FLOODS IN THE LOWER RAPTI RIVER BASIN: OCCURRENCE, CAUSES AND MANAGEMENT

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CERTIFICATE

I, **RAJESH KUMAR**, certify that the dissertation entitled **"FLOODS IN THE LOWER RAPTI RIVER BASIN: OCCURRENCE, CAUSES AND MANAGEMENT"** for the degree of **MASTER OF PHILOSOPHY** is my bonafide work and may be placed before the examiners for evaluation.

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Date: (Rajesh Kumar)

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Chapter One

Introduction

1.1 Introduction

Floods are an integral part of hydrological cycle. They occur periodically whenever the inflow of water exceeds the outflow in an area. They are essential elements in the creation and maintenance of many ecosystems and in the geomorphic evolution of landscape.

Floods are basically, topological hazards, but hydrometerological factors also play an equal role and thus magnify the situation. The role of man in magnifying the flood situation has tangibly increased and therefore, is no more a pure natural hazard. Man has encroached the flood plain, controlled and modified river courses and destroyed the ecological balance for immediate tangible benefits. This unmindful work of man has changed the river regime, altered the channel morphology that accentuated flooding in an area. This is true in the case of Rapti river basin.

The floods are the most universally experienced hazard. The total flood plain area of the world accounts for only a small portion (3.5%) of the total land surface but supports considerable 16.5% of the world population[1]. In India, 1/8th of total geographical area is prone to flood[2]. In the case of Uttar Pradesh, 30.32% area is liable to flood out of total geographical area of 240.93 lakh hectare.[3]

Floods are natural phenomena. The floodwater spills over or breaks the conduit and inundates areas, which are normally not under water. In a natural process, floods bring down sediments from the upper catchments and through erosion of the river banks and beds, deposit them over the flood plain, determine the channel size, shape, as well as the nature of aquatic life. Large floods are primary forces; responsible for the sculpturing of landscape and for the formation of valleys, flood plains and deltas.

Floods have some economic values. They are necessary to replenish soil fertility by periodically adding nutrients and fine grained sediments in flood plain. Clearing of the debris delivered by the tributaries, scouring of the channel bed and banks, deposition of fine sediments and nutrients on the flood plains and the recharge of soil moisture are some of the important and essential tasks performed annually by floods. Without periodic floods, river channels would choke with sediments and overgrown vegetation. Such a situation would not only destroy riparian vegetation and aquatic life, but would be potentially more dangerous for people occupying river banks, flood plains and the deltaic regions. But floods can also cause loss of lives, temporary destruction of animal habitat and complete damage to urban and rural infrastructure.

1.2 Trends in Flood Damages in India

As per the estimate of the National Flood Commission, the total area liable to floods in India is 40 million hectares. The cumulative flood affected area and damages in India for the period 1953-1996 are given in Table 1.1 and 1.2, respectively. Figure 1.1 shows the cumulative flood damages in India. All show an increasing trend. It can be seen that the curves of the total damages and cumulative cropped area damaged due to floods show more deviation over the years particularly after 1972. This indicates that more and more area other than agricultural land is affected by floods.

Table 1.1: Cumulative Flood Affected Area in India

Year	Area affected	Cropped area affected
1953-56	28.46	9.96
1953-60	52.91	15.62
1953-64	73.98	25.52
1953-68	94.45	33.84
1953-72	126.46	50.35
1953-76	163.03	67.3
1953-80	207.44	91.82
1953-84	242.16	108.57
1953-88	284.53	132.89
1953-92	310.15	143.02
1953-96	331	151.758

Source: Central Water Commission (FM and DP Directorate)

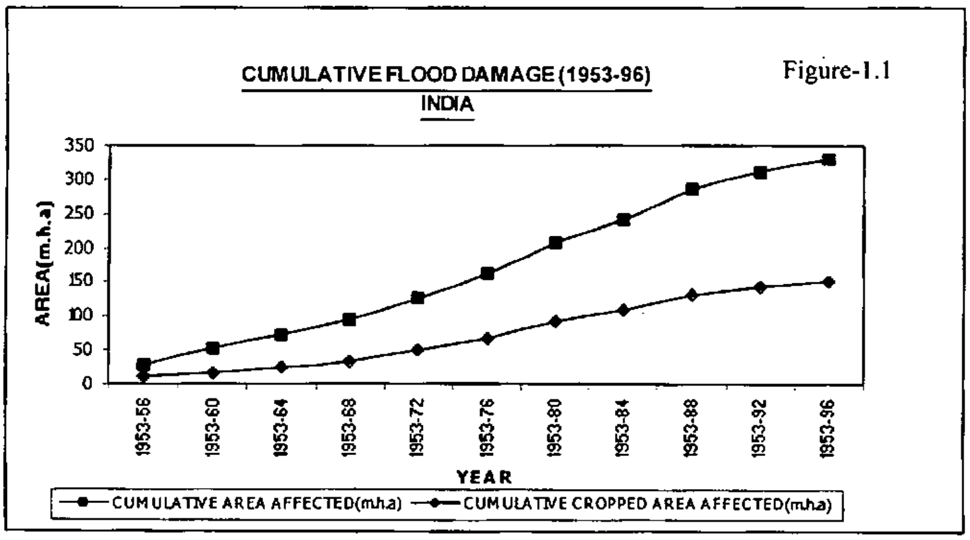


Figure 1.2 shows the cumulative flood damages in value term. The flood damages are increasing over the years, particularly after 1970. Although loss of crops constitutes the major part of the total damages, in recent years the value of damages to public utilities and houses is increasing. This shows that in recent decades flood prone areas are put into high value land use. It is therefore, important to know the causes of floods, the nature of terrain that floods produce and the way flood plains are used, method of controlling floods, managing flood episodes in order to minimize the flood damages.

Table 1.2: Flood Damages in India (at 1981-82 wholesale price index)

Year	Crop	House	Public utilities	Total
1953-56	204.84	96.98	18.17	1728.99
1953-60	356.55	129.59	50.56	2921.86
1953-64	550.81	149.43	65.94	4003.55
1953-68	914.75	207.54	105.98	5470.52
1953-72	1881.12	403.27	426.81	9599.27
1953-76	3587.31	654.44	967.79	11366.21
1953-80	5755.35	1355.76	2209.85	19790.59
1953-84	9061.25	2412.9	5085.36	26498
1953-88	15383.74	4737.26	11446.33	37427.893
1953-92	18264.81	5502.08	15056.8	41498.15
1953-96	20058.16	6034.78	16772.83	43210.55

Source: Central Water Commission (FM and DP Directorate)

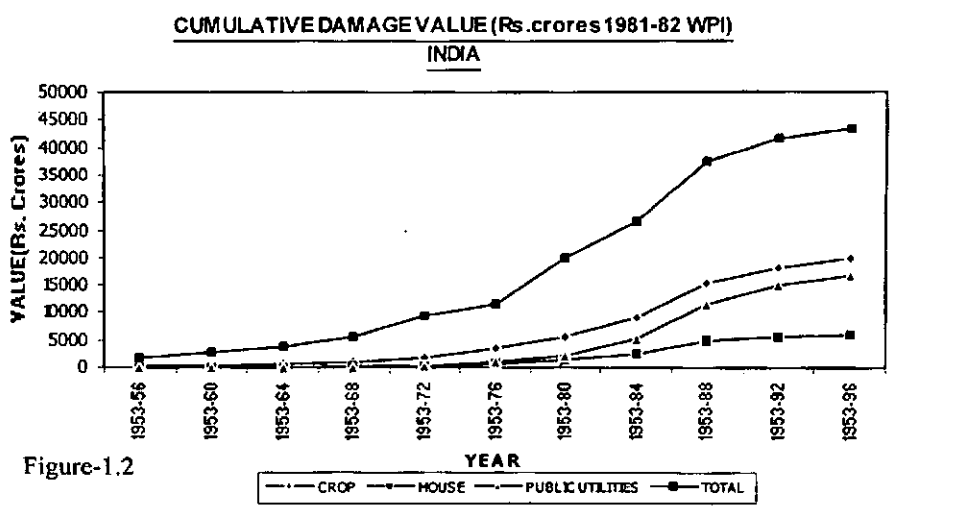


Figure-1.2

1.3 Definition of Floods

The term 'flood' has been defined in a number of ways as follows:

1. A flood is a relatively high flow, which overtakes the natural channel provided for the runoff[4].
2. Extremely high flows or levels of rivers, whereby water inundates flood plains or terrains outside of the water-confined major river channels. Floods also occur when water levels of lakes, ponds, reservoirs, aquifers and estuaries exceed some critical values and inundate the adjacent land, or when the sea surges on coastal lands much above the average sea level[5].
3. A flood is a body of water which rises to overflow land which is not normally submerged[6].
4. A flood is a rise usually brief, in the water level in a river to a peak, from which the water level recedes at a slower rate[7].

Thus, these definitions suggest that a flood must be a purely natural phenomenon, although natural processes are virtually affected by human activities.

In India, a river is said to be in flood when its water level crosses the danger level (D.L.) at a particular G/D site[8]. Danger level for a site is usually one metre above the warning level (W.L.). This level when attained by a river at a site will initiate issuing warnings as flood damage begins at this level[9]. When a flood crosses the D.L. by 1 metre or more, it is termed as 'major flood' at that site; when it is 5 metres or more, it is called 'severe flood' and floods 10 metres or above the D.L. are called 'devastating floods'.

1.4 Types of Floods

On the basis of the meteorological and geomorphological characteristics of different basins of Indian region, four types of floods have been recognized: 1. Flash floods, 2. Single peak floods, 3. Multiple peak floods and 4. Synchronized floods.

The short-lived, violent storms in mountainous and / or arid areas produce sudden or flash floods. Such floods are unpredictable and are often very destructive in nature. The 1979 mega flood on the Luni river in Rajasthan was of this type[10]. Flash floods are also generated by the failure of natural dams, which are common in the Himalayan region. The August 1998 dam failure caused a flash flood in the Malpa Gad in Kumaun

Himalaya[11]. The single peak floods are particularly common on the rivers of the Indian Peninsula, and are associated with discrete, widespread and heavy rainfall events. The occurrence of successive flood generating meteorological conditions over a basin produce a series of floods. Such floods are relatively common in the Himalayan rivers.

Widespread and intense rainfall can sometimes generate floods in the main rivers, as well as their tributaries, almost at the same time. The synchronization of flood peaks of the major rivers is generally responsible for massive floods. Such floods are common in the Ganga basin. The 1978, 1987 and 1998 floods in the Ganga basin were of this type.

1.5 Causes of Floods

Prolonged, heavy and widespread monsoon rainfall is generally considered to be the main cause of large floods. The major causes of floods are as: 1. Heavy and prolonged rainfall, 2. Deforestation, 3. River bed aggradation due to siltation, 3. High sinuosity and very low gradient, 4. Back water effect from *Tals* and the main river to its tributaries, 5. Obstruction of natural flow by roads, railway lines, bridges and 6. Failure of dams etc.

