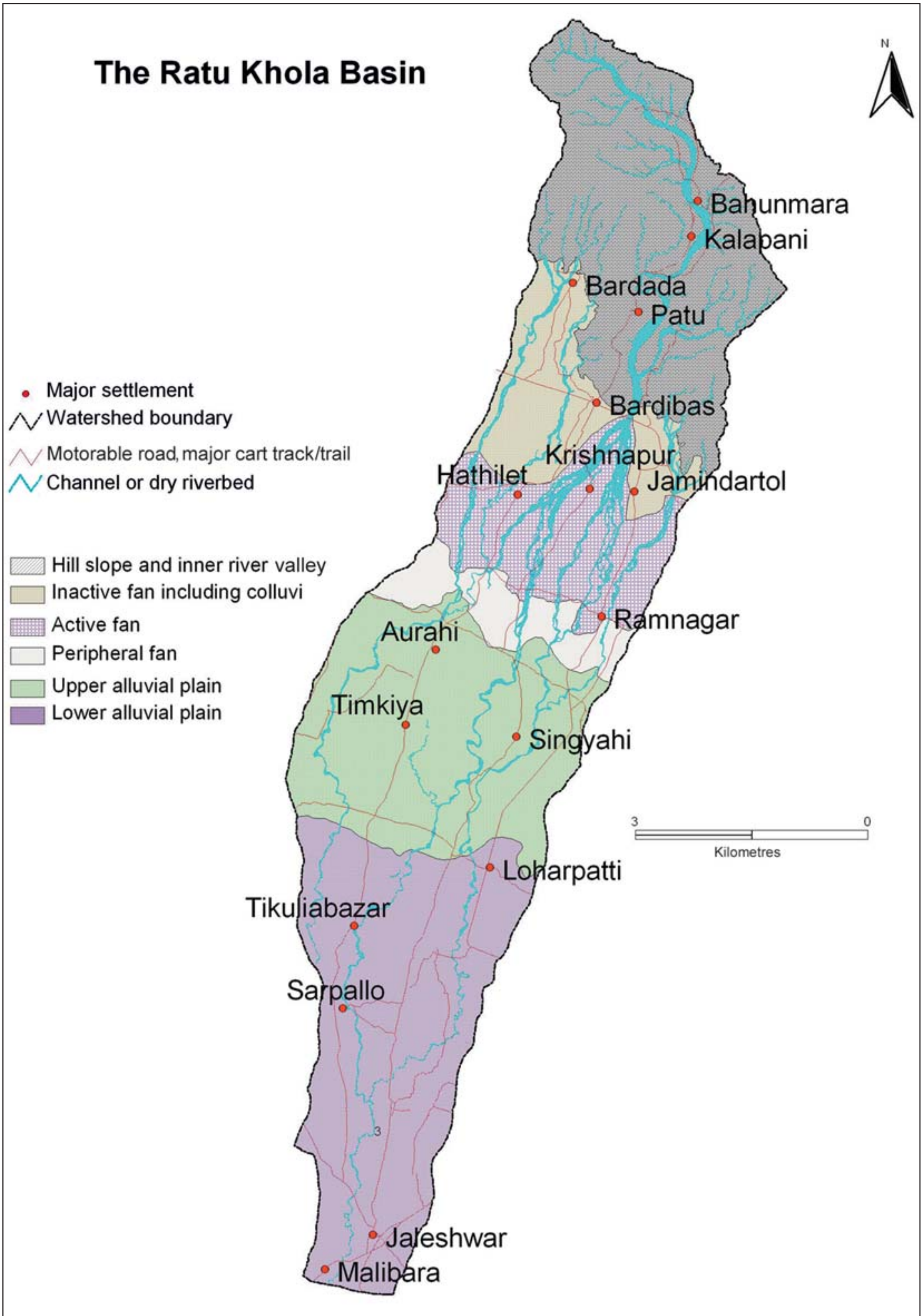

Figure 2.2: **General geomorphology of the Ratu Khola Basin**

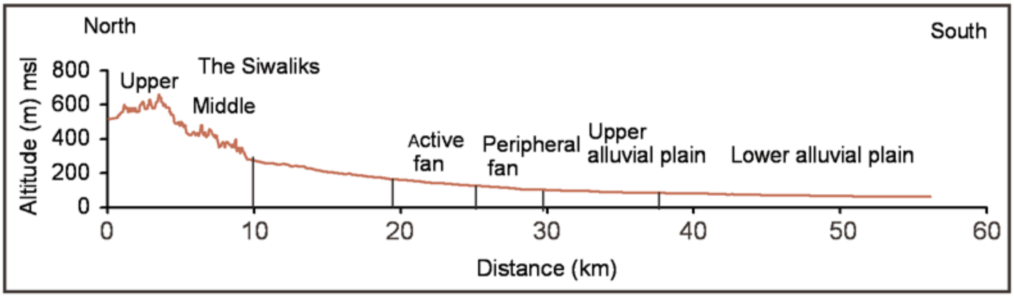

Figure 2.3: **Topographic profile of the basin along a north-south cross-section**

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.

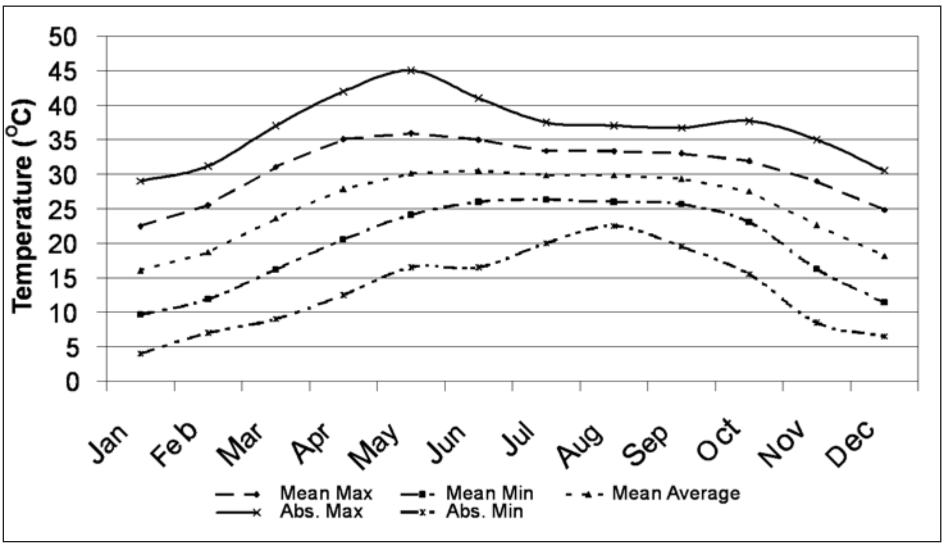

Figure 2.4: **Mean monthly temperature recorded at Jaleshwar, 1969-1996**

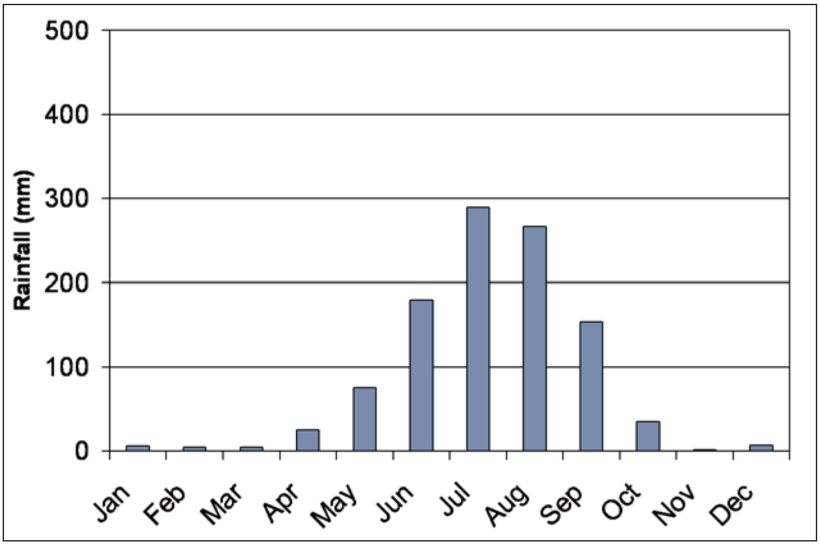

Figure 2.5: **Mean monthly rainfall recorded at Jaleshwar, 1969-1996**

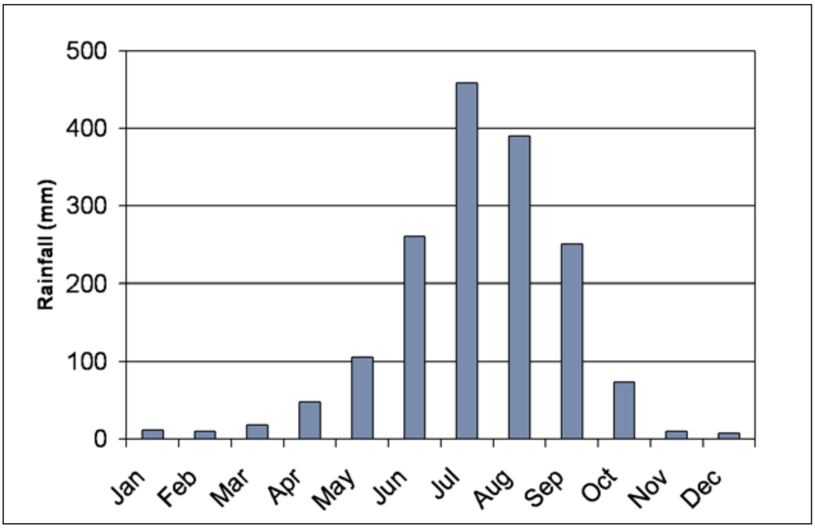

Figure 2.6: **Mean monthly rainfall recorded at Tulsi, 1956-1996**

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.

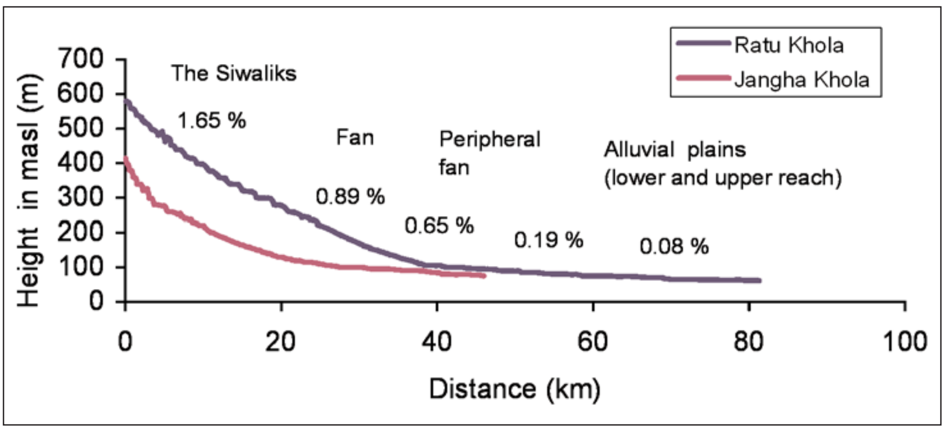

Figure 2.7: **Longitudinal profile of the Ratu Khola and Jangha Khola**

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.

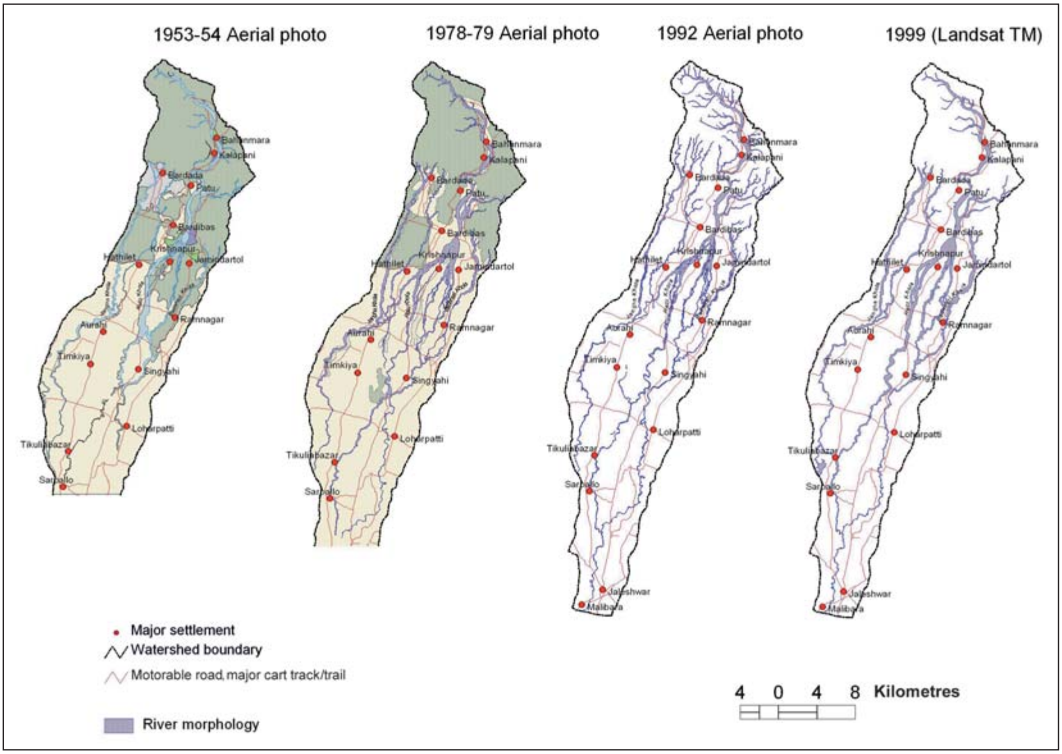

Figure 2.8: **River network traced from aerial photos and imagery at different periods**

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.

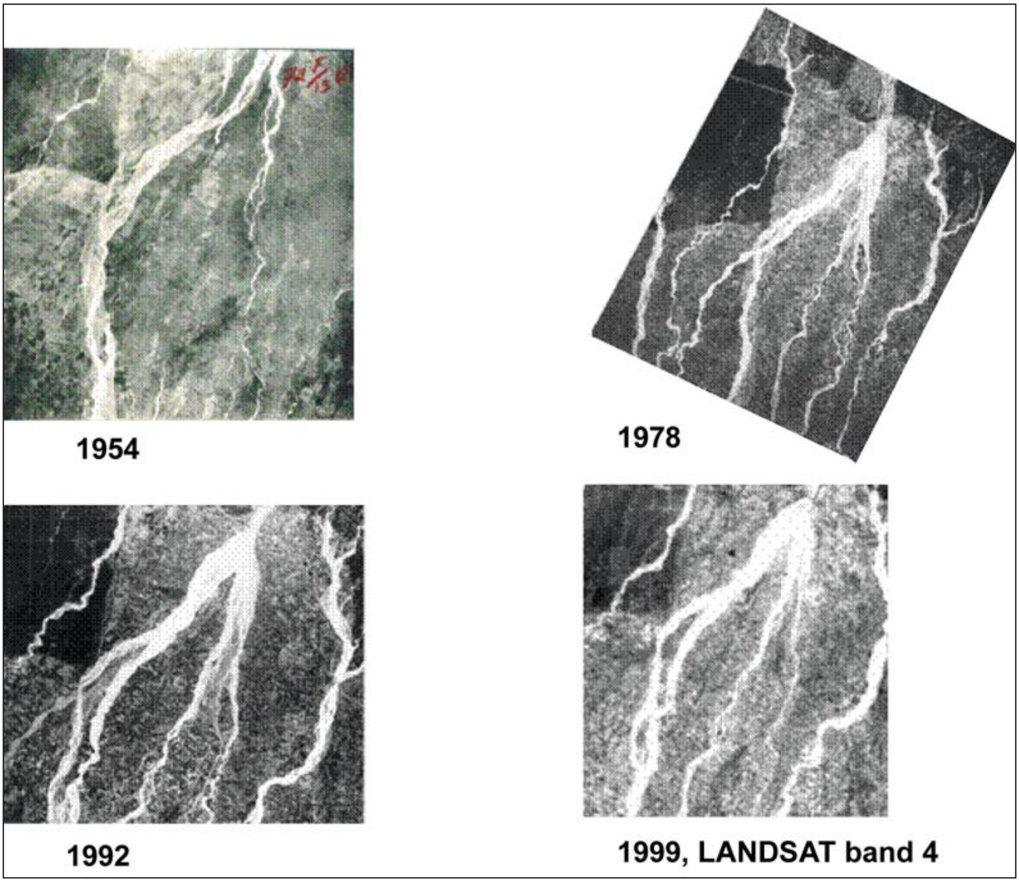

Figure 2.9: **A closer view of the river channel network, 1954-1999**

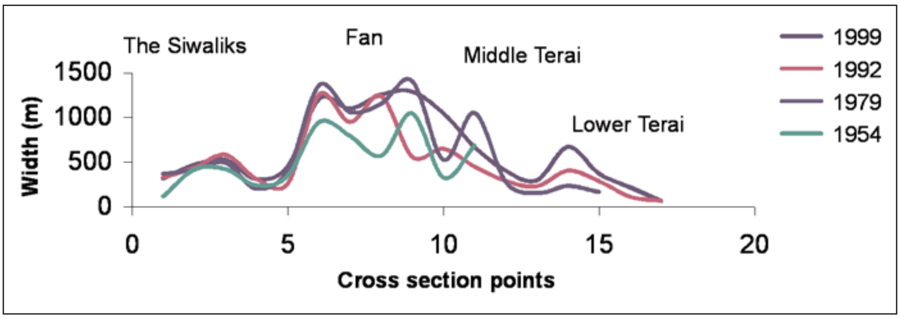

Figure 2.10: **Channel width of the Ratu Khola measured at different cross-sections**

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.