1.6 Approaches to Flood management in general

Three steps to manage the devastating floods in the basin are as follows:

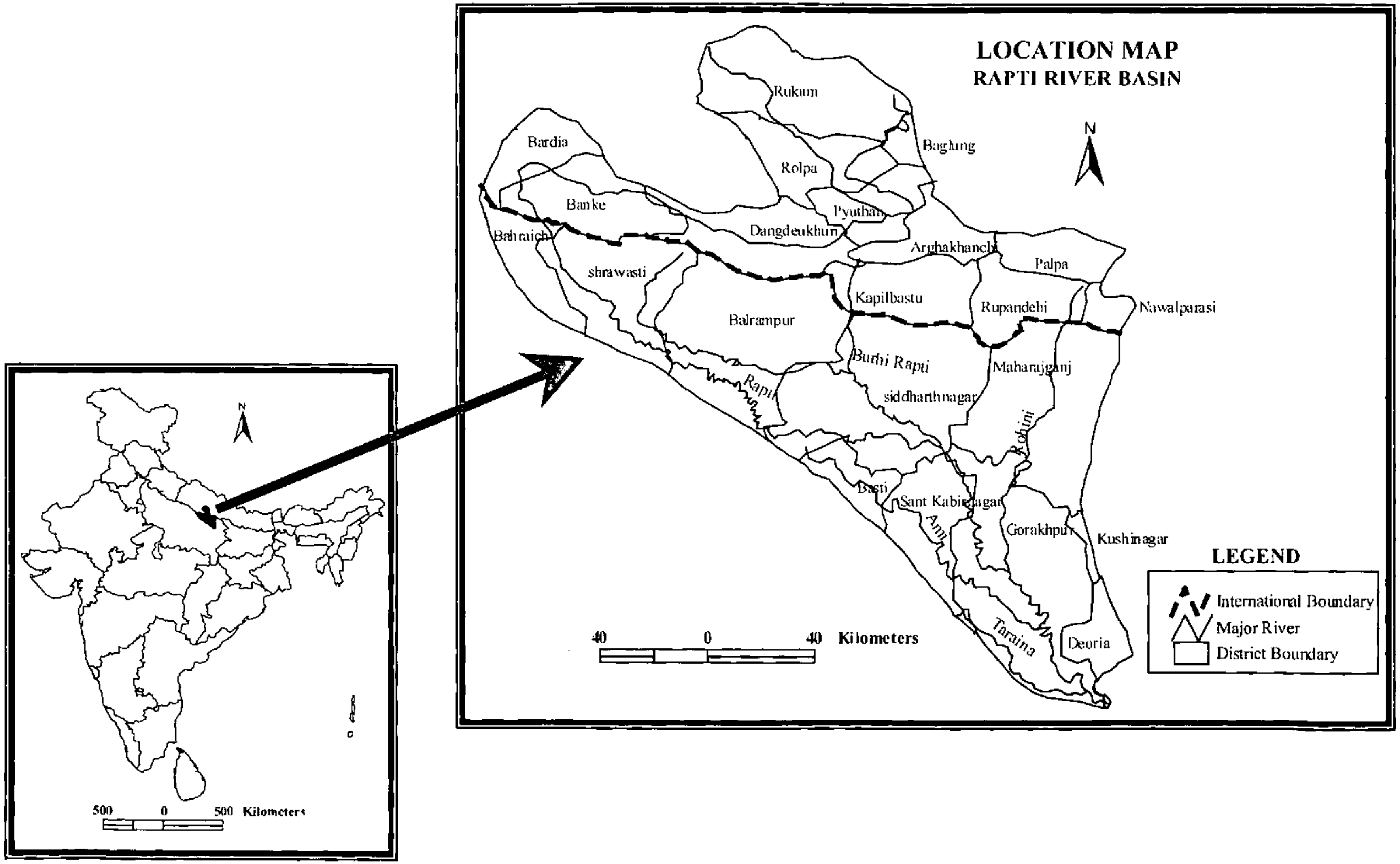
A. Structural measures: Construction of dams and detention reservoirs, raising of villages, construction of embankments, afforestation in river basin, channel and drainage improvement in flood plain and urban areas and flood proofing.

B. Non-structural measures: Flood plain zoning, flood forecasting and warning, and disaster relief etc. and

C. People's participation.

1.7 Reason for choosing the Area

People maintain affinity with the flood environment inspite of risk and frequent losses, because it has considerable economic value. The Rapti river basin bears the highest amount of flood losses due to its unique location. Considerable parts of the districts of Bahraich, Balrampur, Sarawasti, Siddharthnagar, Maharajganj,



500 0 500 Kilometers
LOCATION MAP
RAPTI RIVER BASIN
Rukum
Bardia
Baglung
Rolpa
Banke
Pyuthan
Bahraich
Dangdeukhuri
Arghakhanchi
Palpa
shrawasti
Kapilbastu
Rupandehi
Nawalparasi
Balrampur
Burhi Rapti
Maharajganj
Rapti
siddharthnagar
Rohini
Basti
Sant Kabirnagar
Ami
Gorakhpur
Kushinagar
Taraina
Deoria
40 0 40 Kilometers
LEGEND
International Boundary
Major River
District Boundary

Map 1.1

Santkabirnagar, Kushinagar, Gorakhpur and Deoria come under the flood prone area. Since, the built-up area is increasing in the flood prone areas at an alarming rate; it has magnified the flood losses and altered the regime of the Rapti river. Inspite of human factors, the natural factors such as, heavy prolonged rainfall, drainage congestion, backwater effect of the main rivers and tals etc. also magnifies the flood situation. This study therefore, has been taken to consider the above said factors and to find out the best solution to reduce the adverse consequences of floods for the betterment of the people living in the basin.

1.8 Study Area

The Rapti river lies in the Ganges river basin and is a tributary to Ghaghara river which is also a major tributary to the Ganges. The Rapti river basin extends from 26°18′ 00″ N to 28°33′06″ N and 81°33′00 E to 83°45′06″ E and covers an area of 25637 km^2 out of which 42 % (10809 km^2) lies in Nepal and 58 % (14828 km^2) in Eastern Uttar Pradesh.

The Rapti river flows through the districts of Rukum, Baglung, Rolpa, Pyuthan, Dangdevkhuri, Banke, Bardia of Nepal territory and Bahraich, Shrawasti, Balrampur, Siddharthnagar, Santkabirnagar, Gorakhpur and Deoria districts of Eastern Uttar Pradesh (Map 1.1)

1.8.1 Physiographic Region

On the basis of the relief, the Rapti river basin can be divided into following physiographic regions:

I The Mountain Region

II The Inner Tarai Region

III The outer Tarai Region and

IV The Plain Region (Saryupar Plain)

I The Mountain Region

This region consists of the Lesser Himalayas. It extends from the Mahabharat range in the south to the Lesser Himalaya. In the north, its height varies in between 1830m to 4010m.This region is called the *Midlands*[12]. The mountains run parallel, east to west. It consists of the Rapti, the Madi, the Jhimruk, and the Lungri valleys, which contain alluvial soil (Map 1.2).

The Mahabharat Range

This chain of mountain runs parallel to the lesser Himalaya in west to east direction. Its height varies from 1520m to 3660m.some tributaries of the Rapti river rise from springs in this range[13].

II. The Inner Tarai Region

This region is called the *'Bhitri Madhesh'*, which lies, between the Mahabharat mountain in the north and the Churia hills in the south. Its height varies from 610m to 1830m.These mountain ranges are separated by wide valleys called dun, which is a wide and elevated valley. The Rapti Dun is important, which contains alluvial soil but has an unhealthy climate.

The Churia Hills

These lie south of the Mahabharat range. They are the foothills of the mighty Himalayas. Their height varies from 610m to 1220m.They are called Siwalik hills in India. Landslides are frequent in these hills.

IV.The Outer Tarai Region

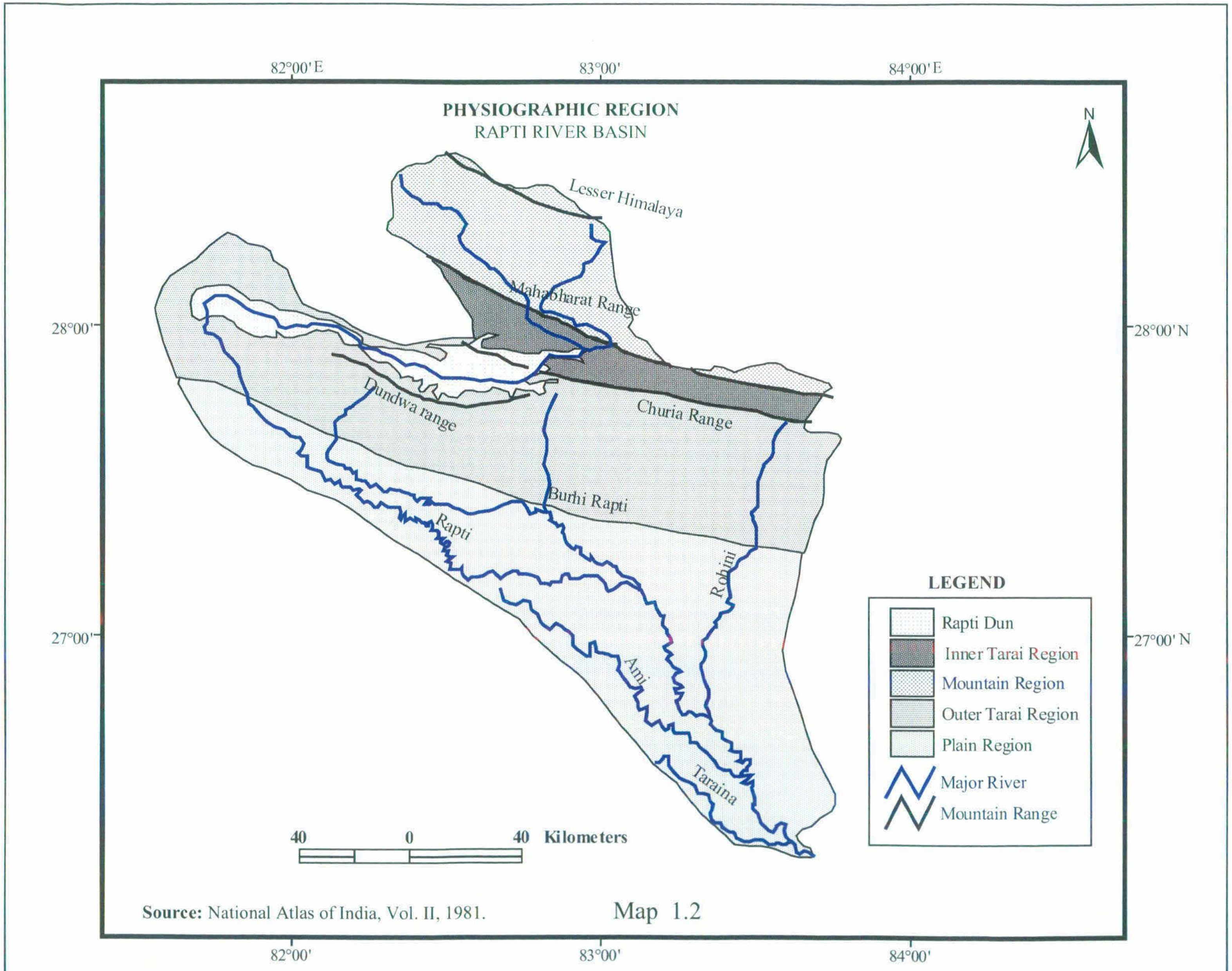
The outer *Tarai* region lies between the plain region in the south and Churia hill in the north.Its height is below 300m.The tarai drained by the rivers such as, the Rapti, Kain, Gholia, Dangmara, Bhainbar, Banganga, Arrah, Ghonghi, Rohini and so on from west to east, respectively. A strip of the *Tarai* in the north consists of sandy soil and pebbles. It is called the *Bhaber*. It is full of marshes and forests. Due to fall in gradient from north to south, a number of terraces, formed of alluvial fans, are found in between the plain and the Siwalik foot hills[14].

The Dundwa Range

This range lies south of the Rapti dun. It is a longitudinal spur of the Siwalik range[15].

V. The Plain Region (Saryupar Plain)

This plain region is a part of the Saryupar plain, which lies south of the tarai region. The general elevation is 80m above the MSL and its general slope is towards the east[16].



Source: National Atlas of India, Vol. II, 1981.

Map 1.2

Physical landscape is produced actually, by local eminences such as, river levees and bluffs or sand features like *Dhus,* oxbow lakes, *Tals*, *Chaurs*, dead arms or remnants of the river channels and frequently perceptible notches and slopes carved by the rivers at the outer edge of the Bhangar tracts[17].

1.8.2 Geology

There is a large trough, which is called Gorakhpur trough in the southeastern part of the basin, over 8000m deep. It indicates that the entire region has suffered great down warping due to Himalayan upheaval[18].

Geologically, the Rapti river basin may be divided into three zones: I. The Northern Mountain Zone, II. The *Tarai* Zone, and III. The Plain Zone

I. The Northern Mountain Zone

The rocks of this zone are folded and tertiary in age. The mountains ranges such as the Lesser Himalaya and the Mahabharata range consist of hard granite and crystalline rocks and are somewhat older than the Churia hill, which consists of sand, clay and soft rocks[19]. Thus, the hardness of rocks varies from north to south.

II. The Tarai Zone

In the northern part of the *Tarai* zone, the alluvial architectural studies on exposed Siwalik section reveal that the major sandstone bodies are of 1000m thick[20]. These sandstone bodies are underlain by a major erosion surface and generally are capped by a palaeosol. The major sandstone bodies are separated by 100m thick mudstone dominated palaeosol bounded sequences, which contain minor sandstone bodies (one to few meters thick). These sequences are the over bank deposits formed by filling of local low-lying area through small channels and crevasses followed by progressive shifting through avulsion[21]. This depositional environment is analogous to the modern interfan areas in the Rapti river basin.

III. The Plain Zone

It is formed of sand, silt and clay materials mostly deposited by the Rapti river and its tributaries. The top surface (about 30m) of this region can be divided into two sub zones:

A. *Bhangar*

This zone is formed by the old alluvium. It covers upland tracts beyond the annual flood limit. It is generally, below 100m from MSL.

B. *Khadar*

It is formed by new alluvium soil, which is annually replenished by new deposits through overbank flow. The nodular limestone conglomerate known as *Kankar* is more abundant in *Bhangar* than in the *Khadar* alluvium because of more riverine character of the *Khadar*.

1.8.3 Soil

There are five factors such as, parent material, climate, topography, organism and time, involved in soil formation. These factors vary across the Rapti river basin. Thus, the major soils of the basin are as:

1.Red Soil

In the northern part of basin the soil is mixed with limestone, granite, sand, clay etc in some places. Red soil is mainly composed of hard stone, limestone and mica.

2.Tarai Soils

Tarai soils are found in the inner and outer *tarai* region. This type of soil, covers the Rapti Dun and northern part of Bahraich, Gonda, Basti, Sarawasti, Maharajganj and Siddharthanagar districts of the plain region. They are poorly drained and receive seepage water continuously from the upper Bhabhar Zone. Soils are highly leached heavy clay soil and suitable for rice cultivation. The pH. value ranges between 6.6 to 7.2[23].

3.Calcium Soil (Alluvial)

The whole river basin is covered by this type of soil excluding the *Tarai* zone. The clay content does not exceed 20% and hence these soils are classified as loam. These soils are rich in nitrogen and potash. These soils are suitable for sugarcane cultivation. The pH value varies from 6.8 to 7.6 and above[24].

Apart from the above classification, alluviums are divided into two categories: I. *Khadar* Soils and II. *Bhangar* Soils.

I. *Khadar* Soils

These are newer in age and cover the flood plains in the vicinity of rivers. Khadar soils do not have any characteristics soil profile[25]. They are suitable for the *Bhadai* and *Zaid* crops. Silt is prominent in these soils.

II. *Bhangar* Soils

These are old alluvium and cover the upland tracts beyond the annual flood limit. They are rich in lime content and suitable for rice cultivation. They are sticky and well drained.

The soil structure facilitates good subsurface flow in plain region. Poorly drained *Tarai* soil causes considerable seepage of water, which joins the subsurface flow in the plain, resulting in return flow, and during floods resurges on the surface thereby expanding the flooded area.

1.8.4 Climate

Due to difference in altitude, the Rapti river basin has two distinct climatic regions, temperate climate prevails in mountainous region, while the plain has subtropical climate.

1. **Temperate climate:** The area between the *Mahabharat* range and the Lesser Himalayas has a temperate climate. Summers are warm and winters are cool to severe. The temperature varies between 0°C to 37.7°C. Average rainfall is about 152.28cm[26].
2. **Subtropical Climate:** The inner *Tarai*, the outer *Tarai* and the plain region experience typical monsoon type of climate (cwg climate according to Koppen classification) with dry winter season. The climate is very hot in summer. Daily maximum temperature may go upto 46.5°C. The western part is hotter than the eastern part. The subtropical climate has four distinct seasons that are as follows:

A. The Winter Season

The easterly humid winds are replaced by the dry north- westerly winds. The region receives small amount of rainfall due to western disturbances. Normally, temperature ranges from 7°C to 29°C[27].

B. Summer Season

In this season, the pressure gradient become steeper from west to east and wind blows with increasing velocity (6.4 km/ hr in March to 10km/hr in the mid- June), with decreasing humidity and increasing temperature and the wind velocity leads to the formation of hot winds in this region called *'Loo'*.

C. Southwest Monsoon Season

The southwest monsoon season begins in the middle of June and ends in the middle of October. The region gets 75% of annual rainfall in this season. The average rainfall of the plain region is approximately 100cm. The rainfall decreases from the northern part to the west-central part of the basin[28]. The rains are caused by the passage of low pressure system along the monsoon trough.

D. Post Monsoon Season

This season begins in the middle of October and ends in December and is generally characterized by decreasing temperature and rainfall.

1.8.5 Vegetation Cover

Different types of vegetation are found in the basin due to variation in climate and altitude from north to south. The major categories of the vegetation are as follows:

1.Temperate Coniferous Forest

This is found in the upper northeastern part of the basin i.e., north of the Mahabharat range. The major trees such as, Sallo, Dhupi, Deodar, Gojan, Kalikath with Rhododendrons are found.

2.Temperate Deciduous Forest

This is found between the Mahabharat and the Churia ranges. The trees have broad leaves. Sals, Bamboo, Walnut, Chestnut etc. are the major varieties of the deciduous forest[29].

3.Tropical Forest

This monsoon forest consists of evergreen trees because of heavy rainfall. It is found in the southern part of the basin. Most of these forests have softwood, while some have hardwood. Hardwood trees like Sal (Shorea robuste), Shisam (Delberia sisso), Sankhuwa etc. and softwood trees like Pipal, Mahuwa, Khair etc. are found in this forest.

At some places, bamboo trees and cane reed are found. In drier parts of the *Tarai* region Elephant and Sabai grass are found. The forest in the Bhaber region is very thick. Some grasses like Bher (zizyphus glaberrima), Moonj (Erianthus moonja), Kans (Saccharum spontaneum), Jhau etc. are found in Diaras[30]. Babul tree is found both in *Bhangar* and *Khadar* regions.

1.8.6 Economy

The economy of the basin is based on agriculture. A three-harvest system is prominent. Wheat, paddy, sugarcane, barley, jawar, oilseeds, pluses etc. are the major crops of the basin.

1.9 An Overview of Literature

The dynamics of river and associated problems like floods in particular have been studied extensively by scholars all over the world. Much of the physical based research in the area of fluvial geomorphology has pointed out the historical trends.

One of the pioneering study of fluvial geomorphology is the work of Leopold and Wolman. The work of Schumm, Chorley and Gregory and Walling are remarkable.

1.9.1 General Context

Leopold and Wolman (1957) [31] have grouped the alluvial rivers into braided, straight and meandering on the basis of planform and formulated the characteristics of each of these patterns. Braided river is the one that flows into two or more anastomosing channels around alluvial island. Meandering river flows in a winding course.

Chorley (ed) (1969)[32] has included some consideration of the physical geography of rivers and drainage basins together with assessment of their significance in socio-economic geography.

Gregory and Walling (1973)[33] has dealt first, with measurements of basin characteristics and of run off, sediment and solute dynamics and secondly with morphology of flood plains, evaluation of basin form and of their changes in time and space in detail.

Schumm (1980)[34] while discussing the 'planform of alluvial rivers' he says that the alluvial channels are dynamic and subjected to change. Classification of alluvial channels should not only be based on channel pattern but also on the variables that influence channel morphology.

Kayastha and Yadav (1980)[35] elucidate the impact of flood on socio-economic development of Mubarakpur village of Deoria district lying in the Ghaghara flood plain. The study is based on primary survey.

Kayastha (1983) [36] examines the causes of the floods in India. The flood damage during 1953-69 is interpreted vividly. The flood forecast system and the flood management measures are also discussed in detail.

Beven and Carling (ed.) (1989)[37] has compiled the papers on the areas of flood runoff production, flood hydraulics and sediment transport, the interpretation of flood sediments and the geomorphological implications of floods.

Newson (1992)[38] has reviewed the evolution of river management and the history of applied hydrology to contextualise a global study of river basin system and their contemporary management within both physical and social framework.

Miller (1997)[39] has explained the cause of floods, flood plain management through structural counter measures and non-structural flood defence, dam safety and emergency responses together with the floods in Bangalesh, China, Mississipi and Central Europe.

Sinha and Jain (1998)[40] has examined the flooding behaviour of the rivers draining the plains of north Bihar. The gemorphological characteristics of the Gandak, the Kosi, the Burhi Gandak, the Bagmati and the Kamla-Balan rivers have been broadly interpreted in order to develop a better understanding of flooding characteristics of these rivers which record the highest flooding events in the country. Along with a detailed analysis of hydrological data, geomorphological factors influencing the overbank spilling of these rivers have been discussed. Other fluvial processes such as bank erosion, channel morphological changes, and sediment load variation have been also interpreted in relation to overbank flooding.

Das (2000)[41] has elucidated the flood plain morphology, river pattern, runoff analysis, processes of bank erosion and their impact on flood plain dwellers of Subansiri river basin.

Parker (ed.) (2000)[42] has compiled the articles on floods and their management, impact of floods on society, flood plain management from the various countries as, Bangladesh, U.K., U.S.A., Europe and the Netherland.

Ram and Ram (2001)[43] have elucidated unprecedented heavy flood in the Ken river during September 1992. It was observed that the northwestward movement of low pressure area was close to the Ken basin and then it recurved east-wards with strong low level convergence and high level divergence was the main cause of heavy rainfall that caused unprecedented flood in the basin. The backwater effect of the Yamuna river obstructed the flood flow of the Ken river and aggravated the flood fury in the basin.

Sivasami (2002)[44] has elucidated the causes of floods in India and its management through structural and non-structural measures. The flood damage analysis has been worked out through three years cumulative value for the years 1957 to 1997. The environmental effect of floods and reservoirs has been discussed in the light of India.

Sullivan, Ternan and Williams (2004)[45] have attempted to determine the extent to which rainfall trends and land use changes influence the river flow regime and flood responses of a predominantly agricultural Camel catchment in southwest England. The cumulative impacts of a subtle, long-term rise in October rainfall totals, coupled with urban' development and the expansion of arable cultivation in the lower catchment and a rise in the intensity of grazing in the upper catchment, have altered the river regime.

1.9.2 Related Studies

Thapa and Thapa (1969)[46] have elucidated the physical, cultural, economic and regional aspects of Nepal. A detailed account on physical characteristics of Nepal is remarkable.

Rao (1971)[47] has elucidated that the Rapti river flows in a very sinuous course with shallow depth and causes heavy flooding in the districts of Eastern Uttar Pradesh and suggested that the raising of the villages above the annual flood level can reduce the severity of floods in the region.

Bose (1972)[48] has discussed about the physical, cultural, and economic geography of Himalaya. A detailed account on the Rapti river has been elaborated.

Sharma (1974)[49] discusses the general geography of Nepal. Physical features, drainage system, climate, vegetation etc are elaborated.

Singh and Singh (1995)[50] have interpreted the physical and cultural features of toposheet no. 63n/6 in detail.

Kumar and Ram (1994)[51] have discussed the synoptic analogue method for semi-quantitative precipitation forecast (QPF) for the Rapti catchment. They have tested the synoptic analogue of QPF of 1993-flood season with respect to the seven years rainfall data from 1986 to 1992. They have found that the systems, which are far away from the catchment preominantly, produce low rainfall and systems near the catchment areas or active monsoon trough with a tendency to move towards foot hills produce heavy rainfall in the catchment. On the basis of this information, fairly accurate QPF can be issued by the forecaster in advance of 24 hrs for the Rapti catchment.

Dogra (1997)[52] discusses the flood and water logging problems in east Uttar Pradesh and north Bihar. He further states that expenditure on flood control has been increasing rapidly; the area affected by floods has been also increasing. Deforestation in Nepal hills is an important cause of the worsening floods. Haphazard construction of roads and other development works, which do not provide enough room for drainage of water, is another important reason. He also, discusses the limitation and problems of embankment in east U.P. and north Bihar.

Yadav (1999)[53] discusses a detailed appraisal of floods and flood problems of Eastern Uttar Pradesh. He has illustrated drainage and flood characteristics of the region. Due to highly erratic nature of the southwest monsoon rainfall, all the streams are characterized by exceptionally high seasonal floods. Both the magnitude and frequency of the floods have increased due to ecological degradation in the upper reaches of the river. Damage due to flood, impact of floods on flood plain dwellers and floods management measures have been discussed in detail.

Jain and Sinha (2003)[54] review the geomorphic setting, fluvial processes and sediment pattern in gangetic plains and illustrate the hydrological and physical characteristics of the major rivers of the Gangetic plain as the Gandak, the Ghaghra, and the kosi together with the Rapti river.

Thapa (2003)[55] discusses the flood problem of West Rapti river. The 1974 flood of Gorakhpur is also elaborated. He further remarks that the construction of detention reservoirs on the Rapti river can protect the life and property of innumerable people living in the Eastern U.P. Saryu canal controversy and the locational characteristics of West Rapti high dam are also interpreted.