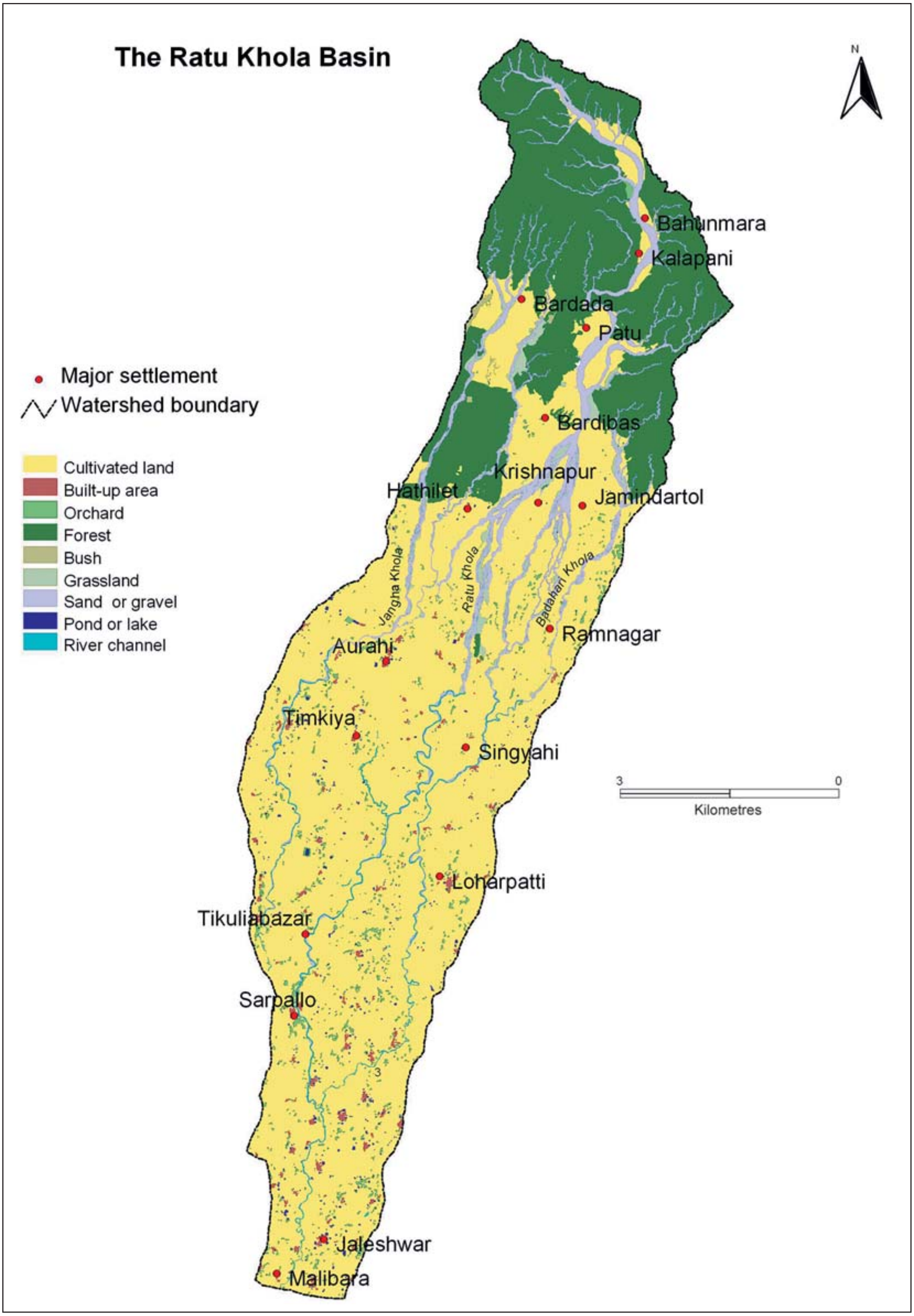

Figure 2.11: **Land use and land cover types, 1996**

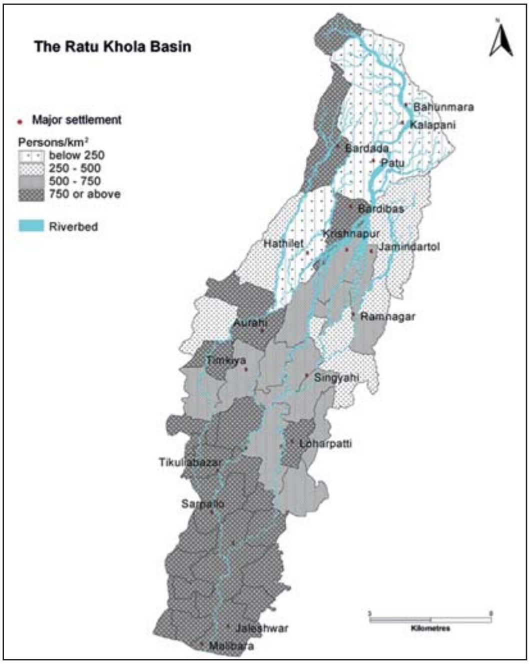

Figure 2.12: **Population density by VDC**

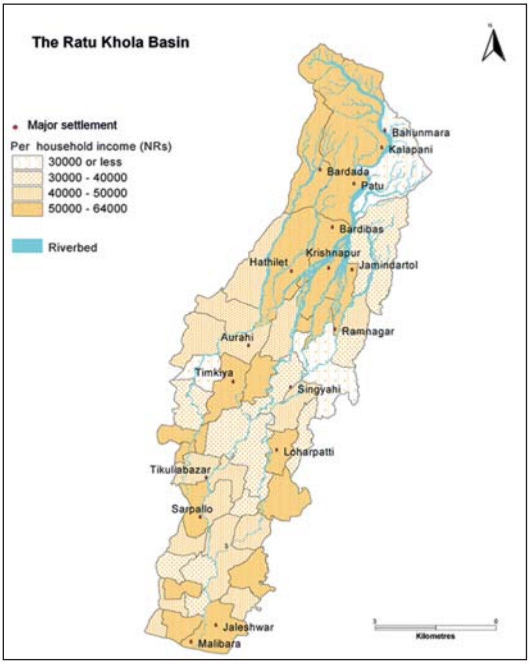

Figure 2.13: **Level of income by VDC**

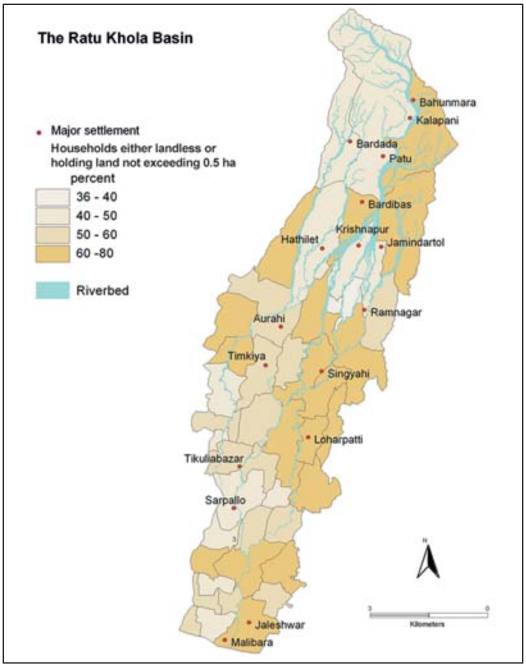

Figure 2.14: **Percentage of landless and marginal farm households by VDC**

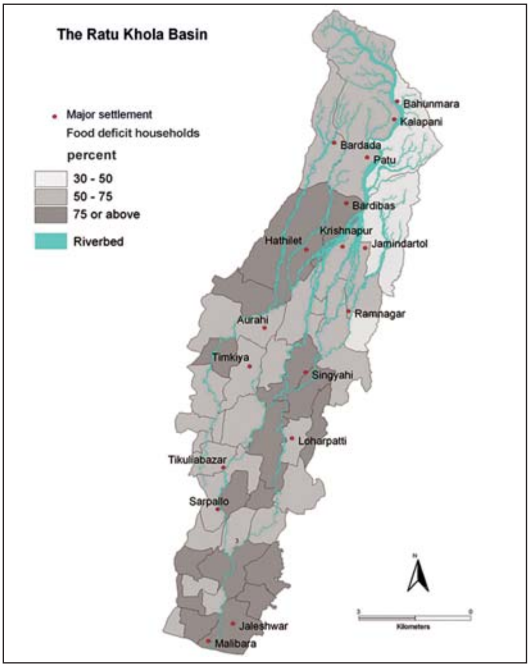

Figure 2.15: **Percentage of food-deficit households by VDC**

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)

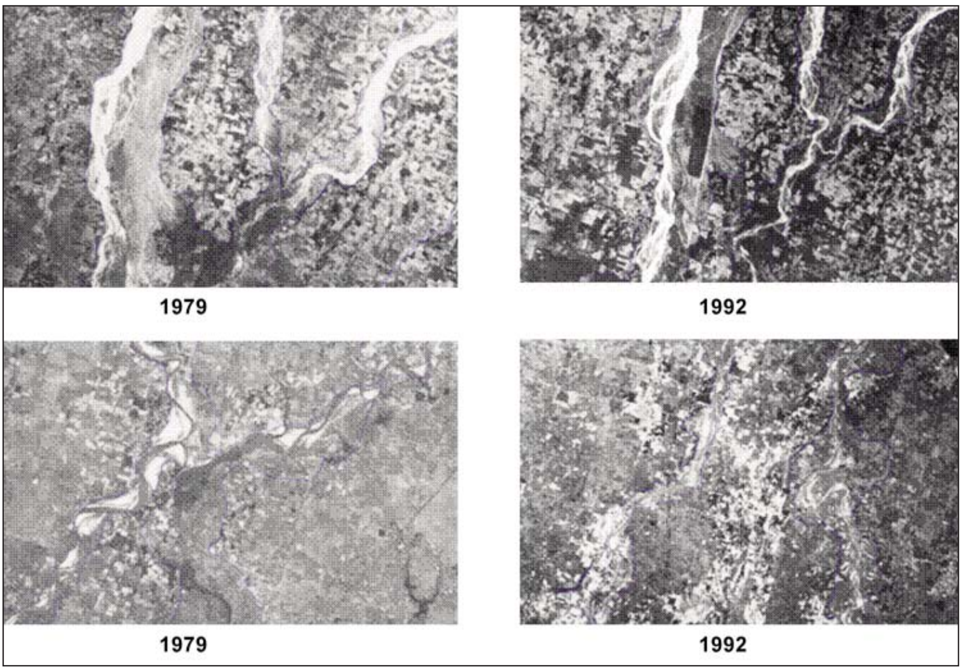

Figure 2.16: **Samples of aerial photographs used for mapping**

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.

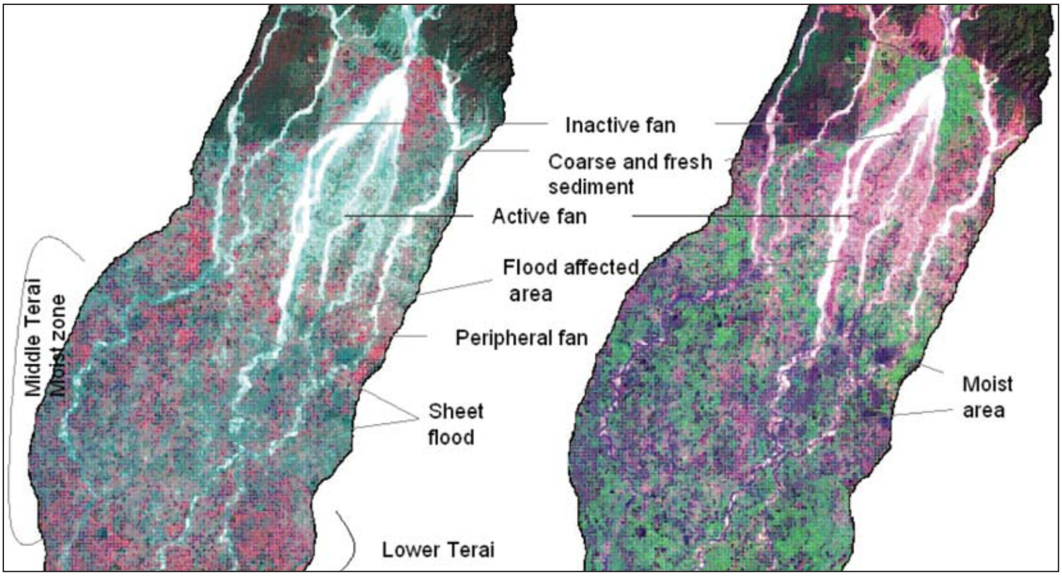

Figure 2.17: **Image interpretation using FCC, 432, and 751**

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

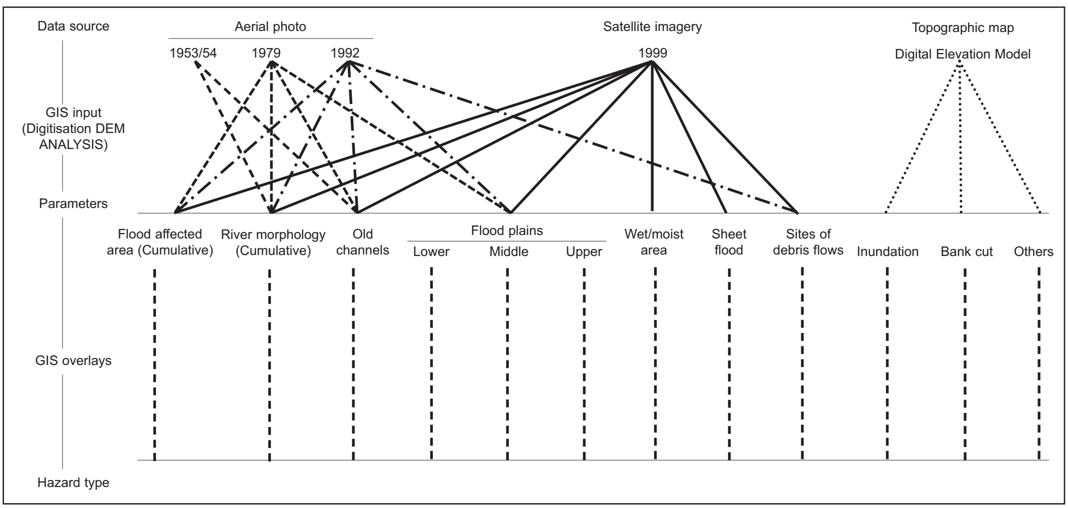

Figure 2.19: **Flood-hazard mapping scheme adopting geomorphic approach**

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

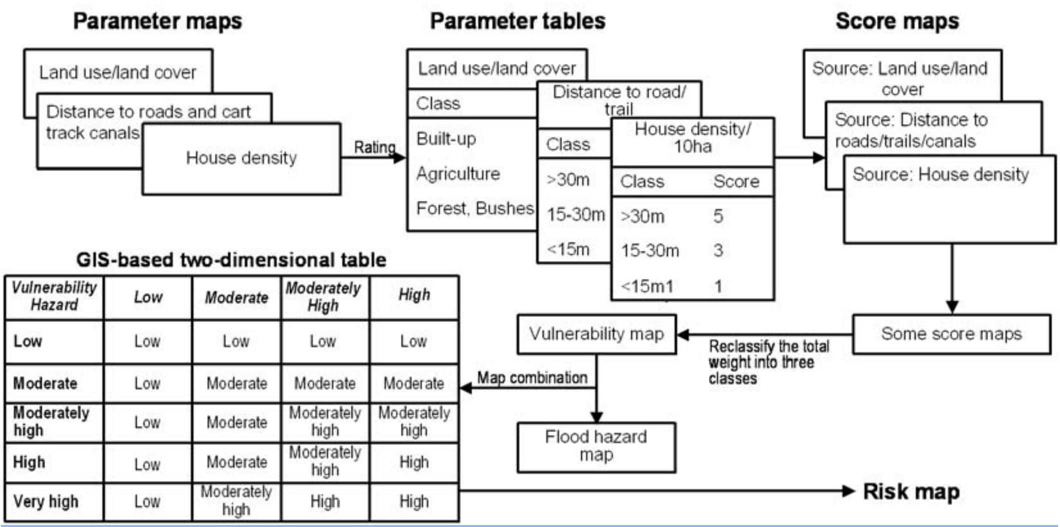

Figure 2.20: **Vulnerability and risk-mapping scheme**

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

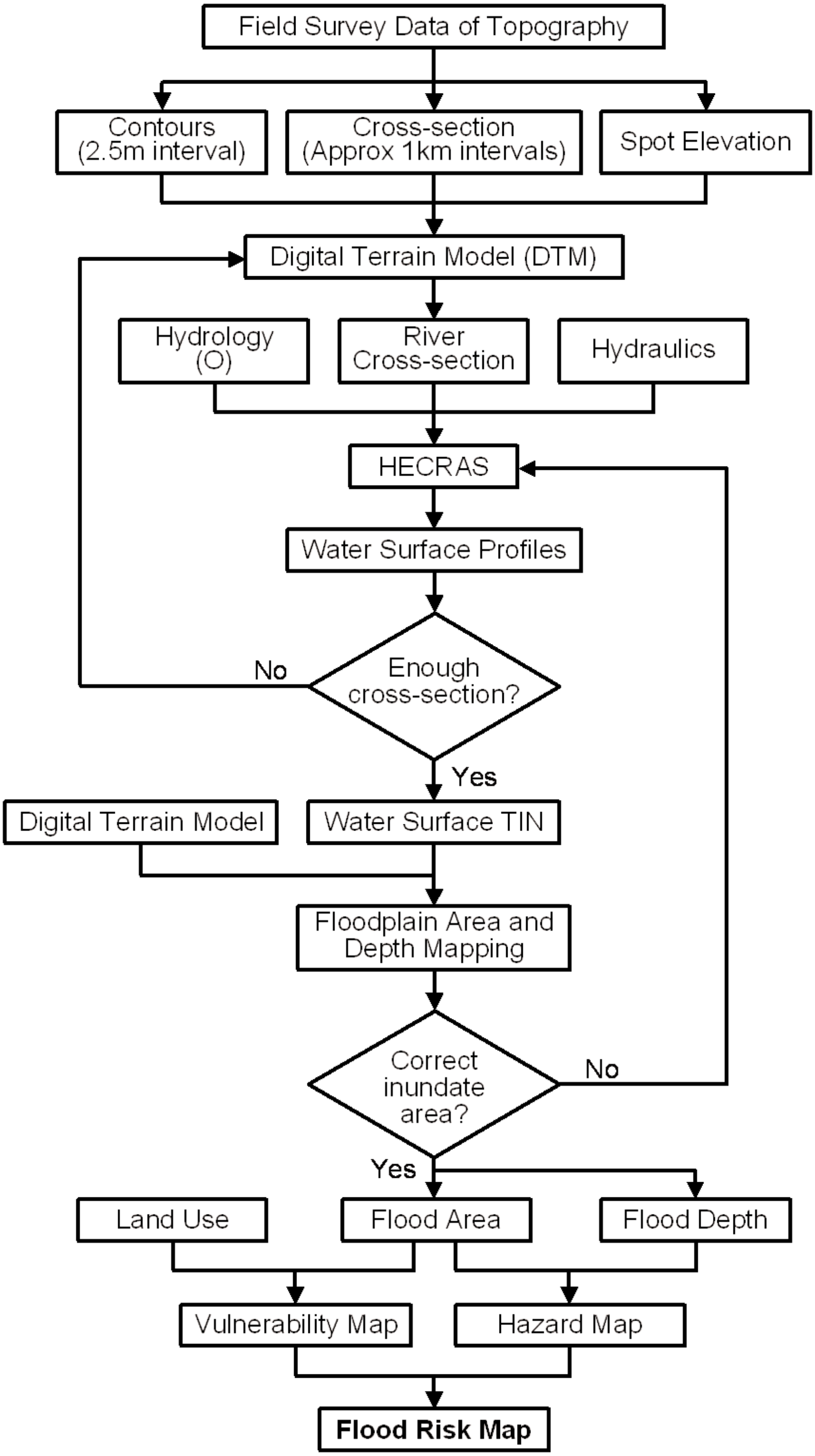

Figure 2.21: **One-dimensional floodplain analysis using HEC-RAS, GIS, and HEC-GeoRAS**