Sinha and Roy (2005)[56] have attempted to understand the geomorphologic processes in the Gangetic plains (Farrukhabad-Kannauj area). Detailed geomorphic mapping of the area suggests that the confluences of the Ganga-Ramganga-Garra rivers have moved both upstream and downstream between 1970 and 2000 in response to river capture, local cut-offs and aggradation. The movement of confluence points both upstream and downstream is mainly caused by local gradient and hydrological fluctuations over a long time scale. There is remarkable difference in the fluvial dynamics of this region compared to the eastern Gangetic plains, where rapid and frequent avulsions are predominant. They also cited the example of the Rapti river that the Rapti captured the Bakla river between 1959 and 1974 due to a large scale avulsion upstream.

1.10 Objective

Floods are the major natural hazard in the lower Rapti river basin and cause damage to agriculture crops, settlements, transport network systems etc. So, there is a need to look into various aspects of flood management in the lower Rapti river basin. The study aims to understand:

1.The Morphology of the lower Rapti flood plain.

2.The flow characteristics of the Rapti river.

3.Land use changes in the flood plain.

4.The effect of land use changes on the flood plain morphology and flood hazard.

5.Floods in lower Rapti river basin

1.11 Data Base

I. Morphological characteristics and land use studies are based on:

1. Topographical Sheet Nos. 63N/1, 2, 5, 6, 7,10 and 11 on a scale 1:50,000 published by Survey of India, 1970-71.
2. Gorakhpur Development Authority map, 2001.
3. National Atlas of India, Vol. II, 1981.
4. Watershed Atlas of India, 1990.

5. Census Atlas of Uttar Pradesh, 1971, 1981 and 1991 and other ancillary information.
6. General Population Tables, Uttar Pradesh, Census of India 1971, 1981 and 1991, Part- IIA.

II. The river discharge data in the Rapti river basin were obtained from:

7. HMG of Nepal, Ministry of Science and Technology, Hydrological Records of Nepal Stream Flow Summary, Kathmandu, Nepal, April 1998.
8. Central Water Commission, Lucknow, 1978-2002.

III.The daily and monthly rainfall data were obtained from:

9. IMD, Pune-5.
10. IMD Substation located in Gorakhpur.

IV.The water level at the G/D sites on the Rapti river were collected from:

11. Flood Forecasting and Warning Network Performance Appraisal, Central Water Commission, 1986-2000, New Delhi.
12. Water and Related Statistics, Information System Organization, Water Planning and Project Wing, 1998-2001, CWC, New Delhi.

V. Flood Report of Gorakhpur district, 2001 and Troubled Water: A Report on 1998 flood were consulted for flood damage assessment.

1.12 Methodology

Traditional hydrograph separation method has been applied for the separation of the component of river regime of the Rapti river. The coefficient of variation (CV) of mean annual discharge has been calculated in order to examine the consistency of discharge. The formula for the coefficient of variation is expressed as:

[CV= (SD/ Mean) x100]

Suitable graphs have been prepared for the interpretation of the discharge data.

The flood plain morphology has been identified through visual interpretation of topographical sheets. The sinuosity index has been calculated with the help of following formula:

[Sinuosity index (SI)= (Channel length / Straight line valley length)]

Flood prone area along the Rapti river has been delineated on the basis of contour, spot height, personal observation and maximum water level attained during the years 1986 to 1999. Land use change detection in flood prone area has been done with the help of topographical sheet and map prepared by Gorakhpur Development Authority (GDA) using ERDAS IMAGINE 8.4 and ARC VIEW GIS 3.2a software. ERDAS IMAGINE 8.4 has been used for sub-setting, geo-referencing, and supervised classification. ARC VIEW GIS 3.2a has been used for digitization, labeling, area and length extraction etc.

Return period and percentage probability have been calculated using maximum discharge recorded at Bhinga and Birdghat (Gorakhpur) G/D sites. Discharge associated with return period i.e., 2, 5, 10, 25, 50, 100 and 200 years has been calculated through the log Pearson type-III method. The daily water level and rainfall at Bansi and Gorakhpur have been interpreted with respect to the synoptic systems, which prevailed over the basin during 1998 monsoon season. The average areal rainfall for the entire lower Rapti river basin has been calculated through arithmetic mean method using the daily rainfall recorded at Bahraich, Balrampur, Bansi and Gorakhpur during 1998 monsoon season. The cumulative average areal rainfall in each rainstorm has been plotted against the day. The maxima of cumulative average areal rainfall has been taken to draw the enveloping curve from 15th June to 29th September 1998 in order to know the duration of flood producing rainstorms. Dry sieving method has been used to determine particle size. The trend in flood loss has been interpreted by three years cumulative value.

Cross-sections from Nausar to the Rapti river and from Ramgarh Tal to Deoria bypass road have been drawn through GPS waypoint altitude in order to know the topography. Maximum water, danger and warning level have been plotted on the cross-section from Nausar to the Rapti river in order to demarcate the flood plain zones i.e., flood way and flood fringe.

1.13 Organisation of Materials

The entire work has been organized into six chapters. The first chapter is introductory in nature, which deals with the geographical personality of the study area, objective, data base, methodology and literature survey. The second chapter deals with flood plain morphology and discharge characteristics. The third chapter discusses the land use change and its impact on the flood plain morphology, floods and catchment. The fourth chapter deals with the causes of floods, flood producing weather systems, rainfall characteristics, flood flow from upper reaches, monitoring of flood, floods of 1998 and flood damages in Gorakhpur district. The fifth chapter deals with the approaches to flood management and human responses to flood and finally, conclusion is given in chapter sixth.

References

1. Kayastha, S.L., (1983), "Floods in India: A Study of their Occurrence, Causes, Forecasting and Control," *National Geographical Journal of India,* Vol. 29, Part 3 and 4, p.121.
2. Sharma, M.K., (2003), "Overview of Flood Management in India", Indian Journal of Public Administration, Vol. 59, No. 3, July-September, p.520.
3. *Floods Related Preparations in the Year 2004, What? And How?*, Irrigation Department, Uttar Pradesh, 2004, p.2.
4. Chow, V.T., (1956), "Hydrological studies of floods in the United State", *International Association of Scientific Hydrology,* Vol. 42, No..., pp. 134-170.
5. Yevyevich, V., (1992), "Floods and Society" in G. Ross, N. Harmancioglu and V. Yevyevich (eds.) *Coping with Floods*, NATOASI Series, Dordreecht, Kluwer, pp.3-9.
6. Ward, R.C., (1978), *Floods: A Geographical Perspective*, Mcmillon, London, pp...
7. World Meteorological Organization (WMO), (1974), *WMO/UNENSO International Glossary of Hydrology,* WMO Publication No. 385, Geneva, pp...
8. Dhar, O.N., and Nandargi, S., (1998), " Floods in Indian rivers and their meteorological aspects", in V. S. Kale (ed.), *Flood Studies in India* (Memoir No. 41), Geological Society of India, Bangalore, p 2.
9. Kulshrestha, S.M., (2000), *Flood Management in India,* Joint COLA/CARE Technical Report No. 3, Centre for Ocean-Land-Atmosphere studies/ Centre for the Application of Research on the Environment, Maryland, pp....

10. Sharma, K.D., Vangani, N.S., Chatterji, P.C. and Singh, G., (1982), " A Severe Flood in Luni Basin, Western Rajasthan during July 1979: A Case Study", *Mausum,* Vol. 33, No..., pp. 377-384.

11. Paul S.K., Bartarya, S.K., Rautela, P. and Mahajan, A.K., (2000), " Catastrophic mass movement of 1998 monsoons at Malpa in Kali Valley, Kumaun Himalaya, India, *Geomorphology*, Vol. 35 No..., pp. 169-180.

12. Sharma, R.P., (1974), *Nepal: A Detailed Geographical Account*, Pustak Sagar, Bhotahity, Kathmandu, Nepal p.10.

13. *Ibid.,* p.11.

14. Yadav, R.P., (1999), *Floods in Eastern Uttar Pradesh,* Radha Publication, 1999, New Delhi, p.1.

15. Bose, S.C., (1972), *Geography of Himalaya,* Thomson Press Limited, New Delhi-21, p.159.

16. Yadav, R.P., *op., cit.,* p.1.

17. Singh, R.L, (ed.), (1971), *India: A Regional Geography,* NGSI, 1971, Varanasi, p. 191.

18. *Ibid.,* p.190.

19. Sharma, R.P., *op., cit.,* p.11-13.

20. Khan, I.A.,Bridge, J.S., Kappelman, J and Wilson, R., (1997), *Sedimentology,* ...., pp.221-251.

21. Willis, B.J., and Behrensmeyer, A.K., (1994), "..............", *Journal of Sediment Research,* B64, 1994, pp.60-67.

22. Thapa,N.B., and Thapa, D.P., (1969), *Geography of Nepal,* Orient Longman, Calcutta, pp.13.

23. Yadav, R.P., *op., cit.,* p.4-5.

24. *Ibid.,* p.5-6.

25. Singh, R.L., *op., cit.,* p.202-203.

26. Thapa,N.B., and Thapa, D.P., *op., cit.,* p.35.

27. Yadav, R.P., *op., cit.,* p.12-13.

28. *Ibid.,* p.16.

29. Sharma, R.P., *op., cit.,* p.24-25.

30. Yadav, R.P., *op., cit.,* p.11-12.

31. Leopold, L.B. and Wolman, M.G., (1957), *River Channel Pattern: Braided, Meandering and Straight,* Professional Paper, U.S. Geological Survey, pp. 282-B.

32. Chorley, R.J., (ed.), (1969), *Water, Earth and Man: A Synthesis of Hydrology, Geomorphology and Socio-economic Geography,* Methuen & co. Ltd., London.

33. Gregory, K.J., and Walling, D.E., (1973), *Drainage Basin Form and Processes: A Geomorphological Approach,* Edward Arnold, London.

34. Schumm, S.A., (1977), *The Fliuvial System,* John Wiley and Sons, Inc, New York.

35. Kayastha, S.L. and Yadav, R.P., (1980), "Flood Hazard in Lower Ganga-Ghaghara Plain (U.P., India): A Study in Perception and Impact on Socio-economic Development", *National Geographical Journal of India,* Vol.26, Parts II&I pp.19-28.

36. Kayastha, S.L, *op., cit.,* pp.121-141.

37. Beven, K. and Carling, P., (ed.), (1989), *Floods:Hydrological, Sedimentological and Geomorphological Implications,* John Wiley and Sons, New York.

38. Newson, M., (1992), *Land, Water and Development: RiverBasin System and their Sustainable management,* Routledge, London.

39. Miller, John B., (1997), *Floods: People at Risk, Strategies for Prevention,* United Nations Publication, New York.

40. Sinha, R., and Jain, V., (1998), " Flood Hazards of North Bihar Rivers, Indo-Gangetic Plains" in *Flood Studies in India*, edited by V.S. Kale, (Memoir-41), Geological Society of India, Bangalore, pp.27-52.

41. Das, A.K., (2000), *Fluvial Processes in the Flood Plains of Subansiri river and their impact on Arable Land,* Unpublished Ph.D. Thesis, CSRD, JNU, New Delhi.

42. Parker, D.J., (ed.), (2000), *Floods,* Vol. I & II, Routledge, London.

43. Verma, R., and Ram, L.C., (2001), " A Case study of Heavy Flood in River Ken during September 1992", *Mausam, Vol. 52, No. 3,* July, pp. 597-601.

44. Sivasami, K.S., (2002), " Environmental effect due to Floods and Reservoirs" in *Environmental hazard in South Asia* edited by V. Subramanian, Capital Publishing Company, New Dehli, pp.65-82.

45. Sullivan, A., Ternan, J.L., and Williams, A.G., (2004), " Land use Change and Hydrological response in the Camel catchment, Cornwall", *Applied Geography,* Vol. 24, No. 2, pp.119-136.

46. Thapa,N.B., and Thapa, D.P., *op., cit.*

47. Rao, K.L., (1979), *India's Water Wealth,* Orient Longman Ltd., New Delhi.

48. Bose, S.C., *op., cit.*

49. Sharma, R.P., *op., cit.*

50. Singh, L.R. and Singh, R., (1995), *Map work and Practical Geography,* Central Book Depot, Allahabad, pp.

51. Kumar, A., and Ram, L.C., (1995), " Semi-Quantitative Precipitation Forecast for Rapti catchment by Synoptic analogue method", *Mausam,* Vol. 46, No. 1, January, pp. 97-99.

52. .Dogra, Bharat, (1997), " More flood with Flood Control", *Economic and Political Weekly,* Vol.32, No.18, May 3, pp.33-34.