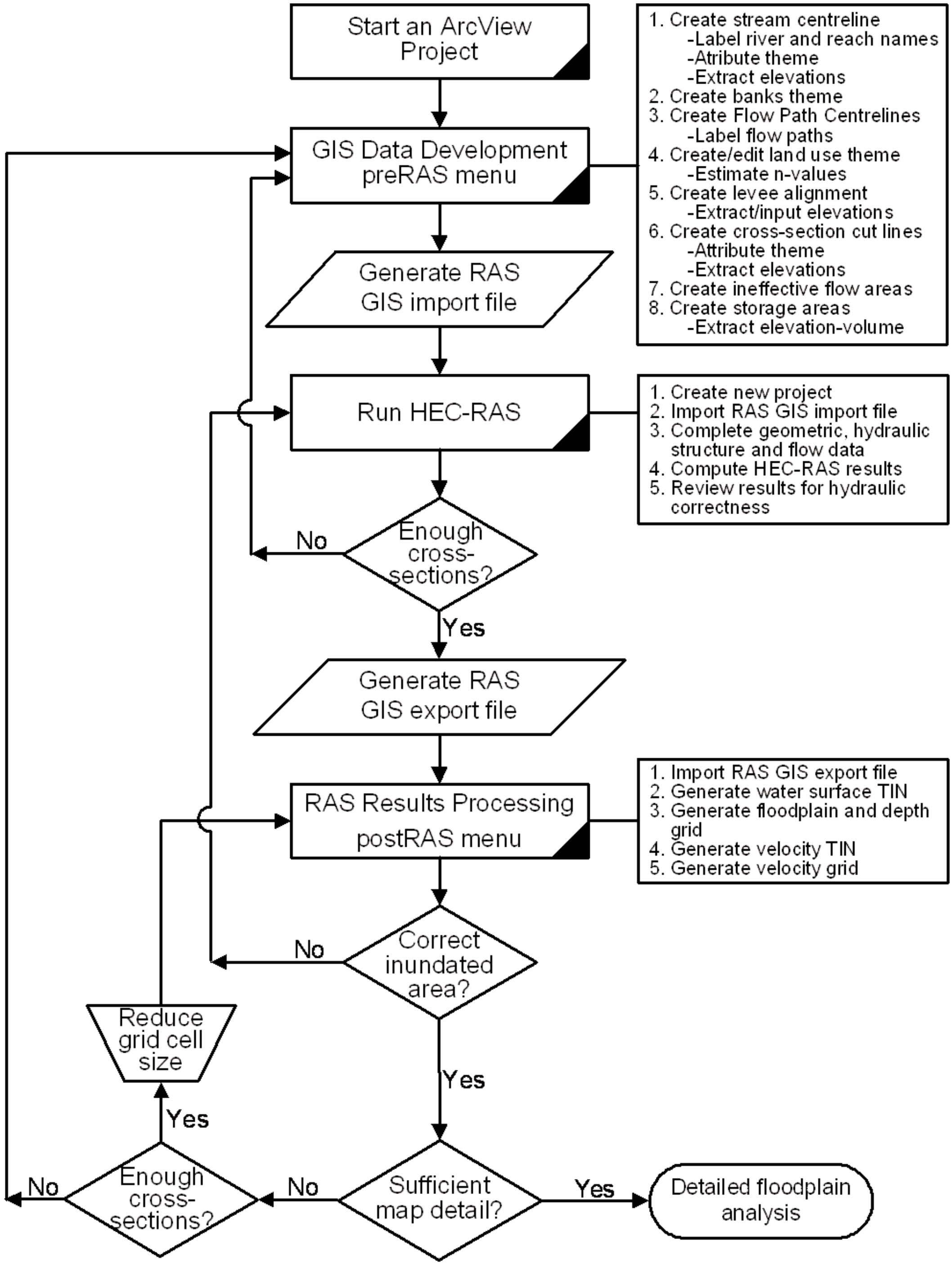

Figure 2.22: **Process flow diagram for using HEC Geo RAS**

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

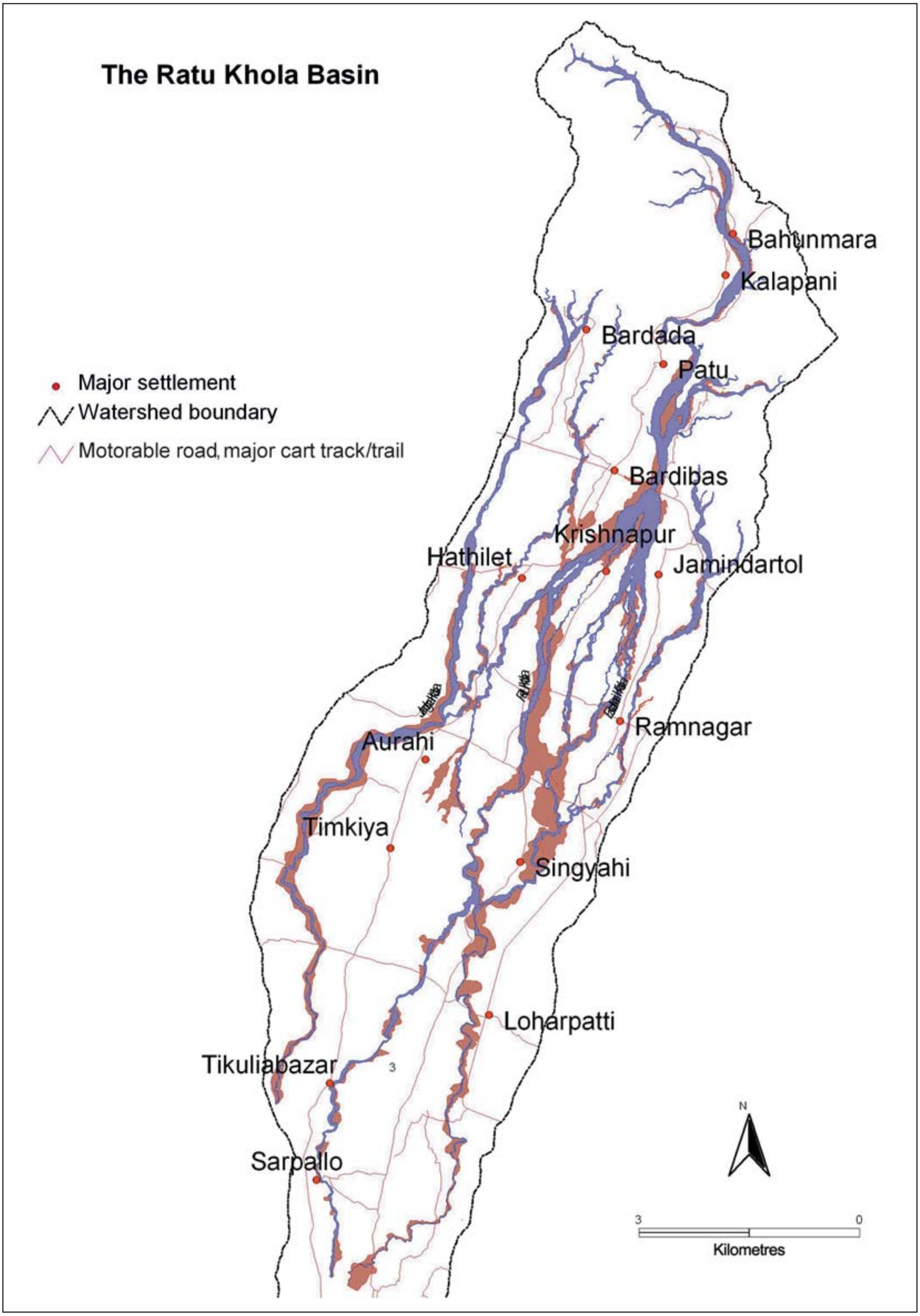

Figure 2.23: **Flood-affected areas, 1978/79 aerial photos**

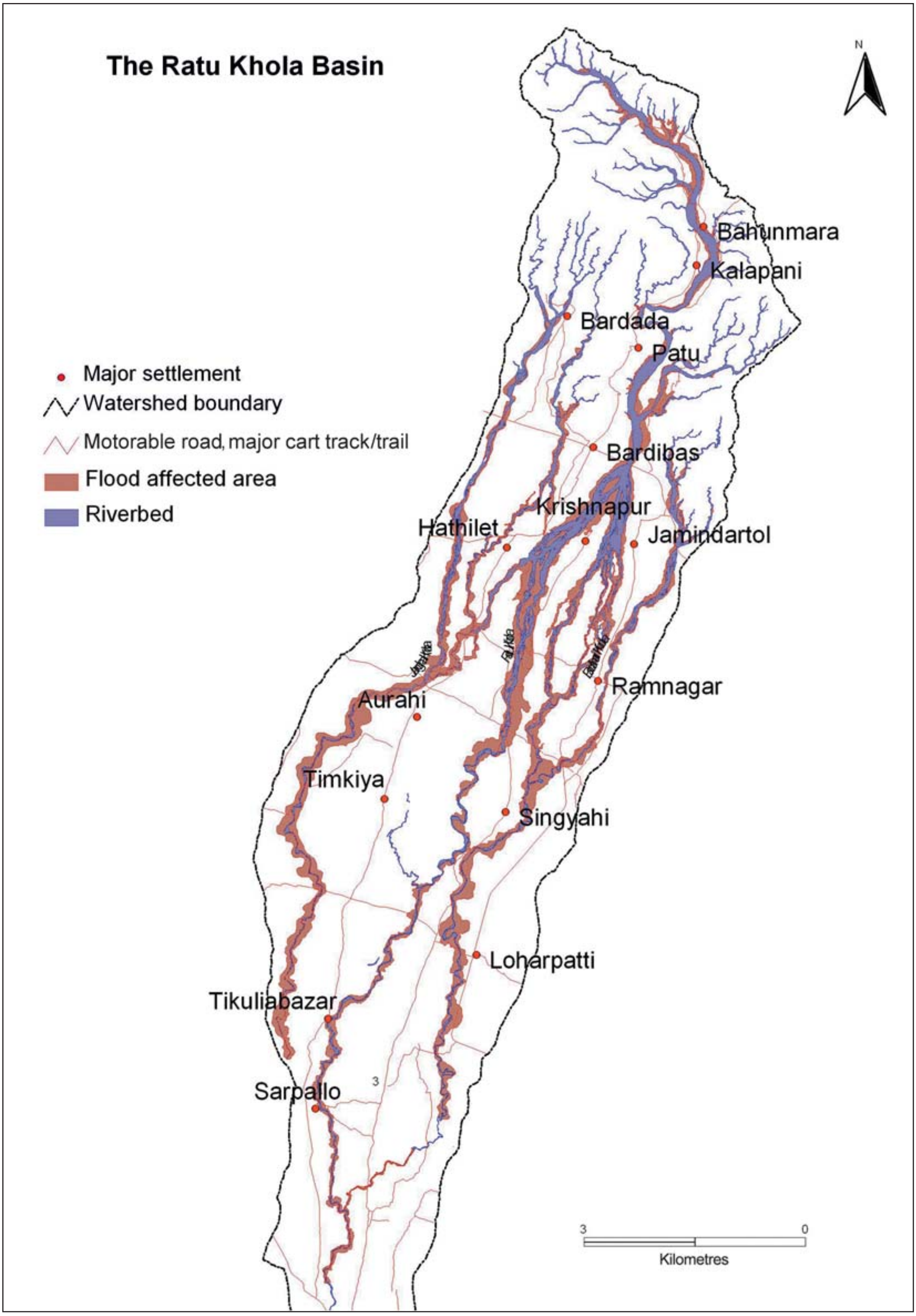

Figure 2.24: **Flood-affected areas, 1992 aerial photos**

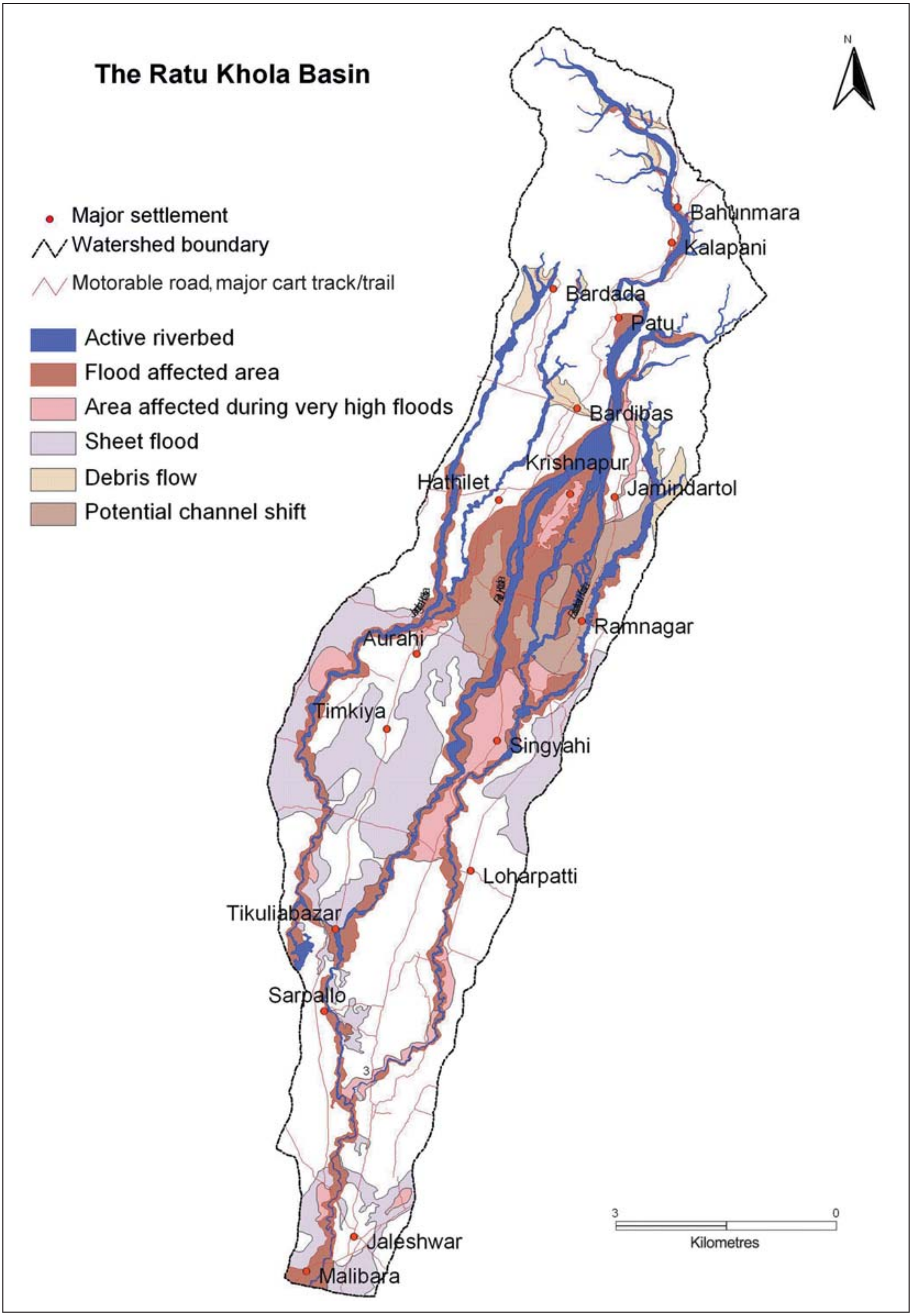

Figure 2.25: **Flood-affected areas, 1999 Landsat TM imagery**

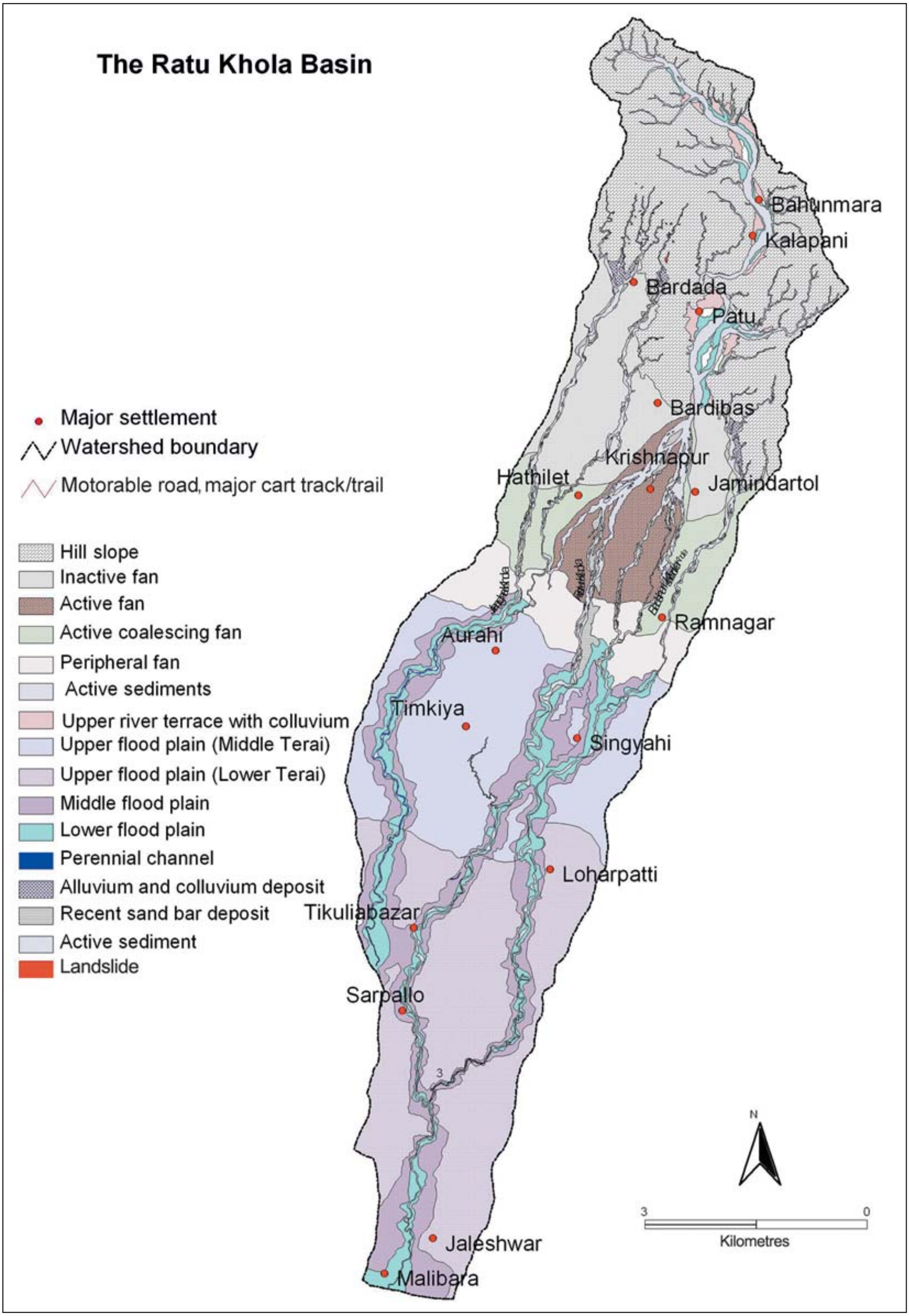

Figure 2.26: **Terrain unit map**

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

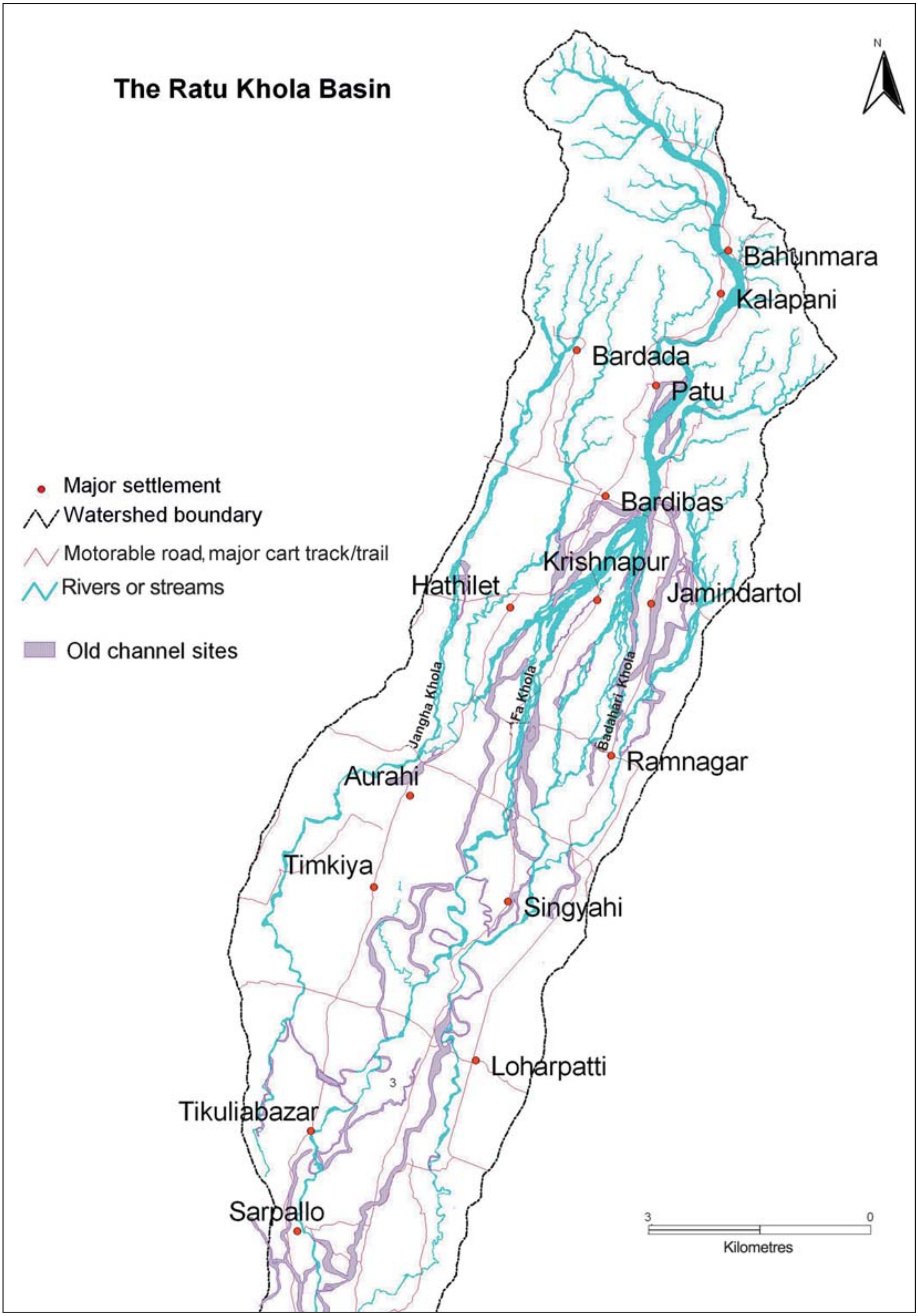

Figure 2.27: **Old river channel courses**

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.