53. Yadav, R.P., *op., cit.*

54. .Jain, V. and Sinha, R., (2003), "River System in the Gangetic Plains and their Comparison with the Siwaliks", *Current Science,* Vol.84, No.825, April, pp.1025-33.

55. Thapa, AB, (2003), "West Rapti high Dam Project", *Spotlight,* Vol.22, No.47, June 06, pp...

56. Sinha, R. and Roy, N.G., (2005), "Alluvial Geomorphology and Confluence Dymnamics in the Gangetic Plains, Farrukhabad-Kannauj area, Uttar Pradesh, India", *Current Science,* Vol.88, No.12, June 25, pp.2000-2006.

Chapter Two

Morphology and Flow Characteristics of the Rapti River

2.1 Introduction

The study of flood plain is of great importance to understand the surface form and flood problem of the region. Flood plain has been defined by many scholars. Some definitions of flood plain are as follows:

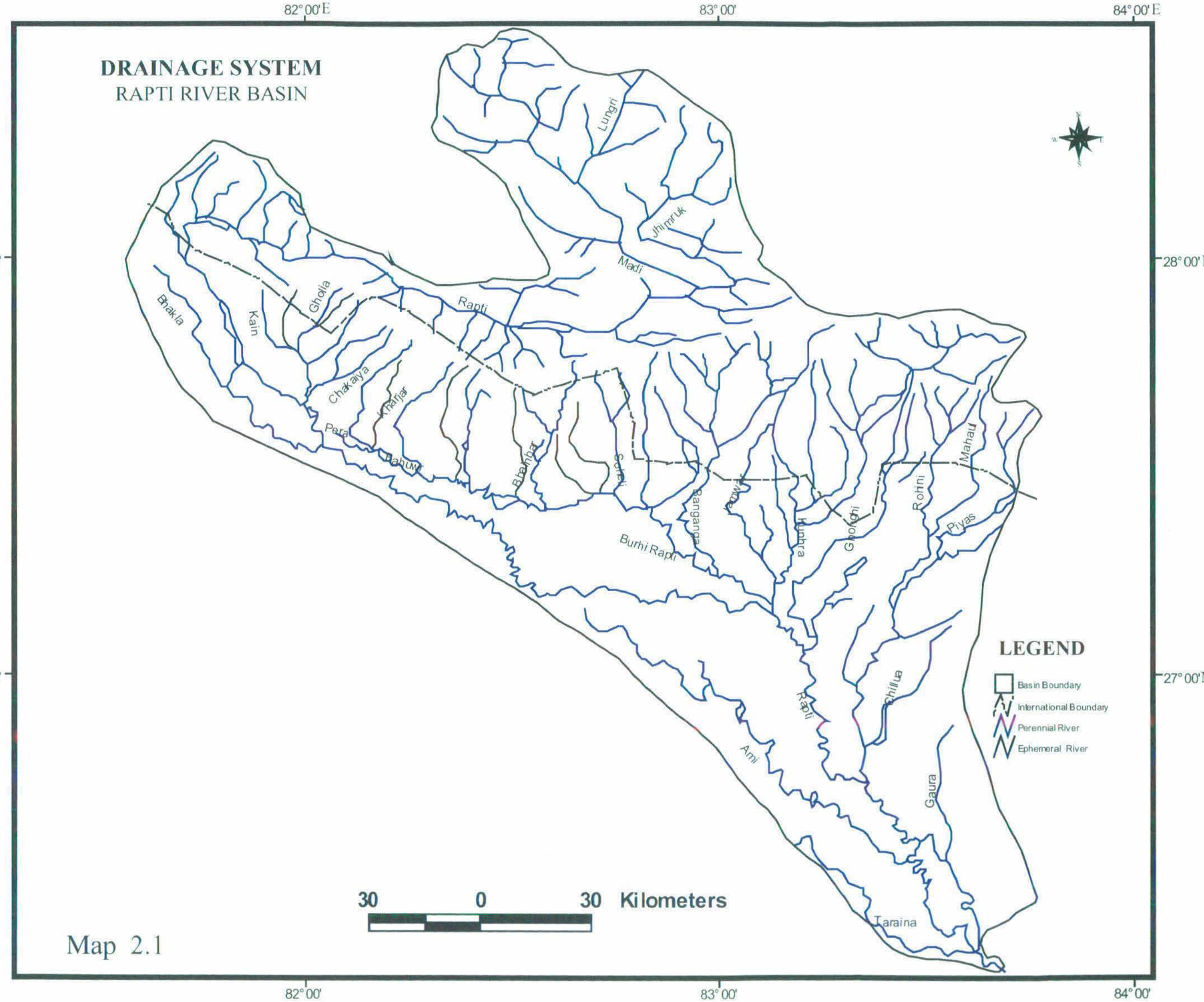
1.The flood plain represents that area across which the river escapes during floods[1], 2. The smooth strip of land bordering the river channel, embracing the river pattern and inundated at times of high stage is described as the flood plain [2], 3. Flood plains are liable to inundation. They are best understood in the context of meandering streams shifting meanders working over the valley bottom alluvium, eroding their outside bends but depositing on the insides and forming a depositional strip along the length of the valley[3], and 4. Flood plain is the area that is flooded, despite the erection of costly flood management structures[4].

Thus, channel erosion and aggradation (or scour and fill) combined with shifting of meander are collectively responsible for flood plain evolution and modification. Apart from channel deposit, flood plain is produced by over bank deposition. The suspended sediments are deposited on the flood plain when the river water is out on the plain during floods. The predominance of either of these two kinds of depositional environments (channel deposit and over bank deposit) is dependent upon the frequency of discharge that inundates the flood plain.

2.2 Drainage Network

The general slope of the region generally governs the drainage pattern, which is from northwest to southeast. The drainage pattern is dendritic in general and general characteristic features available throughout the basin reveals that the rivers meet at acute angles and several tributaries form parallel or sub-parallel lines to the main stream.

The Rapti river originates in the Siwalik Himalaya of Nepal at an elevation of 3600m[5]. After flowing through Nepal for 152 km, it enters Eastern Uttar Pradesh in Chanda Pargana, east of the Kundwa village of Bahraich district[6]. It flows in a very sinuous course with shallow depth and causes heavy flooding in the districts of Eastern Uttar Pradesh[7]. It flows through the districts of Bahraich, Balrampur, Sarawasti, Basti and



Source: National Atlas of India, Vol. II, 1981 and Watershed Atlas of India, 1990

Gorakhpur and joins the Ghaghara on its left bank near Barhaj town of Deoria district. The total length of the river is 566 Km (Map 2.1 and Table 2.1).

Table 2.1: Length* of Major Rivers of the Rapti River Basin

Sl. No.	River Name	Length (in km)
1	Jhirmuk	81
2	Lungri	35
3	Madi	86
4	Bakla	41
5	Kain	51
6	Bhawa	21
7	Gholia	23
8	Dangmara	30
9	Hathikund	20
10	Chakaiya	40
11	Pera	13
12	Kharjar	39
13	Bahuwr	85
14	Nakti	33
15	Bhainbar	46
16	Soheli	35
17	Banganga	77
18	Burhi Rapti	95
19	Banganga	77
20	Kunhra	66
21	Ghonghi	99
22	Rohini	125
23	Mahaul	51
24	Piyas	72
25	Balia	18
26	Chillua	44
27	Gaura	72
28	Ami	147
29	Taraina	67
30	Rapti	566

* Length of the rivers is calculated through Arc View GIS 3.2a software.

The area of Rapti river basin is 25637 Km^2. The Rapti river is a foothills fed river. It derives enormous amount of sediment from the foothills and also from within the plain and a large proportion is re-deposited in the plain after local reworking [8]. Some hydrological characteristics have been given in Table 2.2.

Table 2.2: Hydrological Characteristics of the Rapti river

River Type	Foot hill fed
Total Basin Area (km^2)	25637
Av.Sediment Load (mt/year)	15.6
Sediment Yield (10^3t/year/km^2)	0.78
Av. Annual Rainfall in Upper reaches (cm)	170
Av. Annual Rainfall in Lower reaches (cm)	110

Source: Jain and Sinha[9], 2003,p.1026 and Yadav[10], 1999,p.19.

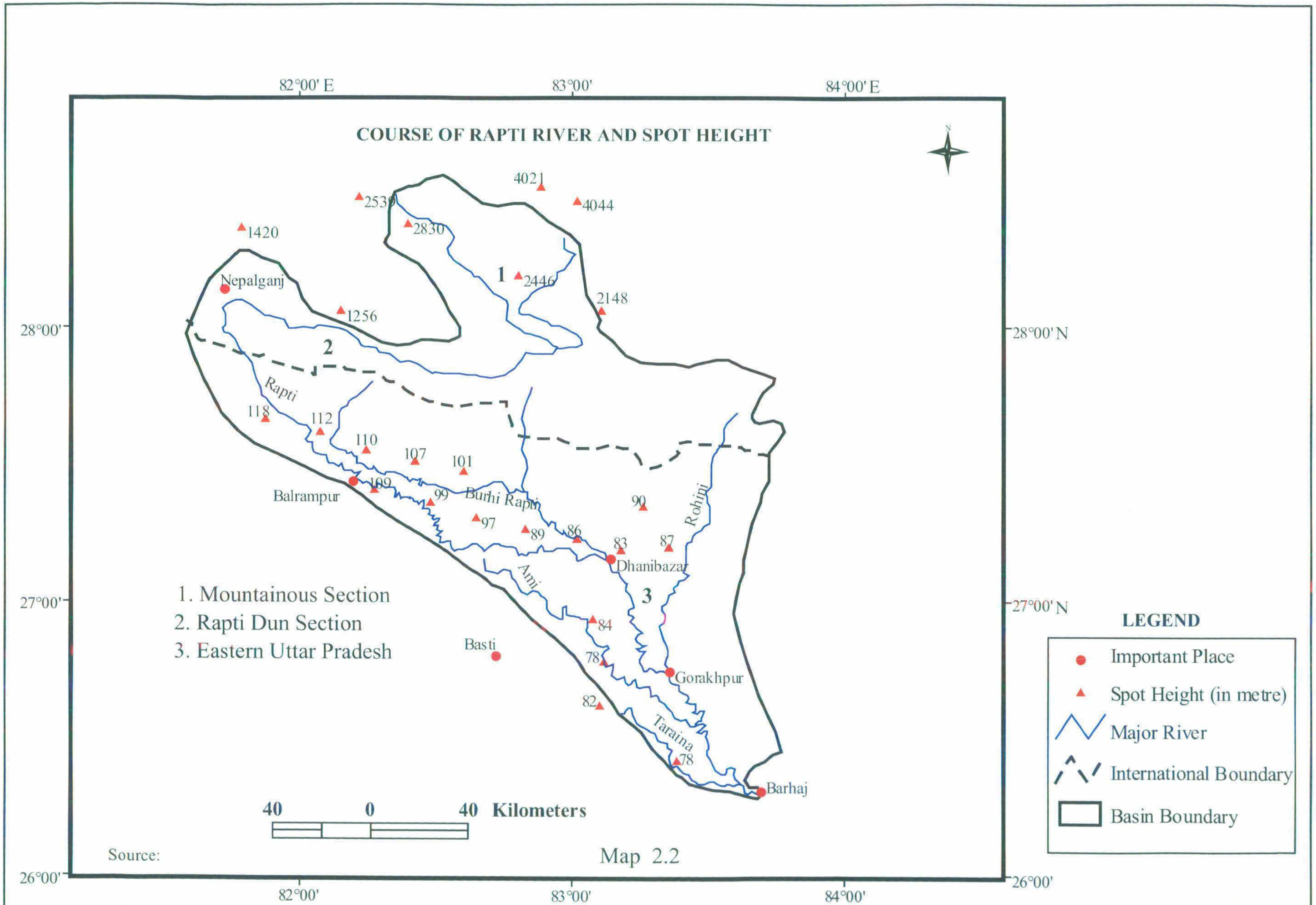
The course of the Rapti river can be divided into three sections (Map 2.2). The very first section is mountainous. In this section, the river runs in a longitudinal valley from W-N-W to E-S-E. Here, it receives combined waters of Madi, Lungri and Jhirmuk. Its altitude drops from 3000m to 1500m and the slope of this section is steep[11].

The second section of the valley is called Rapti Dun. The river flows from E-S-E to W-E-W upto Nepalganj. Here, the river turns again E-S-E presenting an elbow towards Nepalganj[12]. The altitude of this section varies from 150m to 300m and the slope is gentle (100cm/km.).

In the third section, the Rapti river enters the *Tarai* region of Eastern Uttar Pradesh. In this particular *Tarai* region, the gradient is very low throughout its easterly course but from Dhanibazar to the city of Gorakhpur, it is 15cm/km and again it drops to 8cm/km in the lower reaches[13]. The altitude of this section varies from 80m to 100m. In this section, the major left bank tributaries of Rapti river join to form Burhi Rapti. Both Burhi Rapti and Rapti flow parallel to each other for considerable distance and the *doab* is marked by flat terrain without any drainage. The main Rapti river flows close to the watershed that separates it from *Bhangar* land.

The major left bank tributaries are Bakla, Kain, Burhi Rapti, Ghonghi, Rohini,and Gaura. But those on the right bank are old bends of the Rapti river, which are of little importance. The Ami and the Taraina are major among them.

1. The Bakla: It is the chief affluent of the Rapti. It originates in the *Tarai* region of Nepal and flows for a considerable distance through Bahraich district. The total length of the river is 41 km (Table 2.1). It joins the Rapti at Piprahwa near Bhagwanpur[14].



Source: National Atlas of India, Vol. II, 1981 and Watershed Atlas of India, 1990

2.The Kain: The Kain is another affluent of the Rapti. It comes from Tulsipur *Tarai* and is fed by the Hathikund and numerous other streams. The total length of the ken is 51 km (Table 2.1). It joins the Rapti below Bhinga at Lachhmanpur Gurpurwa [15].

3.The Burhi Rapti: The Burhi Rapti emerges near Mathura, which is situated in the *Tarai* region and flows across Balrampur district in a direction roughly parallel to that of the Rapti river as far as Siddharthnagar border. The total length of the Burhi Rapti is 95 km. The major tributaries of the Burhi Rapti are Pera, Chkaiya, Kharjar, Nakti, Bhainbar, Soheli, Banganga, Jamwar, Kunhra, and Arrah[16].

4. The Ghonghi: It originates from the outer ranges of the hill of *Tarai* region. The total length of the Ghonghi is 99 km. It flows in a deep and well defined channel with a sandy bed [17].

5. The Rohini: It originates in the *Tarai* region and passes through Maharajganj district. Balia, Chillua, Kalan, Piyas, and Mahual are its major tributaries. The total length of the Rohini river is 125 km. It joins the Rapti near Gorakhpur city [18].

6. The Gaura: It is the plain fed river and carries off the overflow from Ramgarh and Narhai *Tals*. The total length of the Gaura is 72 km and it joins the Rapti in Deoria district [19].

7. The Ami: It is a plain fed river. The Reruwa is a small tributary, which joins Ami on its right bank near Banskhor of Basti district. It passes through the large track of paddy lands in Basti, Santkabirnagar, and Gorakhpur districts. The Barar, old channel of the Rapti, joins the Ami river on the eastern border of Maghar pargana of Santkabirnagar district[20]. The total length of the Ami river is 147 km and it joins the Rapt. in Gorakhpur district.

8. The Taraina: It is also a plain fed river. It originates in the south of Unaula Pargana of Santkabirnagr district. The total length of the Taraina is 67 km and it joins the Rapti in Bansgaon tahsil of Gorakhpur district[21].

2.3 Channel Pattern

The term "channel pattern" describes the planimetric form of streams. In other words, by channel pattern it is meant, the configuration of a river, as it would appear from an airplane[22]. Channel pattern differs from one stream to another stream due to differences in geological history, stream slope, discharge pattern, sediment load and time.

The main channel patterns are straight, meandering, braided and anastomosing . The characteristics of each pattern are given in Table 2.3.

Table 2.3 Characteristics of Channel Patterns

Stream type	Description	Width to Depth Ratio	Sinuosity	Bankfull Velocity (m/s)	Stream Power
Straight	Single channel with meandering thalweg, well defined banks, often containing bed rock, channel is stable, with minor widening or incision, sediment load is suspended and/or bed load; load is usually small in comparison to transport capacity. Cross-sections tend to have marked central hump. Found in short reaches.	Low<40	Low 1.0-1.5	High>3	High
Meandering	Single winding channel, usually with well defined banks, channel shifts mainly due to erosion by undercutting on outside of bends, causing the outward growth and down valley migration of meanders. Pools from in this region of high velocity and turbulence. Cut offs can occur across the base of a meander loop. Sediment load is mainly suspended and balanced with transport capacity.	Low <40	Moderate to high 1.5-4.0	Low to moderate 1-3	Low to moderate
Braided	Multiple channels with	High	Low to	Varied,	All

	bars and islands, often with poorly defined banks of non-cohesive materials. Channel and bank erosion follows a fairly random pattern. Flow is concentrated into flanking chutes, increasing velocity and sediment transport capacity. Sediment load is primarily bed load, and load is large relative to transport capacity.	>40	moderate 1.0-2.0	depending on slope and straightness of individual channel	ranges, from high in straight streams to low in sinuous stream with islands, channel bars.
Anastomosing	Multiple channels with relatively permanent, stable vegeted islands, in comparison to braided streams where channelways are constantly shifting. Banks are cohesive and sediment load is primarily suspended.	Low <10	Varied	Varied	Moderate

Source: (Gardon, Macmahon, and Finlayson, 1993 pp. 316-317)[23].

The Rapti river and its tributaries carry considerable amount of sediments from their head reaches and deposit them in the plain. Since the plain receives around 1500 mm of rainfall in a year, mostly in the four months of the monsoon season, the rivers rework the sediments during floods creating typical flood plain features. In this section the channel pattern of Rapti river has been discussed.

The sinuosity varies in rivers from a value of unity (1) to a value of 4 or more. Rivers, having a sinuosity of 1.5 or more, are called meandering and below 1.5 straight[24]. This definition is somewhat limited because the meandering channels also have some degree of symmetry in their curvature (Map 2.3). In this study, sinuosity index of 1.5 has been used as a criterion for meandering channel. The sinuosity indices are given in Table 2.4. The stretches (L1 to L7) have been selected randomly on the basis of channel curvature. Overall sinuosity of Rapti river (from Balauha to Barhaj) is 2.019. Thus, the Rapti river is basically a meandering stream and has a highly sinuous course.

Table 2.4: Sinuosity Indices of the Rapti River

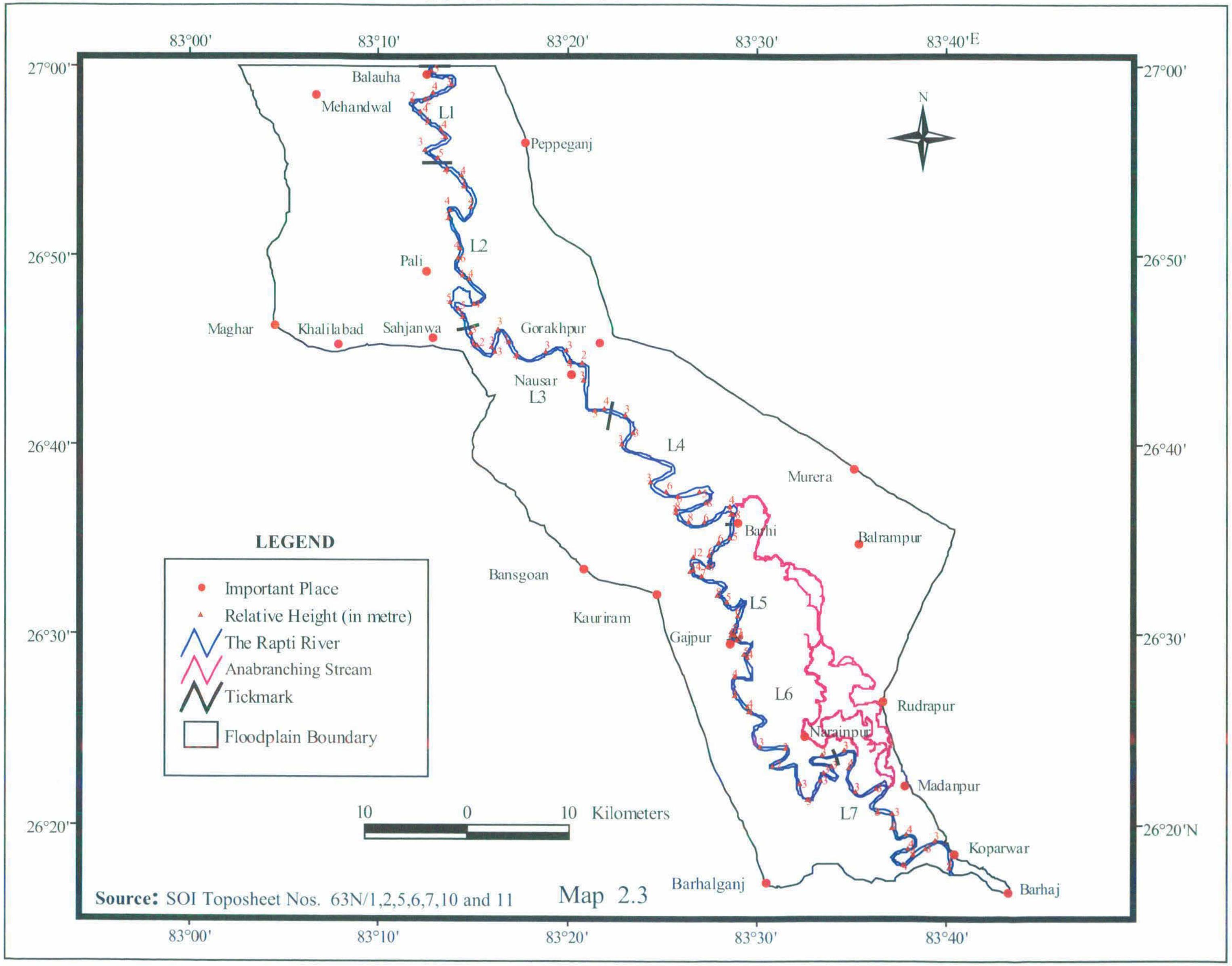
Section No.	Channel length (in Km.)	Straight Line Valley Length (in Km.)	Sinuosity Index (SI)
L1	16.51	9.41	1.75
L2	25.02	16.51	1.51
L3	22.68	15.05	1.5
Upper Reaches (L1, L2 & L3)	**64.21**	**40.97**	**1.57**
L4	29.12	15.3	1.9
L5	19.06	11.28	1.68
L6	36.42	14.44	2.52
L7	29.57	15.31	1.93
Lower Reaches (L4, L5, L6 & L7)	**114.17**	**56.33**	**2.03**
All Sections	**183.479**	**90.87**	**2.019**

The Rapti river has a gradient of 15cm/Km from Dhanibazar (in the district of Siddharthnagar) to Gorakhpur city, while the gradient from Gorakhpur city to Barhaj is 6.5cm/Km [25]. As a result, the sinuosity of upper reaches (L1, L2 and L3) is lower than the lower reaches (L4, L5, L6 and L7). Another reason for the high sinuosity in the lower reaches is the backwater effect of Ghaghara river that makes the Rapti river more sinuous in lower reaches. The Rapti riverbed has become shallow due to siltation. Therefore, it also causes backwater effect into its tributaries i.e., the Rohini, the Ami, the Gaura and the Taraina.

Another pattern that has been identified is the anabranching stream. Anabranching is the division of a river by islands whose width is greater than three times water width at average discharge[26]. Islands usually persist for decades or centuries, support well-established vegetation and are at approximately same elevation as the surrounding flood plain. They may have been excised by avulsion from that floodplain during periods of aggressive over bank flow[27]. The individual branching joins the main channel but sometimes it joins the other channel as well (Map 2.3). Anabranching streams are characterized by low gradient. They carry only the floodwater and transport mainly suspended load and a little bed load.

Anabranching streams are the most common features of lower Rapti flood plain. The surface of the islands located between the anabranching streams are covered by settlement, vegetation and agriculture fields.

MEANDERING STRETCH, RELATIVE HEIGHT AND ANABRANCHING STREAM
LOWER RAPTI FLOOD PLAIN



Map 2.3

2.4 Flood Plain Feature

The lower Rapti river basin is characterised by very gentle slope. Meandering and anabranching streams carrying significant quantities of sediments, rework the valley floor during floods creating typical flood plain features.

The flood plain features are mainly of three types. They are 1. features formed due to channel deposits, 2. channel margin or bank deposits, and 3. those formed by the flood basin deposits (Table 2.5).

Material eroded from the concave side tends to be deposited on the convex side of the next downstream meander. However, rigorous cross current may transport some sediment across the channel towards the convex side [28].