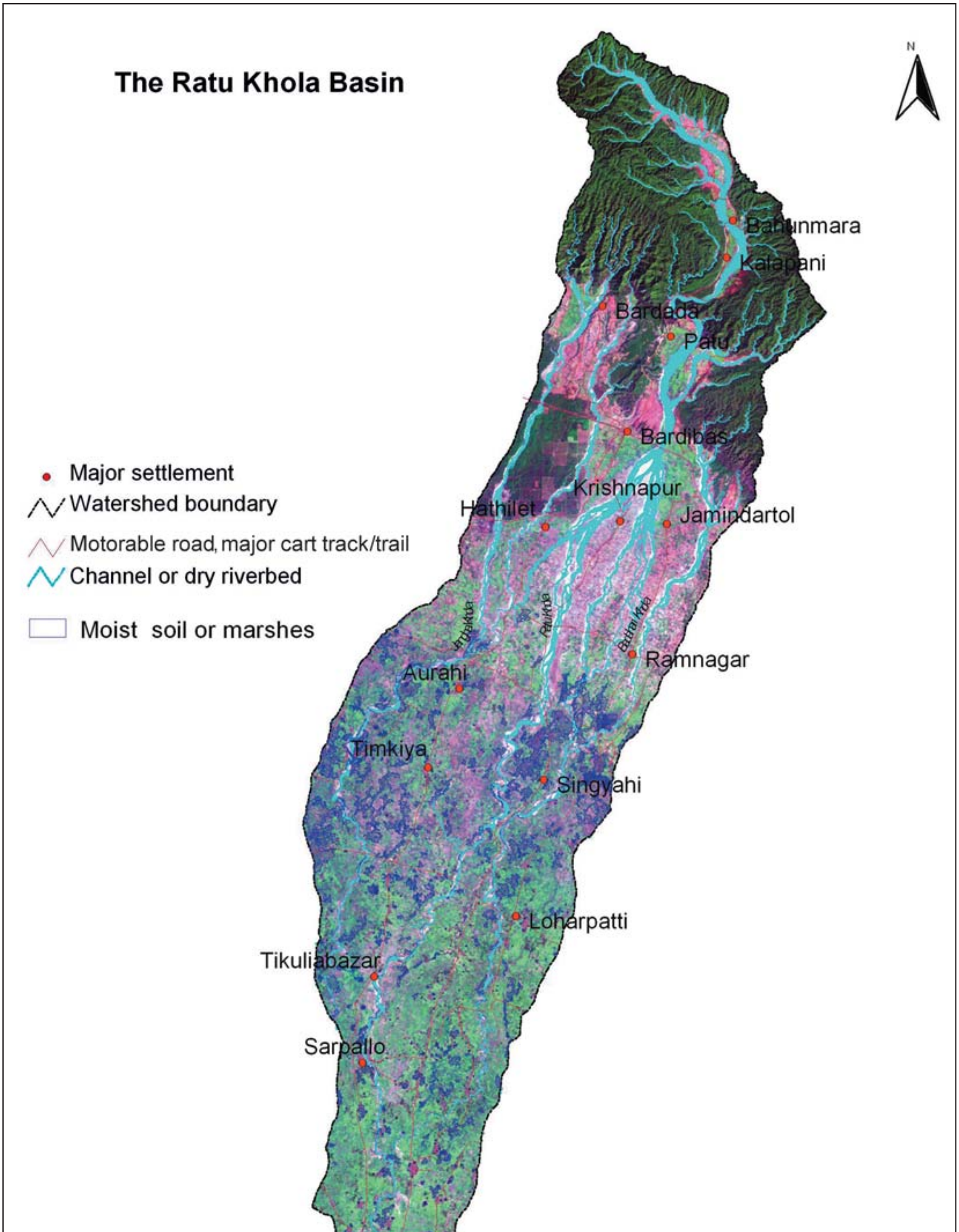

Figure 2.28: **Moist areas and marshes**

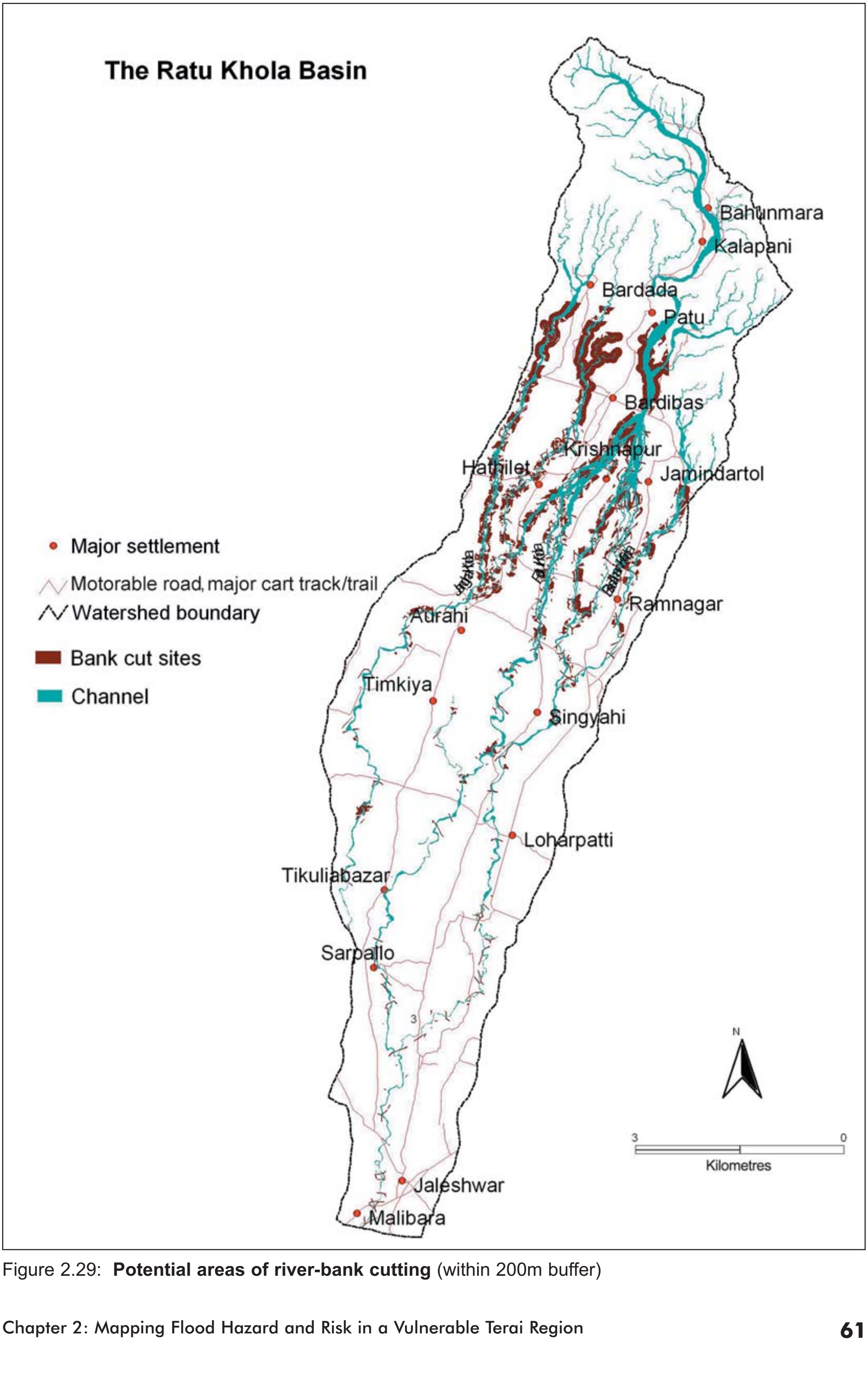

Figure 2.29: **Potential areas of river-bank cutting** (within 200m buffer)

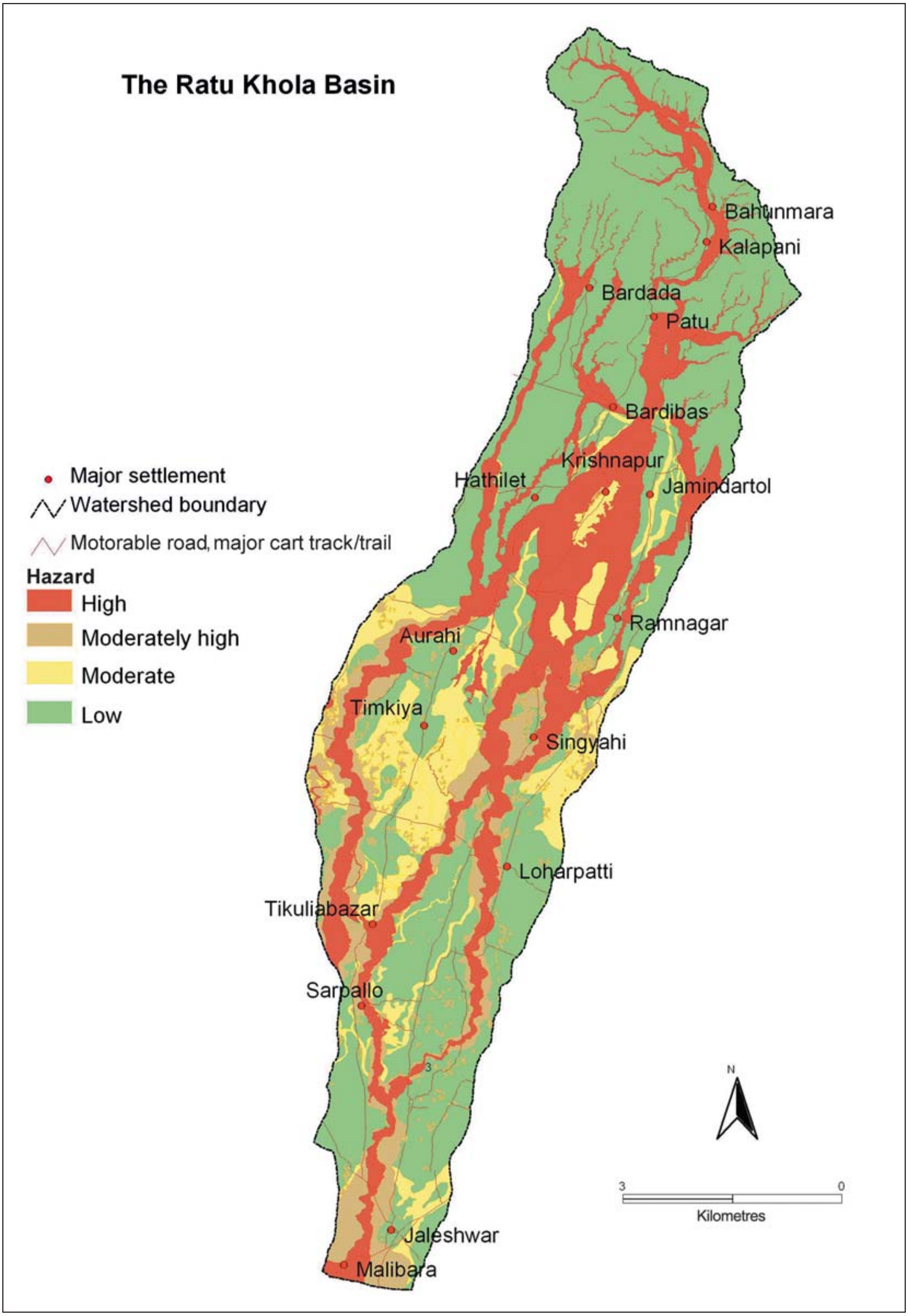

Figure 2.30: **Composite flood-hazard map**

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.

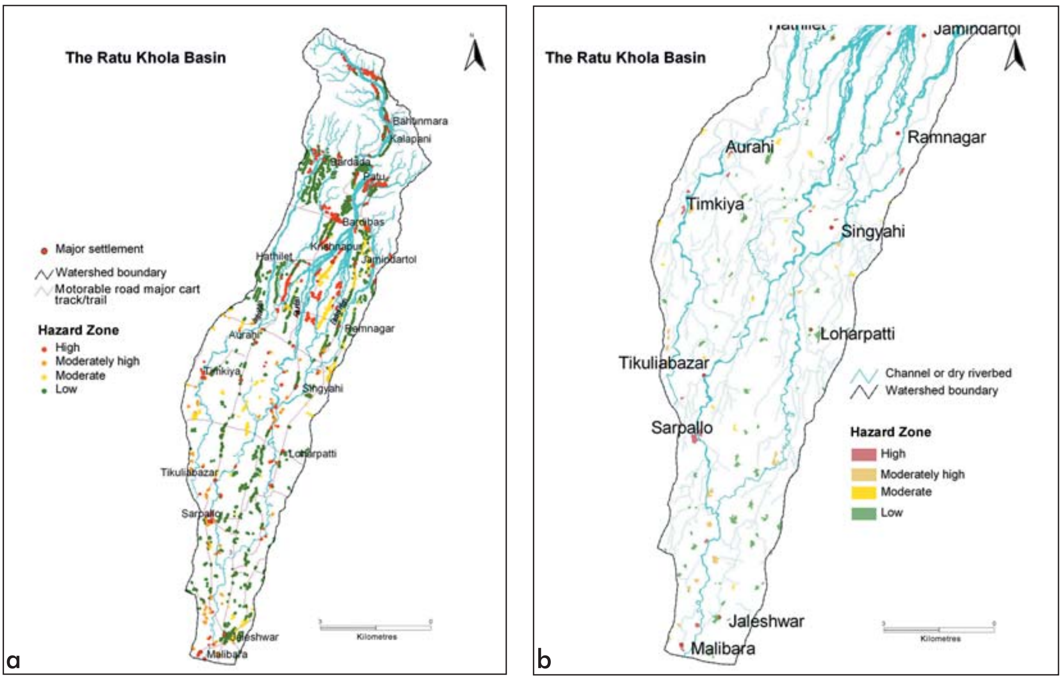

Figure 2.31: **House units (a) and built-up areas (b) at risk from flood hazard**

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.

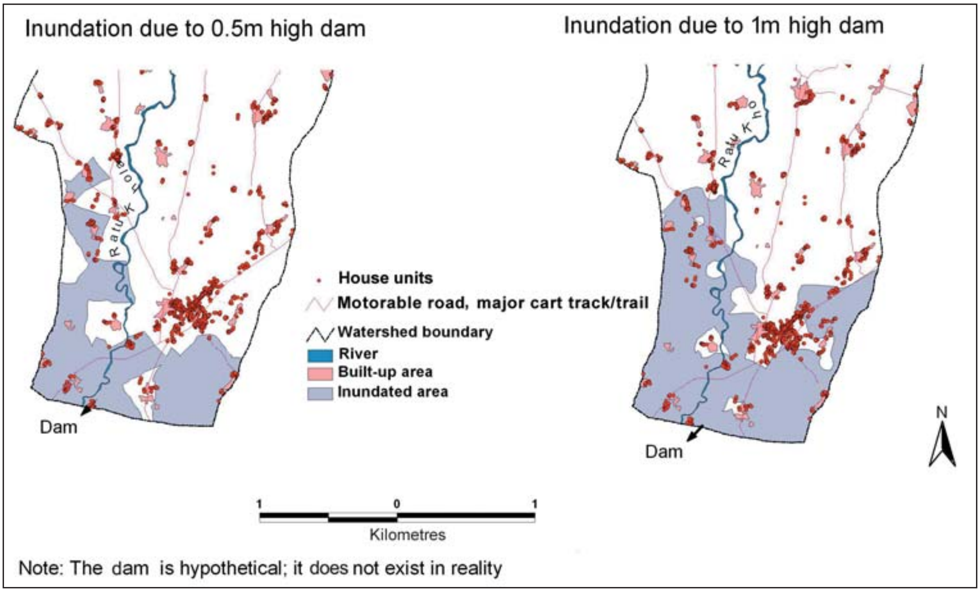

Figure 2.32: **Theoretical inundation due to flow intervention by a structure at the Indo-Nepal border**

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.

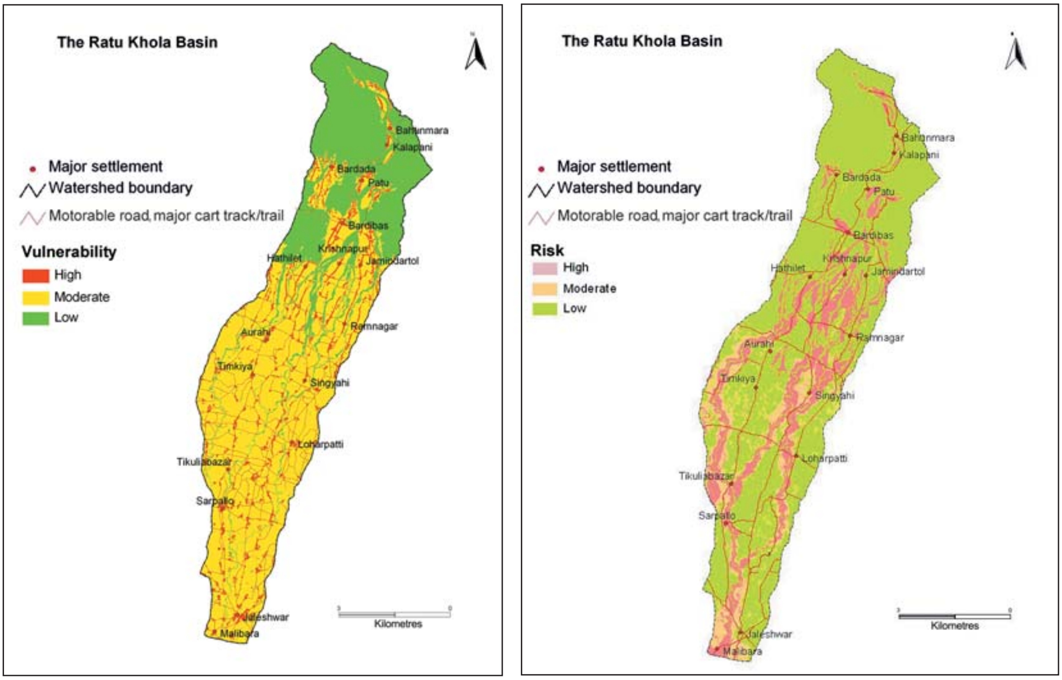

Figure 2.33: **Vulnerability** (left) **and risk maps** (right)

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.

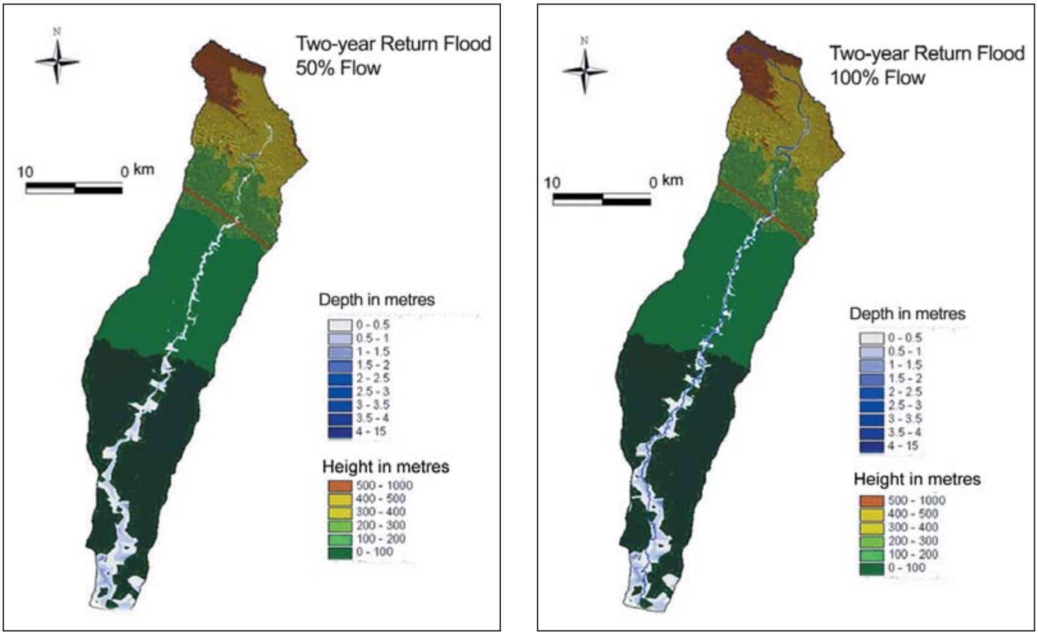

Figure 2.34: **Two-year return flood with 50** (left) **and 100%** (right) **flow**

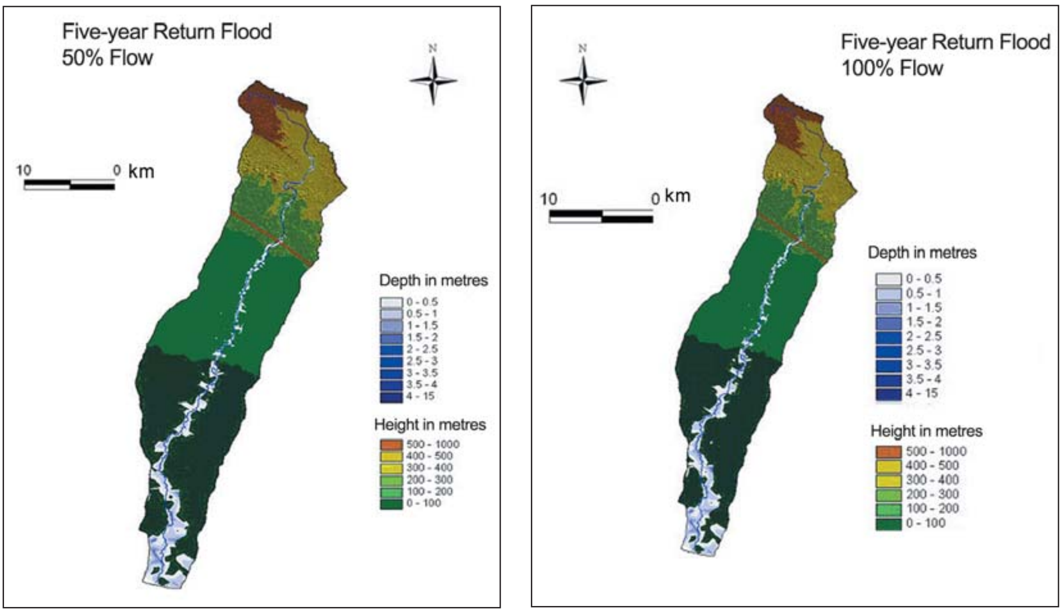

Figure 2.35: **Five-year return flood with 50** (left) **and 100%** (right) **flow**

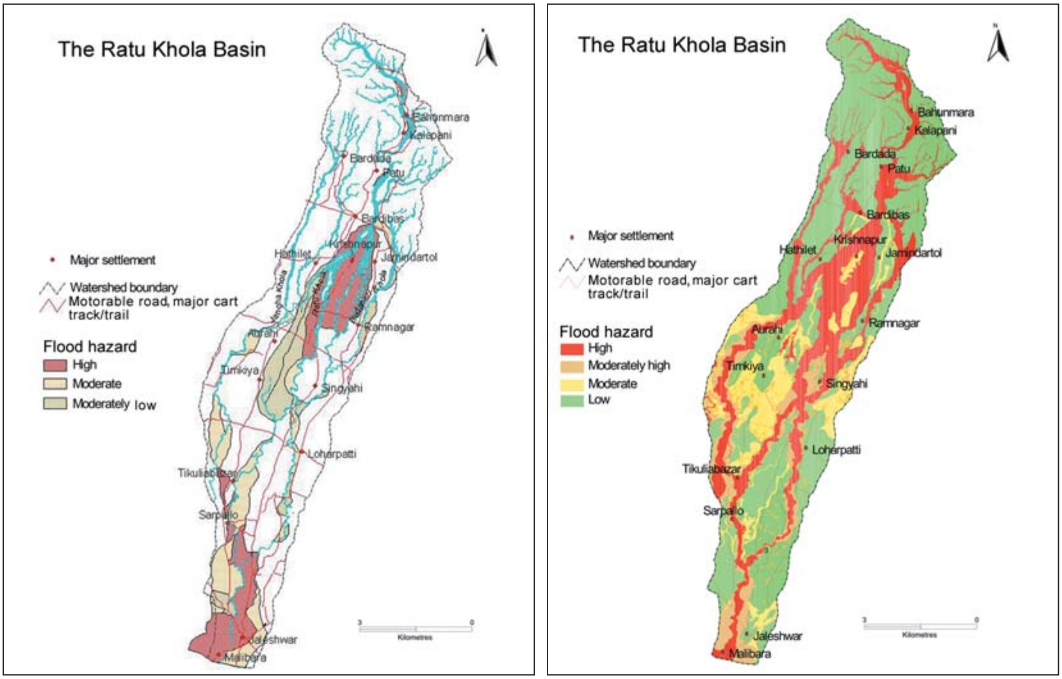

Figure 2.36: **Flood-hazard maps: social** (left) **and geomorphic** (right) **approach**

Chapter 3

Preparing for Disaster, Reducing Risk, Building Resilience:

Study Results and Recommendations

Community members build gabion walls to prevent the Ratu Khola flooding their farms.

Introduction

Though the loss and damage from some natural hazards are high, in the long run floods cause more damage and devastation than any other natural hazard. Although floods cannot be controlled, losses due to floods can be reduced to a great extent by implementing a proper flood-management programme. A holistic flood-mitigation and management strategy, including pre-flood planning, operational flood management, and post-flood response, is necessary to reduce the loss. An understanding of the level of hazard, risk, vulnerability, and the capabilities of local people to respond to disaster provides the basis for developing holistic flood-mitigation and management strategies.

Building community capabilities to anticipate, cope with, resist, and recover from the impact is important for effective flood mitigation and management. Hazard, risk, and vulnerability mapping and zoning, awareness creation, early warning systems, and preparedness planning are some of the important tools for building a disaster-resilient community. One of the steps in promoting community resilience is to improve its emergency preparedness and capacity to respond. This can be achieved through provision of an emergency population warning system, shelter, evacuation, stockpiling of supplies and equipment, and training of emergency services.

The results of flood-hazard, risk, and vulnerability mapping in terms of location and level of exposure in the Ratu Watershed have been presented in Chapter 2. An attempt is made in the following to assess hazard, risk, and vulnerability in the Ratu Watershed. Socioeconomic vulnerability, focusing on the losses from floods and other water-induced disasters is also discussed. Local coping capacity was assessed in terms of the socioeconomic characteristics of the people exposed to floods and other water-induced disasters. People's responses in terms of flood mitigation and management in the past are also discussed and efforts aimed at promoting community resilience are also briefly described in this chapter.

Methodology

Assessment of hazard, risk, and vulnerability in the Ratu Watershed was based on primary data collected from the field from July to August 2003. Primary data, basically on past hazards, socioeconomic conditions, vulnerability, response capabilities, and efforts made by local people to mitigate floods and other water-induced disasters in the recent past, were collected during field work.

Information on the magnitude, recurrence intervals, and damage from different types of disaster was collected through group discussions with the help of structured checklists. Local elders and knowledgeable people were consulted to collect data from the past.

Socioeconomic data of all the VDCs located in the Ratu Watershed were collected with the help of a structured checklist prepared for this study. In order to assess the response and recovery capabilities of individual households, information on the perception of local people about flood hazards and efforts made to mitigate hazards at household level was collected through household surveys. Because of time constraints, it was not possible to survey all the households in the basin so stratified random sampling was adopted. Stratification or zonation of areas was carried out based on the expected level of hazard: high, medium, or low. Thirty households from each hazard zone (high, medium, low) were selected at random for the survey. Households from different areas were chosen in such a way that all the areas within the basin were represented.

In order to enhance community resilience and equip the communities with necessary information, a micro-level study was carried out to identify and delineate safe areas for evacuation routes and shelters in the downstream area, and training was given to local people on precipitation and river discharge stage reading in upstream areas. The methodology adopted to identify and delineate safe areas for evacuation routes and shelters is discussed below.

The Jaleshwar municipality and its adjoining areas downstream from the Ratu Khola were selected for detailed flood-hazard mapping with enhanced topographic maps (Figure 3.1). For this, a detailed topographic survey was carried out with 20 cm accuracy. After incorporating topographical information obtained from the detailed field survey, a triangular irregular network (TIN) and contour map with intervals of 10 cm were generated. A cross-sectional survey was carried out along the river over a span of 3 km upstream near Gena Bathnaha to 2 km downstream near Dhabauli. Each cross-section contained topographical information covering 200m right and left of the centre line of the river. Detailed information about existing river-training work (mainly levées) and their present conditions, and other features such as roads, mule tracks, land use and land cover, was also collected during the field survey.

The water-surface profile was calculated using HEC-GeoRAS software. The step-wise procedure followed for HEC-GeoRAS during processing has been shown in Figures 2.20 and 2.21 in Chapter 2.

The relationship between rainfall and runoff was examined using the TANK model. Since the Ratu Basin has no observed discharge data, the calibrated parameters of the TANK model for the Bagmati Basin (Gauge stn. 586) was used on the assumption of similar catchment characteristics.

The rainfall of the basin was computed using rainfall data recorded at Tulsi (Stn. 1191) and Gausala (Stn. 1122) on the basis of area weightage of their respective Thiessen polygons. The area of the basin and its percentage weightage for the rainfall for Jaleshwar gauging station were estimated.

The rainfall data for the years 1979, 1980, 1987, 1988, and 1989 recorded at Tulsi and Gausala meteorological stations provided by the Department of Hydrology and Meteorology were used to simulate the corresponding discharge. The rainfall-runoff trends for wet season months (June-September) and their correlation coefficients (R^2) were calculated using linear, polynomial power, exponential, and logarithmic functions. The corresponding regression equation having the highest 'R^2' value was then used to forecast the discharge for different rainfall events.

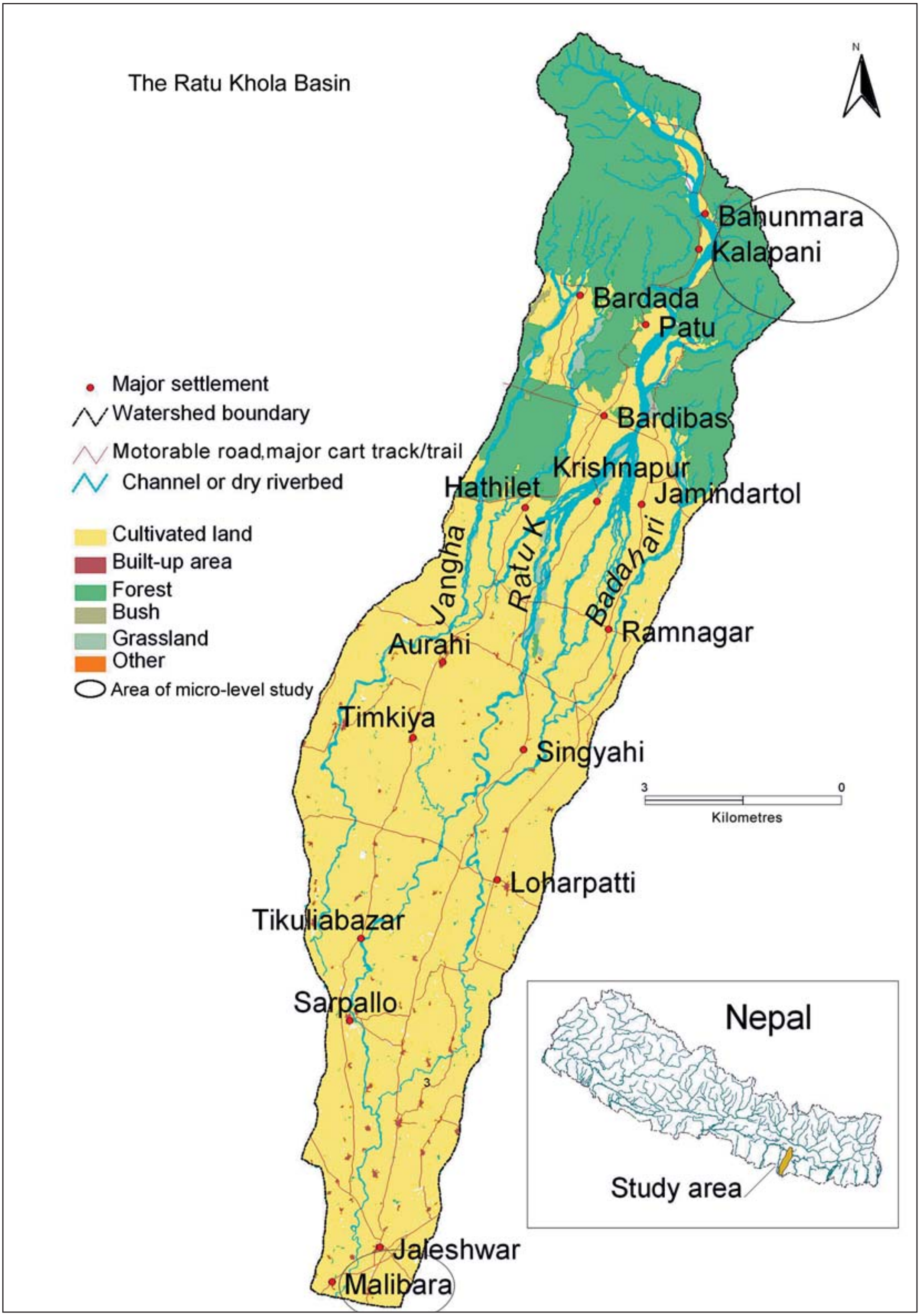

Figure 3.1: **Location of areas selected for the micro-level study**

Frequency analysis for rainfall was carried out. The one-, two-, and three-day maximum rainfall was calculated for return periods of 2, 5,10, 25, 50, and 100 years with Extreme Value Type-I distribution (Gumbel Distribution), the results were presented in Table 2.4 in Chapter 2.