Rivers of the flood plain are characterized by the formation of bars. Bars are the major depositional features in the channel. Bars can be classified by their location in the stream. They are as follows:

1. **Point bars:** They primarily form on the inner bank of meanders and often create sandy beaches, which slope gradually into the water. Point bars are not visualized on the topographical sheets.
2. **Alternative bars:** They occur periodically first along one bank and then along the opposite one, with a winding thalweg running between the bars. They also create a meandering pattern at low flow.
3. **Channel junction bars:** They develop where tributaries enter a main channel.
4. **Transverse bar:** They cross the width of stream often at an angle diagonal to the flow. They are not found in the lower Rapti flood plain.
5. **Mid channel bars:** They are characteristics of braided reaches. In the Rapti river such types of bars are found in the middle part of the channel.

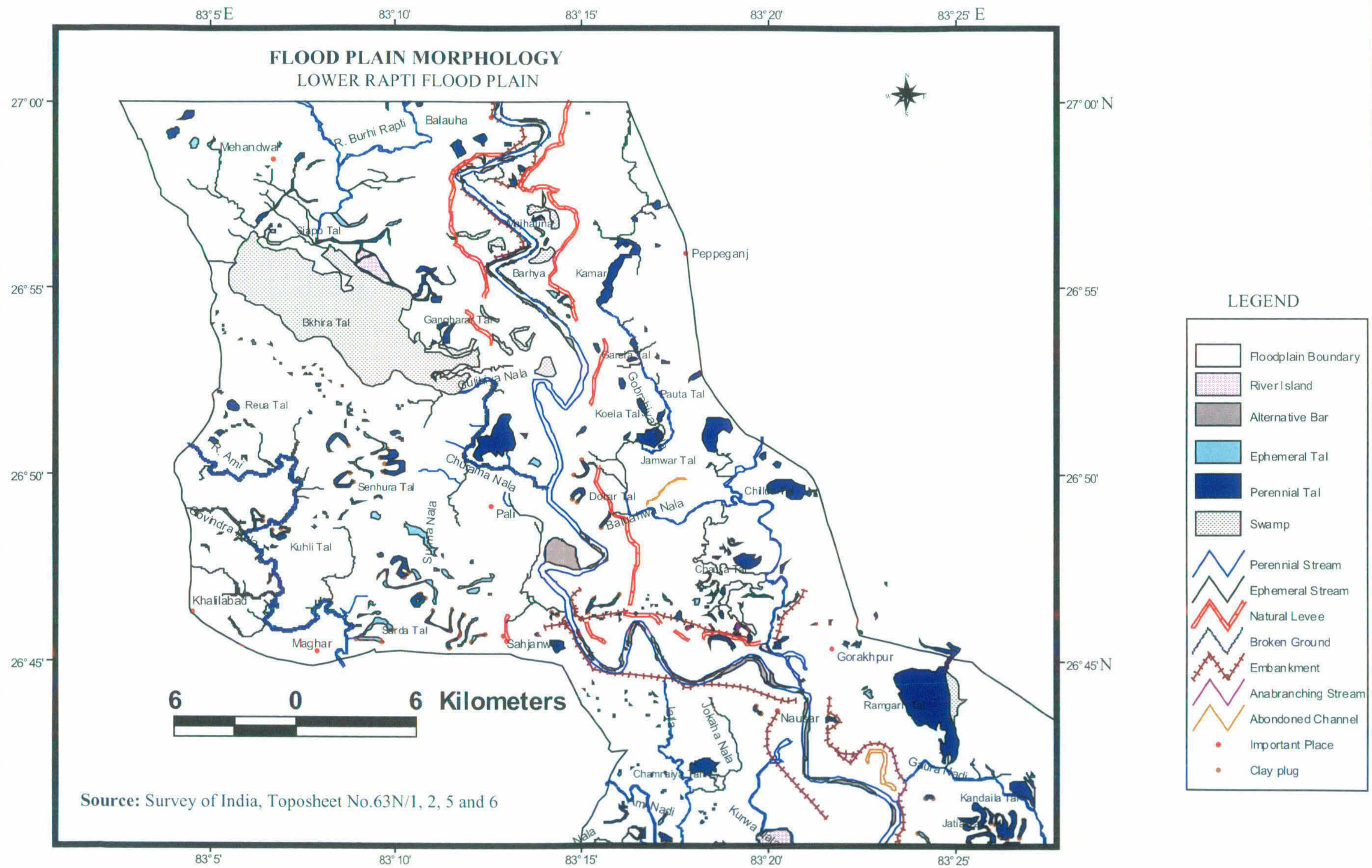
Table2.5: Flood Plain Features

Lateral accretion:	Point bars	A succession of point bars with intervening swales comprises a meander scroll
	Channel bars	
	Alluvial Islands	
Intermediate types:	Cutoff channels	Chute cut off where a new channel is developed along a swale in a bar. Neck cut off develop by slow accumulation of fine material and organic matter in cutoffs.
	Channel fills	Clay plugs develop by slow accumulation of fine material and organic matter in cutoff.
Over bank Features:	Levees	Wedge-shaped ridges of sediment bordering stream channels, best developed on concave banks and may be 4.5-5 m high on banks of Mississippi.
	Crevasse splays	A system of distributaries channels on the levee slope when water escapes through low section or breaks in natural levee.
	Flood basins	Back swamps, which are poorly drained, flat, and relatively featureless with little or no relief.
Ancillary features:	Lakes	In cutoffs, abandoned channels, meander scrolls or where a tributary is blocked.
	Deferred tributaries	Where a tributary flows parallel to the main river for some distance because of an aggraded alluvial ridge.
	Alluvial ridge	An aggraded meander belt above the general flood plain level. Avulsion may occur if the river suddenly abandons its course for new course at a lower level on the flood plain.

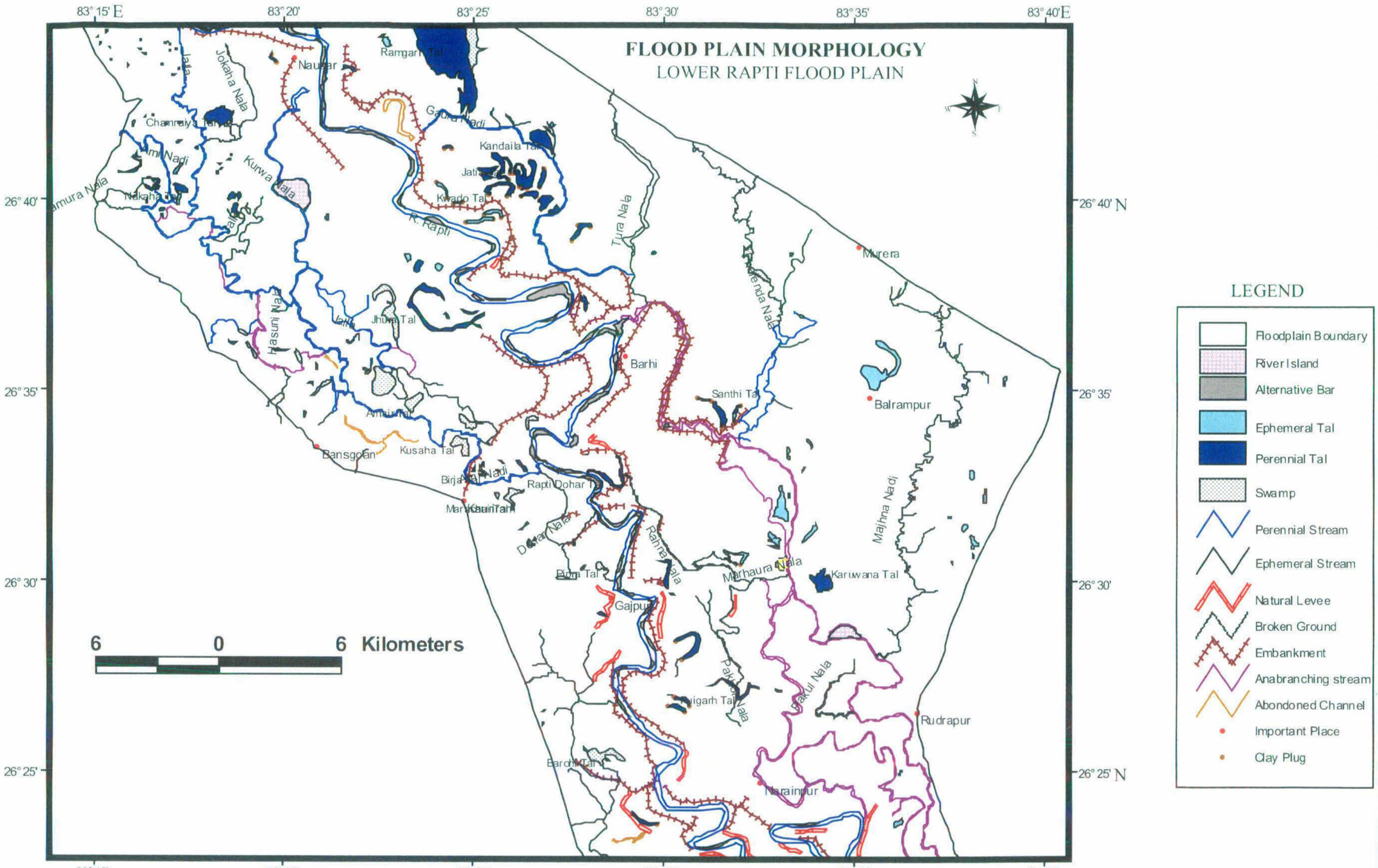
Source: Gregory and Walling, 1979 p.263 [29]

Besides alternative and mid channel bars, there are alluvial islands, which are formed by river accretion. Some of them are vegetated and small hamlets have developed over them. The very large islands are used for cultivation (Map 2.4 a, b and c).

Ox-bow lakes are the most common feature in the flood plain. These features are mostly formed along both sides of the Rapti river. Most of the *Tals* and the lakes are paleochannel of the Rapti river. Accumulation of silt blocked the paleochannels, creating


FLOOD PLAIN MORPHOLOGY
LOWER RAPTI FLOOD PLAIN
83° 5' E
83° 10'
83° 15'
83° 20'
83° 25' E
27° 00'
26° 55'
26° 50'
26° 45'
27° 00' N
26° 55'
26° 50'
26° 45' N
Balauha
R. Burhi Rapti
Mehandwal
Siapp Tal
Bkhira Tal
Ganghara Tal
Gulharia Nala
Maihauna
Barhya
Kamar
Peppeganj
Sareta Tal
Gobraiya
Pauta Tal
Koela Tal
Jamwar Tal
Reua Tal
R. Ami
Chilua Tal
Chuhrana Nala
Senhura Tal
Dobar Tal
Baijanwa Nala
Pali
Govindra
Kuhli Tal
Surma Nala
Chanda Tal
Khalilabad
Sarda Tal
Maghar
Sahjanwa
Gorakhpur
Ramgarh Tal
Naushar
Jokaha Nala
Chamraiya Tal
Ami Nadi
Kurwa Nala
Gaura Nadi
Kandaila Tal
Jatia
Nala
6 0 6 Kilometers
Source: Survey of India, Toposheet No.63N/1, 2, 5 and 6
LEGEND
Floodplain Boundary
River Island
Alternative Bar
Ephemeral Tal
Perennial Tal
Swamp
Perennial Stream
Ephemeral Stream
Natural Levee
Broken Ground
Embankment
Anabranching Stream
Abondoned Channel
Important Place
Clay plug