Finally, a flood-hazard map was prepared based on the enhanced topographic information along with estimated flood peaks of a 2-, 5-, 10-, 25-, 50-, and 100-year return period using Dicken's formula (Table 2.2 in Chapter 2) and various flood events obtained from the regression equation having the highest 'R^2' value.

Results

The results of the assessment of flood hazards, risk, and vulnerability are presented below. Attempts are also made to discuss the response and resilience of the local people.

Loss and damage from different natural hazards

Different types of hazards occur in the watershed causing great loss of lives and property. These include landslides, debris flows, floods, riverbank cutting, river-channel shifting, droughts, earthquakes, fire, hailstorms, lightning, windstorms, cold waves, and disease and pests. Since many of the settlements are located in the plains area of Bhabar and the Terai, direct losses from landslides and debris flows are not reported. However, landslides and debris flows occur frequently in the upstream areas in the Churia region triggering water-induced disasters such as floods, bank cutting, channel shifting, and river-bed rise in densely inhabited downstream areas.

Thirty-four floods and 30 riverbank cutting events causing loss of property were reported in the watershed during the 42-year period between 1961 and 2003 (Table 3.1). Floods occur almost every year causing loss of life and property in the watershed. Seven events of river shifting in 37 years (every 5-6 years) and 18 events of river-bed rise in 35 years (every two years) were reported. Only one earthquake causing loss of life and property was reported from the watershed during this period.

Fire is a common disaster in the watershed and occurs in one place or another every year. Other climatic hazards that occur from time to time and cause loss of life and property in the watershed include hailstorms, lightning, droughts and cold spells. A total of 16 hailstorms (one in 2-3 years), 20 lightning strikes (one in 2 years), nine hailstorms (one in 5 years), 22 droughts (one in 2-3 years), five cold spells (every year), and 17 events of pest and disease (1-2 years) were reported from the watershed.

Table 3.2 shows the annual loss of life from different hazards in the watershed. About 46 persons are killed annually because of different hazards. More than 41 people die due to cold spells, followed by pests/diseases (2 persons), and floods (1 person). Lightning strikes, fire, and windstorms are also a cause of death almost every year.

Table 3.1: Frequency of different natural hazards and their recurrence intervals			
Types of hazard	Frequency of occurrence	Number of years covered	Recurrence intervals
Floods	34	42	1.2
Riverbank cutting	30	42	1.4
River shifting	7	37	5.3
River-bed rise	18	35	1.9
Earthquakes	1	42	42.0
Fire	45	60	1.3
Hailstorms	16	44	2.8
Lightning strikes	20	41	2.1
Windstorms	9	28	3.1
Droughts	22	52	2.4
Cold waves	5	5	1.0
Pests/diseases	17	26	1.5

Source: Field survey 2003

Table 3.2: Annual loss of life caused by different hazards	
Types of Hazard	Number of Deaths
Flood	1.0
Riverbank cutting	0.0
River shifting	0.0
Riverbed rise	0.0
Earthquakes	0.0
Fire	0.4
Hailstorms	0.0
Lightning strikes	0.6
Wind storms	0.3
Droughts	0.0
Cold wave	41.2
Pests/diseases	2.3
Total	**45.7**

Source: Field survey 2003

Annual loss of property at the watershed level from different hazards is given in Table 3.3. A total of 273 animals are killed every year. About 323 houses, 1,830t of crops, 96 ha of land, and 11 different types of infrastructure are damaged annually from different disasters in the watershed. Floods account for more than 41% of the total value of private and public assets damaged every year, followed by river-bank cutting (27.7%), cold spells (9.8%), fire (5%), riverbed rise (3%), droughts (2.8%), pests and diseases (1.1%), and wind storms (1%). Average per annum loss per household from these disasters is about Rs 550. Assets

Table 3.3: Annual loss of property caused by hazards							
Types of Hazard	Animals (No.)	Houses (No.)	Crops (t)	Land (ha)	Infrastructure (No.)	Amount	
						Million Rs	%
Flood	30.1	132.9	813.5	39.2	5.1	15.53	41.3
Bank cutting	0.6	13.0	184.8	42.4	2.2	10.42	27.7
River shifting	0.7	0.6	14.7	7.1	2.9	2.82	7.5
River-bed rise	0.8	8.0	59.1	7.5	0.1	1.12	3.0
Earthquake	0.0	2.2	0.0	0.0	0.0	0.06	0.2
Fire	14.1	82.9	33.7	0.0	0.0	1.88	5.0
Hailstorm	0.0	5.9	21.4	0.0	0.0	0.19	0.5
Lightning strike	0.7	0.4	0.2	0.0	0.0	0.03	0.1
Wind storm	0.0	76.8	0.2	0.0	0.5	0.39	1.0
Droughts	0.0	0.0	263.9	0.0	0.0	1.04	2.8
Cold spell	183.0	0.0	414.0	0.0	0.0	3.69	9.8
Pest/diseases	43.2	0.0	24.5	0.0	0.0	0.40	1.1
Total	**273**	**323**	**1830**	**96**	**11**	**38**	**100**

Source: Field survey 2003

amounting to nearly Rs 437 (79.5% of the total loss) is lost from each household at the watershed level from water-induced disasters such as floods, river-bank cutting, river shifting, and river-bed rise. Annual loss of property from households located in hazard-prone areas is extremely high.

A survey of 136 households living in hazard-prone areas with varying degrees of risk (high, medium, and low) shows per household annual income of Rs 90,613 with per capita income of about Rs 12,000 (Table 3.4). The main source of income of households living in hazard-prone areas is agriculture (38.6%), followed by services (18.7%), remittances (13.4%), trade and business (8%), and horticulture and vegetables (5%).

In the hazard-prone areas, annual loss per household from different hazards is reported to be Rs 7,389, which is equivalent to 8% of total annual household income. Floods, riverbank cutting, and channel shifting in combination cause more than 70% of the total losses among these households.

A survey of local perception regarding the trend of occurrence of different disasters and the amount of loss from these disasters showed that both the frequency and the loss from floods and river-bank cutting has been increasing in the watershed in the recent past. More than 76% of households perceived an increase in the frequency of occurrences of flood and riverbank cutting and in losses from these events. Though per event loss from earthquakes is extremely high, the occurrence of high magnitude earthquakes damaging large amounts of infrastructure is not so common. Therefore, in the long run, damage from floods, riverbank cutting, and channel shifting is high in the study area. Losses from fire have decreased significantly in recent times, whereas losses from cold wave have

Table 3.4: Annual household income and losses among households in flood-prone areas		
Sources of income and loss	Annual income all HHs (Rs)	%
Agriculture	4,760,450	38.6
Horticulture and vegetables	631,760	5.1
Livestock	363,450	2.9
Cottage industries	18,000	0.1
Trade and business	984,000	8.0
Wages	955,450	7.8
Services	2,310,304	18.7
Remittances	1,649,800	13.4
Pensions	121,800	1.0
Other sources	528,400	4.3
Total	12,323,414	100
Per household income		90,613
Per capita income		11,999
Per household loss		7,389
% of loss in total household income		8.2

Source: Field survey 2003

been increasing. The occurrence of and losses from droughts, hailstorms, pests, and diseases are more or less constant compared to the past. However, there is an increase in the occurrence of windstorms and the losses incurred from them.

Loss and damage from floods and other water-induced disasters

It is evident from the above discussion that the loss of property from water-induced disasters – floods, riverbank cutting, and river shifting – is extremely high compared to loss as a result of other hazards occurring in the watershed. Both the frequency of water-induced disasters and the losses from them have been increasing. Drastic changes in land use and land cover (deforestation), excavation of the river bed for construction materials such as gravel, and development of infrastructure (roads, culverts, bridges, buildings) without due consideration being given to draining the natural flow of water are some of the reasons for an increase in the frequency and magnitude of flood and river-bank cutting in the watershed. A survey of 48 VDCs/municipalities in the watershed shows that on average 955 ha of land are flooded every year in the watershed. Highly damaging floods in terms of loss of human lives occurred in 1961, 1977, and 1997 (Table 3.5). However, the loss of assets was high in 1988, 1993, 1995, 1998, 2001, and 2002 (Figure 3.2).

Flooding due to shifting of the river channel and rises in the river bed due to siltation of sand and gravel along the river channel are also common in the watershed. Seven events of river-channel shifting causing heavy loss of life and property have been reported in the watershed (Table 3.6).

Table 3.5: **Annual loss of life and property caused by flood hazards**

Year	Area flooded (ha)	People killed (No.)	Animals (No.)	Houses (No.)	Crops (t)	Land (ha)	Infrastructure (No.)	Amount Million Rs
1961	1235	6	25	118	1964	111	4	7.84
1963	342	0	48	39	444	44	1	0.99
1965	976	1	23	120	1648	112	0	11.01
1967	139	0	13	97	207	21	0	1.24
1968	45	0	0	0	11	1	1	0.03
1970	186	0	10	10	173	8	0	0.42
1971	1665	0	105	126	2741	112	10	1.63
1973	165	0	0	6	160	3	2	0.31
1974	24	0	0	0	48	15	0	0.75
1975	3479	2	110	341	1641	75	10	5.99
1977	702	8	100	300	3335	78	4	7.57
1978	944	2	5	152	1585	69	0	7.58
1979	265	0	25	63	361	17	3	2.22
1981	15	2	2	5	45	10	1	2.82
1983	221	0	0	0	143	4	2	1.81
1984	627	0	37	53	1021	66	0	16.48
1985	1542	0	120	180	475	10	13	11.23
1987	3284	3	52	544	2151	56	21	19.28
1988	1967	4	20	372	2770	144	6	49.17
1989	470	0	1	33	267	22	3	3.58
1990	324	0	0	0	98	4	0	1.27
1991	70	0	0	10	121	11	2	2.74
1992	328	0	0	7	163	4	0	1.53
1993	1810	0	10	399	3110	162	12	55.09
1994	1195	1	32	127	390	23	14	16.10
1995	1183	0	36	254	548	37	12	58.98
1996	350	0	0	100	275	0	1	5.13
1997	4133	10	322	519	1815	78	17	54.54
1998	1832	0	25	103	954	55	6	23.44
1999	2060	0	35	250	582	27	20	31.20
2000	715	0	0	154	151	0	4	8.62
2001	1533	1	50	395	808	69	14	63.55
2002	5573	0	58	699	3932	201	30	175.49
2003	720	0	0	7	34	3	0	2.70
Average	955	1	30	133	814	39	5	16.0

Source: Field survey 2003

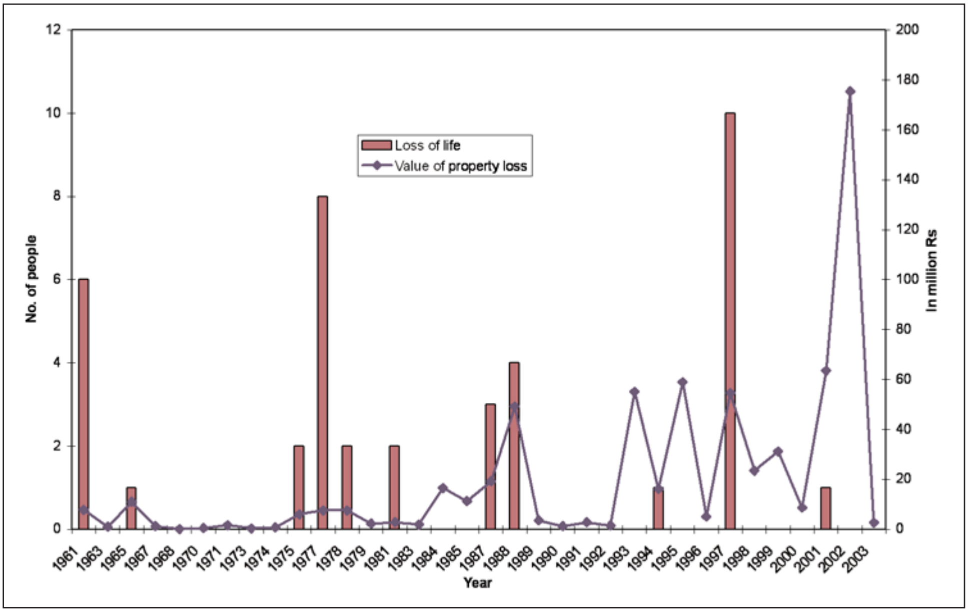

Figure 3.2: **Loss of life and property from flood hazards, 1961-2003**
Source: Field survey 2003

Table 3.6: **Average annual losses and damage**			
	From river channel shifting	**From floods triggered by rises in the river bed**	**From river bank cutting**
Number of animals affected	0.7	0.8	0.6
Number of houses damaged	0.6	8.0	13.0
Crops (in t)	14.7	59.1	184.8
Damage land (in ha)	7.1	7.5	42.4
Number of infrastructural installations damaged	2.9	0.1	2.2
Amount of damages (in million Rs)	2.82	1.12	10.42

Source: Field Survey 2003

Seventeen floods triggered by rises in the river bed causing loss of life and property were reported during the field work. On average, 7.5 ha of land, 59t of agricultural crops, and eight houses were damaged amounting to Rs 1.12 million annually from the flood triggered (Table 3.6).

River-bank cutting during flooding is another major cause of water-induced disaster in the watershed. Table 3.6 shows the losses from river-bank cutting. In a span of 42 years, 32 river-bank cutting events have been reported from the watershed. Every year, about 42 ha of cultivated land, 185t of crops, 13 houses, and two different types of infrastructure are damaged due to river-bank cutting, and damages amount to Rs 10.42 million. The losses were comparatively high in 1988, 1993, 1998, and 2002.

Exposure and risk

Attempts have been made here to assess the people and assets exposed to water-induced disasters in the watershed. We attempted to quantify the proportion of people and assets located in areas susceptible to floods and other water-induced disasters. This information was derived basically from group discussions in each VDC and supplemented by the household survey.

People

Large numbers of people in the watershed are exposed to floods and other water-induced disasters such as river-channel shift, river-bank cutting, and so on. More than half (61%) of a total of 53,323 households in the watershed, or 32,593 households, are exposed to flood and water-related disasters (Table 3.7). Among them are 39% of households residing in hazard-prone areas. Another 22% have land and other property in the hazard-prone areas. The proportion of households exposed to floods and other water-induced disasters ranges from 57.8% in the upper region (Churia and Bhabar), to 58.1% in the middle, and 63.8 % in the lower part of the watershed. The proportion of exposed households of some ethnic groups is extremely high. Ethnic groups with a very high proportion of households exposed to disaster-prone areas are the Danuwar (96%), Kayastha (93%), Shah (93%), Kumar (80%), Nuniya (80%), Magar (75%), Newar (75%), and Halawai (70%). The Magar and Newar are ethnic groups of hill origin; the other ethnic groups are of Terai origin.

Property and Infrastructure

Property and infrastructure owned by the households, the community, and government are exposed to floods and other water-induced disasters in the watershed. These include land, agricultural crops, houses, sheds, irrigation canals, and so on. Similarly, community and government-owned infrastructure exposed to hazards includes schools, roads, dams, irrigation cannels, and others.

Table 3.7: Number of households exposed to water-induced disasters

Districts	Region	Watershed		Hazard-prone area			
		HH (No.)	Population	HH living	HH with land only	Total HH	%
Mahottari	Lower	28,607	173,241	11,795	6,469	18,264	63.8
	Middle	13,680	77,787	5,779	2,108	7,887	57.7
	Upper	8,348	46,129	2,470	2,600	5,070	60.7
	Total	**50,635**	**297,157**	**20,044**	**11,177**	**31,221**	**61.7**
Dhanusha	Middle	603	2,982	415	0	415	68.8
	Upper	2,085	10,855	470	487	957	45.9
	Total	**2,688**	**13,837**	**885**	**487**	**1,372**	**51.0**
Total	Lower	28,607	173,241	11,795	6,469	18,264	63.8
	Middle	14,283	80,769	6,194	2,108	8,302	58.1
	Upper	10,433	56,984	2,940	3,087	6,027	57.8
	Total	**53,323**	**310,994**	**20,929**	**11,664**	**32,593**	**61.1**

Source: Field survey 2003

The main land-use type in these areas is agriculture, followed by forests and grazing land (Table 3.8). Nearly 14,112 ha of 'khet' (irrigated agricultural land), 247 ha of 'bari' (unirrigated agricultural land), 89 ha of grazing land, and 870 ha of forest land is located in areas susceptible to floods and other types of water-induced disasters

Table 3.8: Land use in areas susceptible to flooding

Land-use type	Area (ha)	%
Khet	14,112	92.1
Bari	247	1.6
Grazing land	89	0.6
Forest land	870	5.7
Total	**15,318**	**100**

Source: Field survey 2003

The major crops grown in the watershed are paddy, maize, potato, sugarcane, lentils, and different types of leguminous crops. Nearly 47% of all the crops grown in the watershed are grown in areas susceptible to floods and other water-induced disasters. Among the crops grown barley, soybeans, red gram, and other leguminous crops are highly exposed to natural hazards. Similarly, more than 55% of all the vegetables and spices grown in the watershed are grown in hazard-prone areas. Mangoes, jackfruit, bananas, papaya, pineapples, litchis, guava, and lemon are the main fruits produced in the watershed; nearly 47% of the fruit is produced in hazard-prone areas.

Nineteen thousand nine hundred and four houses, 6,589 sheds, 72 schools, 105 other public buildings, 157 rice mills, 85 temples, and 235 ponds are located in areas susceptible to floods and other types of water-induced disaster in the Ratu Watershed.

Vulnerability

Exposure of households and property

Hazard-prone areas were classified into three groups based on the level of hazard, high, medium, and low. Rating was carried out by local people based on their experiences and their perception regarding the level of danger from floods and other water-induced disasters. The level of vulnerability to hazards has been classified into four categories – very high, high, moderate, and low – on the basis of the magnitude of household property located in areas susceptible to floods and other water-induced disasters. Table 3.9 shows the percentage of households with different levels of vulnerability to different levels of hazard in the Ratu Watershed. Thirty-two thousand five hundred and ninety-three households, 61.1% of the households in the watershed, are living or have property in areas susceptible to floods. Out of these exposed households, 15,514 households (47.6%) have property in a high-hazard zone, 11,929 households (36.6%) in a medium-hazard zone, and 5,150 households (15.8%) in a low-hazard zone. The number of households having houses and above 50% of their property in a high-hazard zone is 6,845 (21%). These households are the most vulnerable from the point of view of exposure. Similarly, the number of moderately to highly vulnerable households with a considerable proportion of property located in a high-hazard zone is 5,639 (17.3%).

Table 3.9: Percentage of households with different levels of vulnerability					
Level of vulnerability	Household possessions in flood prone areas	Level of hazard			
		High	Medium	Low	Total
Very high	House and above 50% of property	21.0	11.9	4.6	37.5
High	House and property 50% and less	12.7	9.7	3.6	26
Moderate	House above 50% of property	4.6	3.7	2.3	10.6
Low	House but 50% or less of property	9.3	11.3	5.3	25.9
Total		**48**	**37**	**16**	**100**

Note: Total figures are rounded to the nearest whole number.
Source: Field survey 2003

Types of houses exposed to hazards

The roofs of nearly 50% of houses, including sheds owned by the surveyed households, are made of 'khapada/jhingati' (leaves or straw). About 51% of the houses have roofs made of tiles (typical brick). Houses with concrete roofs account for less than 1%. The walls of more than 76% of the houses are made of mud and bricks; about 8% of the houses have walls made of 'tati' (bamboo) and hay; and about 12% of the houses have wooden walls. About 82% of the houses are one storey. Many people are poor and cannot afford to build concrete houses strong enough to resist even the stress from sheet flooding or inundation.

Occupation and sources of income of exposed households

Fifty-eight per cent of the population (15-59 years) is economically active, while 42% is dependent(<15 and above 60 years). Agriculture is the mainstay of 60% of the economically-active people living in flood-prone areas. About 27% of the people are students and the rest are mainly engaged in service (5%), wage labour (3%), and jobs outside Nepal mainly in India and the Middle East (3%). Engagement in trade and business and others only account for about 2%.

More than 46% of total household income in flood-prone areas is from agriculture; this includes horticultural products, vegetables, and livestock. The other major sources of income in the flood-prone areas are service occupations (19%), remittances (13%), trade and business (8%), and wage labour (8%). The income from agricultural sources is highly susceptible to damage from floods and other water-induced disasters. Property equivalent to 8% of total income is lost to floods every year, a very high figure. People have to invest a portion of their incomes to reclaim the land and reconstruct infrastructure. Thus, floods and disaster affect people's livelihoods.

Crop productivity and food sufficiency in the flood-prone area

The main crops grown by households sampled in flood-prone areas are paddy, wheat, maize, sugarcane, pulses, and potato (Table 3.10). More than 80% of the cropped area and the production of paddy, wheat, maize, millet, potatoes, and lentils are from flood-prone areas. Though the productivity of the main crops (paddy, wheat, and maize) is below the national average, at 2,700, 1,900, and 1,800t/ha, respectively, in the watershed, the productivity of paddy in the hazard-prone area is comparatively high at 2,156t/ha in the flood-prone area compared

Table 3.10: **Area, production, and yield in the hazard-prone area**

	Within hazard-prone area			Outside hazard-prone area			% within	
	Area (ha)	Production (t)	Yield (t/ha)	Area (ha)	Production (MT)	Yield (t/ha)	Area	Production
Paddy	98	211,292	2,156	20	37,910	1,896	83	85
Wheat	39	48,652	1,247	8	10,530	1,316	83	82
Maize	17	22,710	1,336	3	3,617	1,206	85	86
Sugarcane	15	619,500	41,300	10	707,200	70,720	60	47
Millet	4	2,696	674	0	0	0	100	100
Pulses	12	8,869	739	4	3,535	884	75	72
Potato	7	39,710	5,673	1	4,615	4,615	88	90
Lentil	1	402	402	0	0	0	100	100

Source: Household survey 2003

to 1,896t/ha outside. Low productivity of main crops in this area compared to the national average implies the population's poor capacity to respond to natural disaster.

About 52% of households do not have sufficient food from their own production (Figure 3.3). This clearly suggests that people are highly vulnerable to flood hazards and their capacity to respond, in general, is very low.

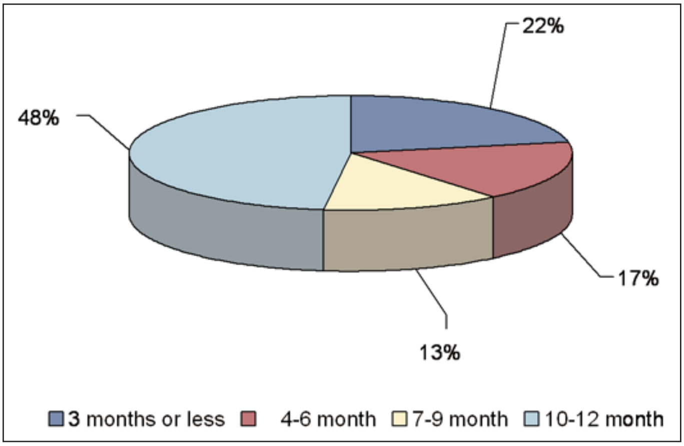

Figure 3.3: **Households with food sufficiency**

Past mitigation and management efforts

Different strategies have been adopted locally by people at individual and community levels to reduce the impact of floods and other water-induced disasters in the Ratu Watershed. During group discussions, it was revealed that emergency and mitigation measures had been implemented in 78 different locations.

Emergency measures

Emergency measures are the most common form of relief response for flood victims. Emergency measures include evacuation and provision of food supplies, tents for shelter, utensils, medicine, and cash. From local sources, it was learned that a total of Rs 4,196,700 had been spent on various emergency measures between 1984 and 2002. This totals an annual investment of Rs 233,150 per year in emergency measures. Out of this amount, the amount spent on food and evacuation was about 49% and 20%, respectively. About 18% was provided as cash to the victims: about 9% was given for the purchase of essential clothing. Money spent on tents and medicine accounted for only 1% (Figure 3.4). The key agencies involved in emergency response are the Nepal Red Cross Society, the District Development Committee (DDC), the Chief District Officer's (CDO's) office, and the Soil Conservation Office, which contributed about 35, 27, 16, and 9%, respectively. Other minor sources of emergency funding are the political parties (2%), the Parliamentary member's fund (1%), and others (10%). However, people still complain that emergency services are inadequate and often lack transparency and equitable distribution.

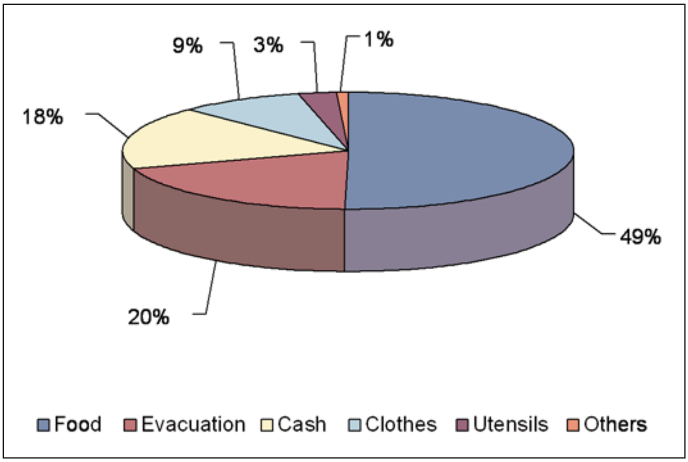

Figure 3.4: **Money spent on various emergency measures**

Flood-mitigation measures

Flood mitigation measures include construction of dams, spurs, retaining walls, plantation and afforestation, and drainage management. During group discussions, it was estimated that about NRs 1.5 million was spent annually on these activities in the watershed. Large sums are spent on the construction and maintenance of retaining/gabion walls, check dams, and spurs (92%). About 5% of the total amount is spent on the construction of dams and retaining walls from local materials and with traditional technology. About 3% of the money for mitigation was spent on plantation and afforestation activities, which are less costly but effective in reducing flood impacts in the long run. The intrusion into natural drainage by the indiscreet construction of bridges, roads, culverts, houses, and other infrastructure without provision of proper drainage has exacerbated the inundation problem recently; and yet a very negligible amount is spent on drainage management. The government and non-government agencies, apart from the local community, involved in mitigation measures are the DDC, VDC, the Water Induced Disaster Prevention Office, Soil Conservation Office, and District Irrigation Office among government agencies; and the Nepal Red Cross Society, a non-government organisation, which has been contributing money for flood-mitigation measures (Figure 3.5). The Churia Watershed Conservation Project, in coordination with the District Soil Conservation and the District Forest Office, has been engaged in watershed management through activities like afforestation and micro-watershed management through erosion and gully controls in the upper catchments.

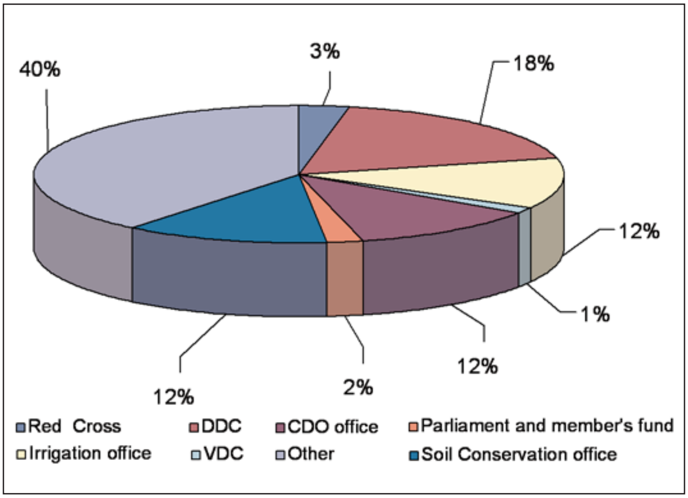

Figure 3.5: **Contributions made by various agencies/institutions for mitigation measures**

Proposed future activities

People have perceived that a fragile basin, heavy and prolonged rain during the monsoon, unstable rivers, growing human occupancy and activities, and development of infrastructure without due consideration for proper drainage are the main causes of increased flood disasters in the area. They have put forward some long-term and short-term flood mitigation proposals for the watershed. The long-term measures include six major components: i) river control through permanent structures such as check dams; afforestation along the river banks and cleaning of the river bed to increase the discharge capacity of the channel; ii) drainage management; iii) conservation of the Churia area through guided human activities; iv) awareness creation; v) improvement in livelihoods through increase in irrigation facilities and providing loans for off-farm employment opportunities; and vi) strengthening local institutions for disaster mitigation. The timely and effective short-term measures recommended by the local people include: i) evacuation of flood-affected people and their portable property; ii) timely provision of tents, food, clothes, utensils, and medicine in a fair and equitable manner; iii) a food for work scheme for the flood victims; iv) provision of shelter with service facilities like drinking water, toilets, and so on in safe localities for the refuge of victims until they can renovate, rehabilitate, or reconstruct their own houses; v) provision of seeds and fertiliser to the victims; and vi) promotion of a rotational fund and a feasible insurance scheme for people living in areas susceptible to flood hazards.

Table 3.11: Estimated cost of proposed emergency measures (million Rs)				
Types of activity	**Estimated total cost**	**Local contribution**	**Expected outside contribution**	**% of local contribution**
Evacuation	182.14	1.83	180.31	1.0
Food	15.14	0.46	14.68	3.0
Clothes	5.82	0.37	5.45	6.4
Tents	0.77	0.03	0.74	3.3
Cash	4.43	0.24	4.19	5.4
Medicine	1.86	0.06	1.80	3.3
Utensils	0.05	0.00	0.05	0.0
Others	35.56	0.00	35.56	0.0
Total	**246.00**	**3.00**	**243.00**	**1.2**

Source: Field survey 2003

For the measures recommended above, people are willing to contribute some of the money needed for the measures recommended. Of the total estimates for the implementation of emergency measures, people are willing to contribute about 5% to all types of emergency response. On average, they can contribute about 1.2% of the total estimated cost (Table 3.11).

Construction and maintenance of gabion walls, spurs and embankments, drainage management, control of the river course, and plantation were perceived as priority activities for physical mitigation measures. However, the contribution expected from local people to implement these measures is very low, i.e., 2.2% (Table 3.12). People are only willing to contribute substantially for plantation and construction of a traditional retaining wall with mud embankments.

Building community resilience

A preparedness plan to reduce the impact of flood disasters has not yet been developed. Keeping in mind the recommendations made during the workshop organised to disseminate and discuss the findings of the first phase, an attempt was made to develop and test the methodology for delineation of safe areas for evacuation routes and shelters downstream and to strengthen local capacity to establish an early warning system through training. This training focused on reading precipitation and river discharge gauges in the upstream area.

Table 3.12: Estimated cost of proposed mitigation measures (Million Rs)				
Type of activity	**Estimated total cost**	**Local contribution**	**Expected outside contribution**	**% of local contribution**
Retaining/gabion wall	429.40	15.14	414.27	3.5
Embankment construction and maintenance	567.90	10.06	557.84	1.8
Plantation/afforestation	2.10	0.33	1.77	15.8
Retaining wall with mud embankment	0.80	0.20	0.60	25.0
Drainage management	193.25	0.77	192.48	0.4
Total	**1193**	**27**	**1167**	**2.0**

Note: Totals have been rounded to the nearest whole number.
Source: Field survey 2003

A short training programme was organised in the Bahunmara area. A rain gauge for monitoring intense rainfall was installed in a primary school, to be used to warn the downstream areas prone to flooding. Teachers and students were trained how to read the rain gauge and record precipitation.

Safe areas for evacuation route and shelter in the downstream area at Jaleshwar municipality and its adjoining areas were delineated for different discharge rates. Ratu Khola is not gauged; the discharge was simulated in response to measurement of 24 hours' rainfall using the TANK model. Flood events with discharges of 160 m^3/s, 180 m^3/s, 507.52 m^3/s, and 1,016.37 m^3/s were used for delineation of the floodplain. The figures were subjectively chosen in order to show degrees of flood hazard. The rainfall events producing these flood events during different months are summarised in Table 3.13.

Table 3.13: **Rainfall events (mm) producing flood events (m^3/s)**

Month	Regression equations	Flood m^3/s	160	180	507.52	1016.37
June	$y = 377.72Ln(x) - 1039$	Rainfall mm	23.91	25.21	60.00	230.79
July	$y = 342.3Ln(x) - 974.94$		27.54	29.20	76.00	336.11
Aug.	$y = 42.314x^{0.5516}$		11.15	13.80	90.40	318.36
Sept.	$y = -0.0266x^2 + 11.464x - 163.82$		30.39	32.43	69.90	170.00

In order to visualise the flood hazard in terms of water depth, maps were prepared by reclassifying flood-area grids into flood-depth polygons bounding the water depth at intervals of 0.15-0.5, 0.5-1.0, 1.0-2.0, 2.0-3.0, 3.0-4.0, 4.0- 5.0, 5.0-6.0, 6.0-7.0, 7.0-8.0, and 8.0-9.0 m. The areas bounded by flood polygons were calculated to make an assessment of the flood-hazard level. The results of this assessment are summarised in Figures 3.6 and 3.7.

Total area flooded in the Ratu Watershed with a two-year return period is estimated to be 35.2 sq. km and it is 39.9 sq. km for a 100-year flood. The classification of flood depth areas indicates that less than 9.34% of the flooded areas have water depths of less than 0.15m for a two-year flood and 5.43% for a 100-year flood. Most of the areas flooded (about 73%) have water depths of less

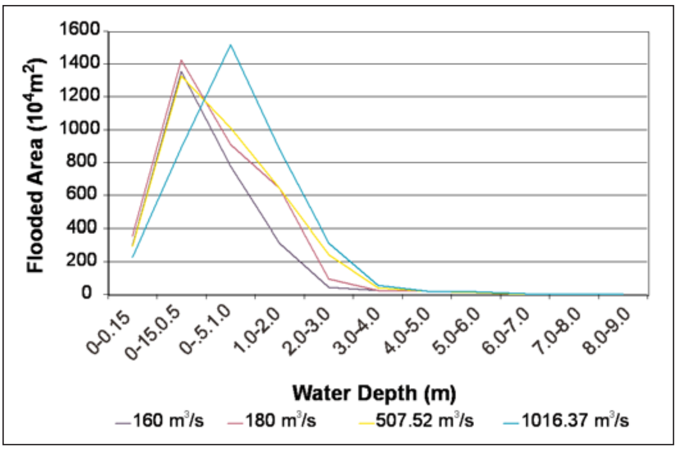

Figure 3.6: **Flooded area versus water depth for different flood discharges**

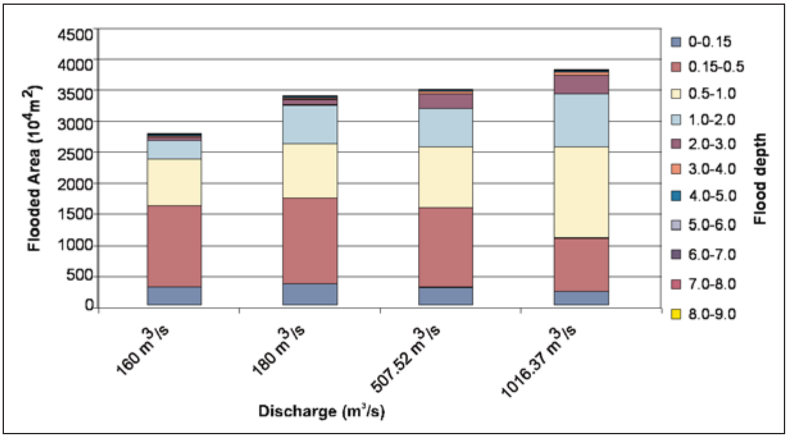

Figure 3.7: **Discharge, flooded depth, and area**

than 1m for a two-year flood and 65% for a 100-year flood. The areas under a water depth of more than 2m are quite small, although the area increases considerably with an increase in the intensity of flooding.

This analysis shows that a flood event of 160m^3/s does not inundate the settlement of the study area. Floods of this size are responses to rainfall of 23.91 mm, 27.54 mm, 11.15 mm, and 30.39 mm for the months of June, July, August, and September, respectively. Flood events of 180m^3/s inundate the settlement of the study area. The flood event of 180m^3/s is the response to the rainfall of 25.21 mm, 29.20 mm, 13.80 mm, and 32.43 mm for the months of June, July, August, and September, respectively. Hence the study area should be warned if the daily rainfall events exceed the value of 23.91 mm, 27.54 mm, 11.15 mm, and 30.39 mm for the months June, July, August, and September, respectively.

Evacuation routes leading to shelter areas for people and their livestock from the flooded zone are traced out on the hazard map following the land with minimum inundation depth. As little as 15 cm of moving water can knock people off their feet (as per FEMA [1995a] recommendation), evacuation must be completed before water levels along the route exceed 15 cm. The routes and the distance to the shelter areas for different localities are summarised in Table 3.14. The campus areas in Jaleshwar, Bakharibhath, and Bela and the western and eastern parts of Bajrahi, Ramaul, and Ratwada have been identified as safe areas for emergency shelter. The levée and road mark the evacuation route for Bela, whereas for other localities only the road network marks the routes.

Besides the small area of Jaleshwar Bazaar, no shelter area is without flooding. Although maximum inundation (up to 2.14 m for a two-year flood) takes place in Bakharibhath, Bela seems the most seriously affected as it floods up to 1.87 m (two-year flood) and evacuation primarily has to follow the levee which may be breached during the period. Evacuation routes for different discharge conditions are shown in Figures 3.8-3.11.

A stakeholders' meeting was organised to disseminate and discuss the results of the mapping exercise to identify safe areas for evacuation routes and shelter. The

Table 3.14: **Classification of relief routes, distance, and shelter areas for different localities**			
Locality	**Relief route**	**Distance (km)**	**Shelter**
Bakharibhath	Road	1.74	Campus
Bela	Levee and Road	2.892	Campus
Bajarahi (East)	Road	-	Bajarahi (East)
Bajarahi (West)	Road	0.338	Bajarahi (East)
Campus Area	Road	-	Campus
Jaleshwar (Bazaar)	Road	-	Jaleshwar (Bazaar)
Jaleshwar (North-East)	Road	0.400	Jaleshwar (Bazaar)
Jaleshwar (West)	Road	0.668	Jaleshwar (Bazaar)
Ramaul	Road	0.915	Bajarahi (East)
Ratwada	Road	-	Ratwada

meeting was attended by 22 participants representing institutions such as Jaleshwar municipality, CPN-UML (Communist Party – United Marxist Leninist), Nepali Congress (D), Nepali Congress, District Development Committee (DDC), the Water Induced Disaster Prevention Office and local leaders and ordinary people from the study sites. During the discussion, many participants highlighted the need for such scientific work in the context of increased flood hazards constraining development activities in Jaleshwar municipality and appreciated the work carried out in the context of it being the first scientific attempt to delineate such areas. However, some participants pointed out that the areas identified as safe sites for shelter are also inundated at depths up to 60 cm during the rainy period and could not be used for evacuation. It was also suggested that these maps could be improved with a dense network of topographical survey points and by involving local people in the survey. Some participants pointed out that almost all the areas are inundated during rainy periods. Hence it is not possible to find a safe area for an evacuation route. Alternatively, boats could be used to rescue people from the inundation zone. It was also recommended that discharge monitoring sites be established along the Ratu Khola and that a siren system be established in the upstream area near Bardibas to warn the community of impending emergency.

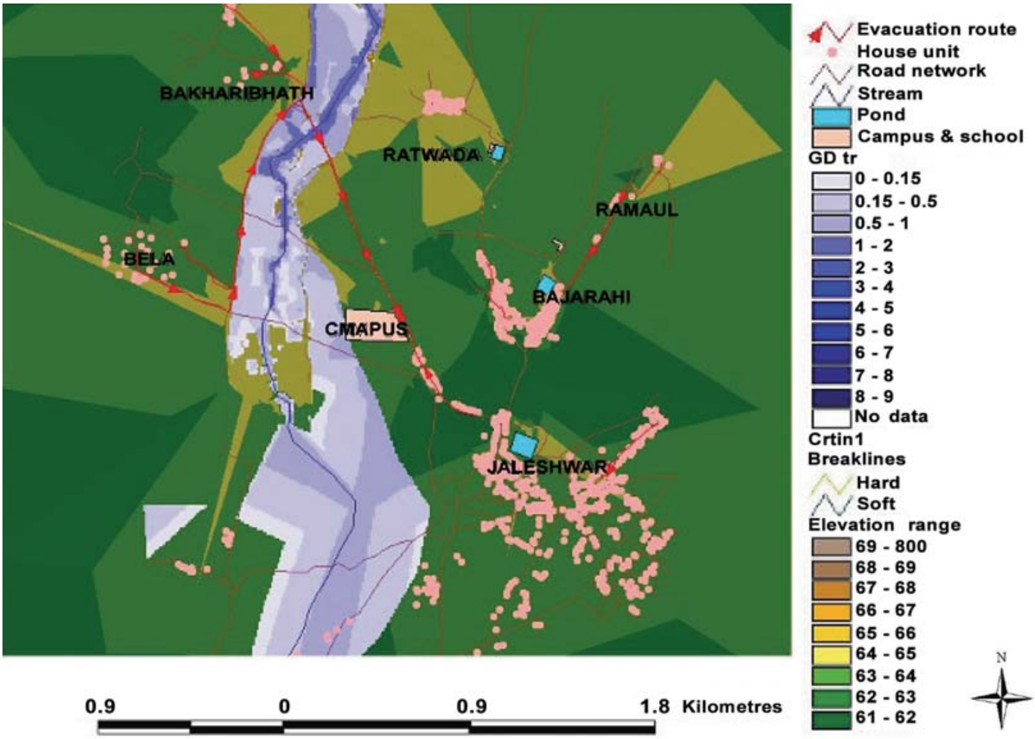

Figure 3.8: **Evacuation route on hazard map for 160m³/s discharge**

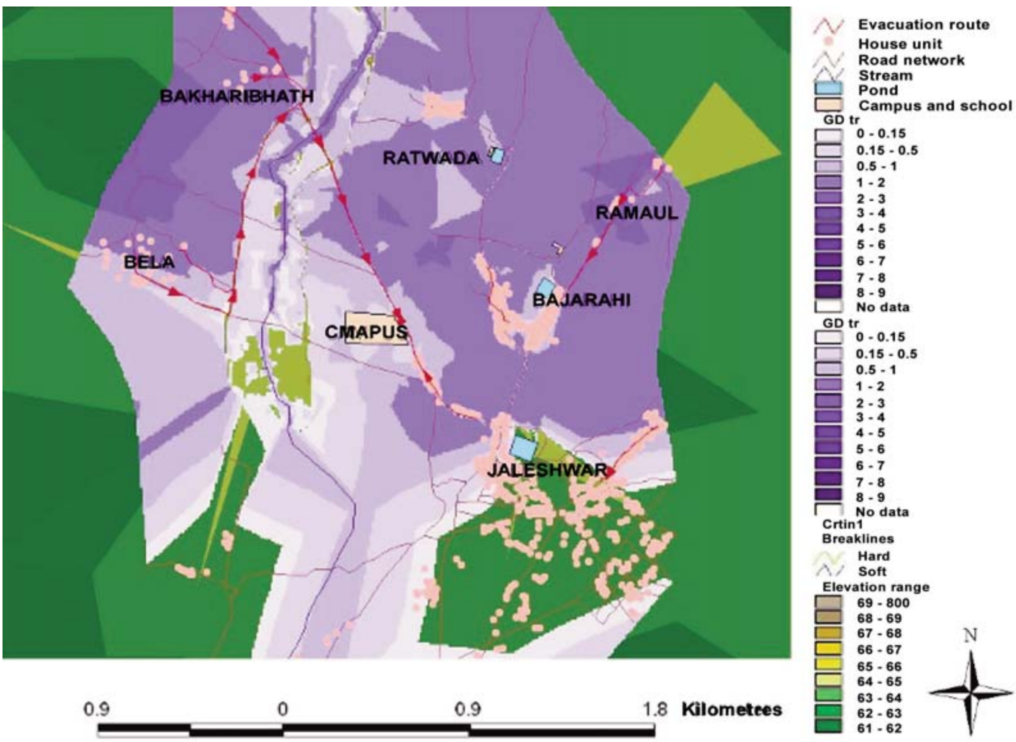

Figure 3.9: **Evacuation route on hazard map for 180m³/s discharge**

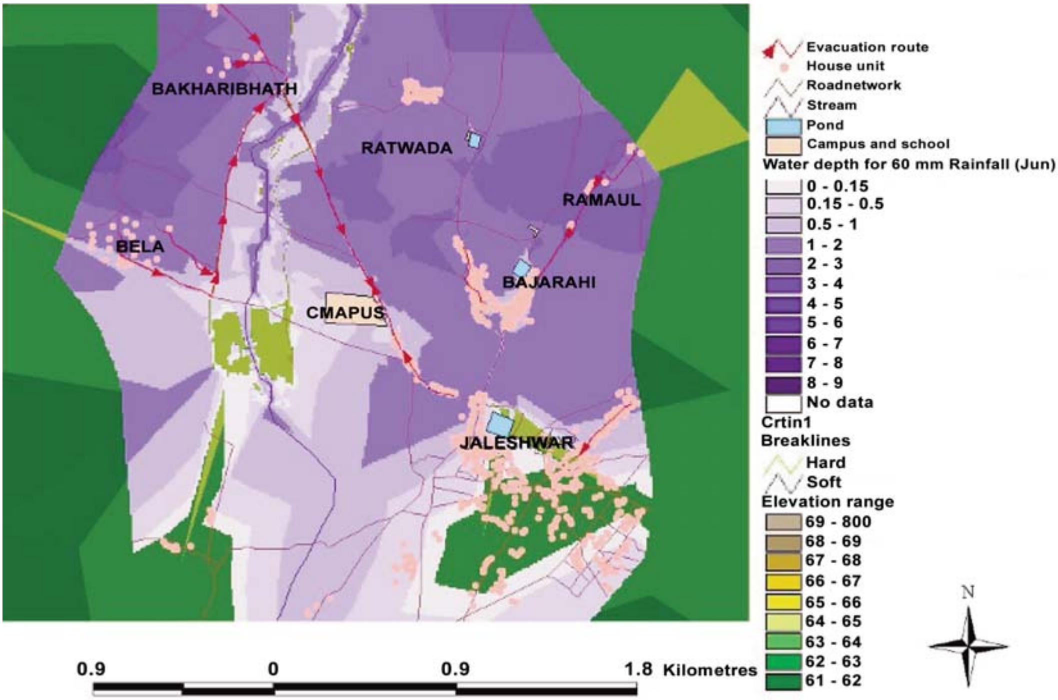

Figure 3.10: **Evacuation route on hazard map for 507.52m³/s discharge**

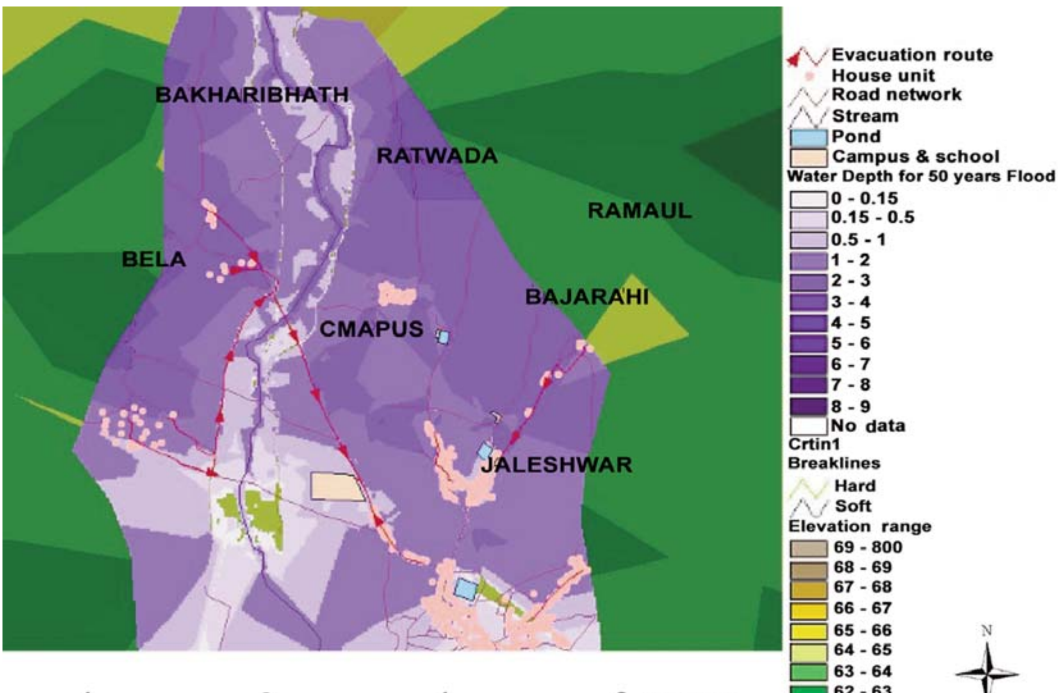

Figure 3.11: **Evacuation route on hazard map for 1016.37m³/s discharge**

Chapter 4

The Larger Picture


Ratu Khola at Bahunmara

Conclusions

The main hazards repeatedly occurring and causing heavy losses in terms of lives and property in Nepal are floods, landslides, avalanches, hailstorms, windstorms, lightning strikes, earthquakes, fire, and epidemics. On an average, natural disasters take 951 lives and damage property worth NRs 1,242 million every year. Of these hazards, the overall impact caused by floods, landslides, and avalanches is most severe. Between 1983 and 2005, on average, 309 people (32%) were killed annually by water-induced disasters such as floods, landslides, and avalanches; this is second only to the deaths caused by epidemics, i.e., 524 lives per year. About 70% of the total families affected from all types of natural disaster in the country are affected by water-induced disasters. Loss of property from floods, landslides, and avalanches combined is about 61%.

On average the estimated losses from floods and landslides are almost 0.6% of the GDP at current prices (2006), 3% of the total budget, 4.7% of total development expenditure, and 14.9% of foreign loans. Unaccounted losses from disruption in transportation, power, water supplies, and normal business from such events were also discouraging. The government spends large amounts of money every year in relief and reconstruction activities. On average, 12.9% of the development expenditure of Nepal and 5.39% of its real GDP are spent on response and recovery activities.

Devastating floods in Nepal are triggered by several different mechanisms: i) continuous rainfall and cloudbursts, ii) glacial lake outburst floods (GLOFs), iii) landslide dam outburst floods (LDOFs), iv) floods triggered by the failure of infrastructure, and v) sheet flooding or inundation in lowland areas due to excessive rain, bank overflows, or obstructions imposed on the flow.

Among the three ecological regions: the Mountains, Hills, and the Terai, the Terai is the most affected by flood hazards. Although loss of life is comparatively low in the Terai districts where floods are the main natural disasters, the extent of the floods' impact in terms of the number of families affected and estimated losses is very high. Nearly 77% of the total losses due to floods, landslides, and avalanches in combination from 1992-2001 were incurred in the Terai. During this period, the loss of houses, livestock, and farmland in the Terai was about 85, 71, and 69% respectively. Families affected by floods in the Terai accounted for 70% of the total.

In the Terai, districts located in the central Terai, such as Rautahat, Sarlahi, Mahottari, and Dhanusa, are seriously affected by flood disasters. A comparison of the losses and damage between 1970-1992 and 1993-2002 shows that these districts have experienced increasing losses from water-induced disasters in the years since 1993.

An extremely rugged, diverse, and dynamic landscape, landlockedness, inaccessibility, dispersed human settlements, and a high rate of human migration have been the causes for a high rate of physical and locational vulnerability. Nepal lies in a high-energy environment with a dynamic landscape with high relief, steep mountain slopes, active tectonics, and highly concentrated precipitation, creating conditions vulnerable to different types of geo-hydrological hazard such as landslides and floods. Nepal does not have easy access to other countries via land and water. This constrains the timely flow of goods and services during emergencies and means of transportation is expensive. Similarly, development of infrastructural services such as transportation, communication, health, marketing, and extension services such as education, skills development, and so on, which play an important role in all stages of flood-hazard mitigation and management; pre-disaster preparedness; during-disaster evacuation and relief activities; and post-disaster rehabilitation and recovery activities, remain poor. Human settlements are dispersed and territorial shifting is great as a result of human migration. Evidence of this is the extent of the population increase in the Terai from 35.2% of the total population in 1952/54 to to 48.4% in 2001. Such a rapid rate of migration and shifting of human settlements in the Terai have led to increased vulnerability to flood hazards.

Nepal is not only highly vulnerable to water-induced hazards from the perspective of physical and locational conditions, but also from socioeconomic conditions because of the low human development profile, poor economic growth, mass poverty, disparity in productive assets and income, heavy dependence on agriculture and its low production potential, inadequate service provision, and lack of political commitment and accountability. Its human development index is very low. About 40% of the population live below the national poverty line. Economic growth has been less than 4%. The parcels of agricultural land are small. Small farmers operating less than 0.5 ha of land comprise about 45% and they own only 13% of the agricultural land. Similarly, the 20% of households at the lowest economic end receive only 5.3% of the national income. Access to safe drinking water, health facilities, and sanitation is poorer than South Asian standards. Government activities in disaster mitigation and management are mainly directed towards post-disaster activities, viz., rescue, relief, and rehabilitation only. There is no coordination among institutions involved in disaster mitigation and management, and there is a lack of integration among such activities.

The importance of flood-hazard, risk, and vulnerability mapping and assessment in developing appropriate disaster-mitigation and management strategies and programmes to reduce the impacts of flood hazards has been realised and such activities have been incorporated into National Development Plans. Many government institutions such as the Disaster Prevention Technical Centre (DPTC), Department of Hydrology and Meteorology (DHM), and the District Irrigation Office (DIO), as well as NGOs and INGOs such as JICA, UNDP, and ICIMOD have been involved in such activities. However, so far, no substantial work has been carried out in this field, hence the reason for this study.

Recommendations

Flooding is a natural process and its complete control is beyond the capability of human efforts. However, the magnitude of flooding and its impact can be reduced to a certain extent through development and effective implementation of land-use zoning guidelines and building codes and standards. The problems of increasing risk and vulnerability are not associated with physical features only, but also with socioeconomic conditions. Programmes well integrated with physical processes and socioeconomic developments are therefore needed. Watersheds are well-defined geophysical units in which the problems of flood hazards can be assessed and monitored properly. Attention should be given to integrated watershed development programmes in national development plans. Political commitment and accountability in devising and implementing such programmes are essential.

The risk of flood hazards in the Ratu Watershed has been increasing. Since Ratu Khola originates in the Siwaliks, there is no risk of GLOFs. (It should be noted that there is a risk of GLOFs in the Terai region, but this is confined to major rivers originating from the high mountain region). However, the risk of flooding and its associated processes such as river-bed rise, bank cutting, and channel shifting is very high. Another common feature in this watershed as in other areas of the Terai is sheet flooding. The frequency and magnitude of sheet flooding and its associated risks have been increasing in recent years. The establishment of infrastructure, such as roads, perpendicular to the drainage paths have contributed in large measure to this rise. All the major rivers in the Terai flow to India. So the development of infrastructure such as roads, barrages, dams, afflux bunds, and dykes downstream near the Nepal-India border increases flood risk and vulnerability in Nepal. This problem has been exacerbated by the construction of a road near the Nepal-India border in this basin. This problem has been realised by the government and a special inundation committee with members from Nepal and India has been established. Yet the committee has not so far been effective in solving the inundation problem in border areas. This problem should be addressed by making the committee effective and exercising regional cooperation by exchanging information and developing an early warning system.

The work in the Ratu Watershed clearly shows that flood-hazard, risk, and vulnerability mapping and zoning using GIS and remote sensing are economic in terms of both time and money, and a useful tool for developing land-use guidelines in order to reduce the impact from flooding. Such work should also be carried out in other watersheds.

Flood-mitigation and management efforts in the past were confined to rescue and relief work and structural measures such as construction and maintenance of retaining/gabion walls, check dams, and spurs. Local people have realised the importance of a preparedness plan incorporating components of watershed conservation and drainage management through proper land-use guidelines, income-generating activities, an early warning system, and creation of awareness. However, a local institutional network to devise and implement such programmes and dissemination of information should be established.

An attempt was made to establish an early warning system and identify safe evacuation routes and areas safe for shelter during the 2nd phase of this work. For this, people were trained to read and record precipitation in the upstream area and discussions took place on the use of maps for delineating safe evacuation routes and shelter areas. These efforts have yet to culminate in the establishment of a local institutional network for early warning and creation of awareness in the community, as recommended.

The capability of local people to respond to hazards and their resilience against them is poor in terms of physical assets, economic conditions, human development, and the technical capability of infrastructure. However, local people are willing to participate in and contribute to flood-hazard mitigation and management. Efforts should be made to tap this sentiment through developing and strengthening local community-based institutions.

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