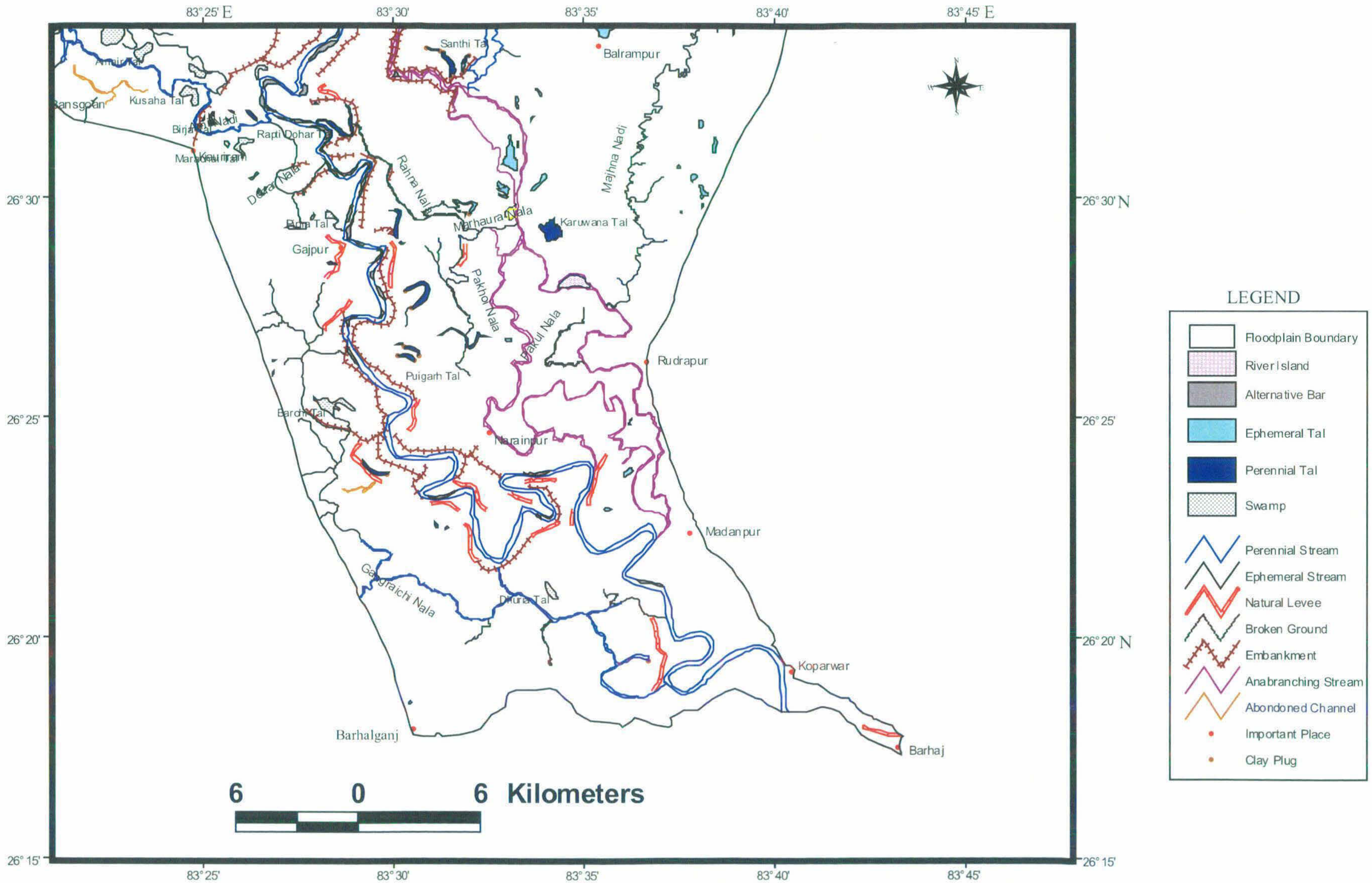
Map 2.4a



Source: Survey of India, Toposheet No.63N/6, 7, 10, and 11

Map 2.4b

FLOOD PLAIN MORPHOLOGY
LOWER RAPTI FLOOD PLAIN



Source: Survey of India, Toposheet No.63N/ 7, 10, and 11

Map 2.4c

depression that is annually filled in by the water either overflowing from the Rapti river and its tributaries and by rainwater during the monsoon season. Some of the major lakes and *Tals* are described in the following section.

1.The Bakhira Tal: This *Tal* is located in Siddharthnagar district. It is 2 meter deep and covers a very large area of about 8km long and 3 km broad. The water comes from the overflow of the Rapti river. After the unprecedented flood of 1998, the confluence point of the Bakhira *Tal* with the Rapti river has been choked near Chormat village. As a direct consequence, the water level is continuously decreasing. Now, the *Tal* is fully covered with reeds. Therefore, it is converted into the marshy land affecting the fish population and the livelihood of the fishermen[30].

2. The Ramgarh Tal: It is located in the southeastern part of Gorakhpur city. This *Tal* is rich in fish and provides livelihood to people in several villages located on its bank.

3.The Narhai Tal: It is located southeast of the Ramgarh *Tal*. It is connected with Ramgarh *tal* by the Gaura river, which carries off the excess water of both the *tals* into the Rapti.

4. The Domingarh and The Karmaini Tals: These lakes are located in the western part of Gorakhpur city. They are formed by the overflow of the Rohini just before its confluence with the Rapti river.

5.The Nandaur Tal: It is located about 9.6 km south of Gorakhpur city.

6.The Amiar Tal: It is located south of the Nandaur *Tal* and formed by the floodwaters of the Ami river.

7. The Bhenri Tal: This *Tal* lies between the Rapti and the Ghaghara rivers in Chillupar Pargana. It is formed by the excess waters of the Taraina river, which passes through the Tal.

8. The Chillua Tal: It is located about 11 km north of Gorakhpur city and formed by the overflow of the Chillua nala, which is a tributary of the Rohini River.

Some ox-bow lakes i.e., *Tals* are swampy in nature. They are present everywhere in the flood plain. Clay plugs are developed on both sides of the ox bow lakes. The surface of these lakes/ *Tals* is covered with aquatic plants i.e., reeds. Further, the ox-bow lakes/ *Tals* can be classified into two groups i.e., perennial *Tals* and ephemeral *Tals*. The backwater from these lakes causes floods in the adjoining areas in monsoon season. The ephemeral

Tals are formed by the floodwater when it enters the relatively low-lying areas. These *Tals* are locally known as *Chaurs*. These ephemeral *Tals* are used for cultivation of *Rabi* crops in winter season.

Abandoned dry channel is the ancillary feature found near the Rapti, the Rohini, and the Ami river.

Over bank / bank deposit features include natural levees. They are wedge shaped ridges of sediments bordering the rivers. It is identified from the topographical sheets on the basis of alignment of settlements, spot height, contours and flow direction of small rivers and *Nalas*.

Broken ground or Bank Slumps

They are generally determined by a combination of factors e.g., shearing away of bank materials, variability of materials and bank sediments and their lack of cohesion. Material slumping into the bed due to caving of bank is more common in meandering channel just downstream from the axis of the concave bend. Broken ground or bank slump is more common along the Ami river and the upper reaches of the Rapti river from Balauha village to Gorakhpur city.

2.5 Discharge characteristics of the Rapti River

Discharge is the volume of flow moving through a given cross section of a river in a given unit of time. It is commonly given in cubic meters per seconds (cumec) [31]. Factors that affect the annual discharge are climate and area.

1.Climatic Factors: The obvious and most effective influence on the annual discharge is the long-term balance between the amount of water gained by a catchment area in the form of precipitation and amount of water lost from that catchment area in the form of evapotranspiration. The relationship between annual discharge, rainfall and evapotranspiration may be modified by short-term factors, as duration and intensity of precipitation and changes in the vegetation cover [32].

2. Catchment Factors: In addition to the water balance of the catchment area, a second group of factors influencing the annual discharge comprises aspects of the physique of the catchment area. If the other factors remain equal, the area of the catchment determines the total amount of rainfall caught. The effect of area may depend upon the prevailing climatic regime. Thus, in a region, where PE exceeds rainfall, a larger catchment is just as likely as a smaller one to have a zero or very low annual discharge. Whereas, in a region in which rainfall exceeds the PE and the catchment area is large as a result the annual discharge will be high[33]. The latter case is true in the context of Rapti river basin.

The average height of the catchment area may affect the annual discharge indirectly through its direct orographic influence on rainfall.

The catchment area of the Rapti river upto Jalkundi is 5150 Km^2. The upper reaches of the Rapti river gets 170 cm average rainfall[34]. The height of the catchment varies between 300m to 4010 m[35]. Thus, the height of the catchment area affects annual discharge through its direct orographic influence upon the rainfall.

2.5.1 Data Base and Limitation

Monthly discharge data at Jalkundi G/D site have been collected from Hydrological Records of Nepal for the period (1964-1995).

The Rapti river basin is a part of the Ganga basin. There is a controversy between Nepal, India and Bangladesh on the Ganga basin so, CWC, New Delhi does not release monthly discharge data on any part of the Ganga basin.

A brief description of Jalkundi site is given in Table 2.6.

Table2.6: Description of Jalkundi G/D site

Field	Nepalganj
Station Number	360
River	Rapti
Location	Jalkundi (Nepal)
Latitude	27° 56′ 50″N
Longitude	82° 13′ 30″E
Station Elevation (m)	218
Drainage Area (in Km^2)	5150

Source: Department of Hydrology and Meteorology, Nepal.

2.5.2 Annual Discharge

The average annual discharge of the Rapti river at Jalkundi is 121.51 cumec with a coefficient of variation of 25.8 percent (Table 2.7).

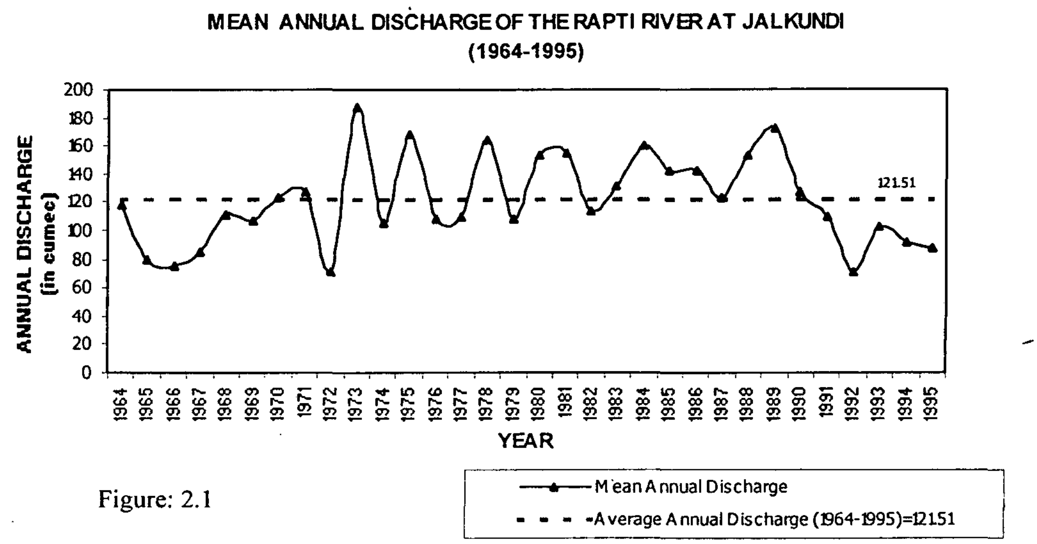


Figure: 2.1

Figure 2.1 shows variation in the mean annual discharge during the period of 1964 to 1995. The maximum mean annual discharge was observed in the year in the year 1973 (188 cumec), while the lowest was recorded in 1972 and 1992 (71.8 cumec). The years 1964 to 1972 have recorded below average annual discharge. The mean annual discharge was generally above average annual discharge during the years 1974 to 1990 and again from 1991 onwards, the mean annual discharge was decreasing below average.

Table 2.7: Average Monthly and Annual Discharges (in cumec) of the Rapti river at Jalkundi (Nepal).

Year	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug	Sep.	Oct.	Nov.	Dec.	Total	Av.Annual
1964	24.8	18.3	15.3	14.7	18.9	46.1	259	354	346	157	123	33.2	1410.3	118
1965	44.1	31.7	32.3	13.5	4.55	57.3	175	296	155	77.5	39.5	27	953.45	79.9
1966	22.8	19.9	15	9.8	5.59	66.1	183	316	148	51.1	29.2	23.8	890.29	74.8
1967	19.6	15.1	14.2	14.1	6.49	55.4	206	261	263	90.8	40.4	30	1016.09	85.1
1968	26.7	22.5	17.8	10.9	3.74	106	259	418	195	172	55.6	35.6	1322.84	111
1969	28.5	22.3	18.7	12.5	9.22	46.2	137	400	368	139	60.7	37	1279.12	107
1970	31.3	25.4	15	8.62	9.67	167	384	328	245	165	54.2	32.9	1466.09	123
1971	26	21.5	15	46.9	41.4	169	320	364	245	142	76.3	40.1	1507.2	127
1972	28.2	27	19.6	12.2	5	36.1	210	150	215	84.7	43.6	27.8	859.2	71.8
1973	41.3	29.2	28.1	13.5	18.1	265	324	475	456	432	11	47.3	2140.5	188
1974	31.6	25.6	19.4	14.1	7.51	23.3	289	451	205	112	47.9	31.2	1257.61	106
1975	26.9	22.9	17.4	11.6	5.78	98.8	467	534	469	239	63.8	40.3	1996.48	168
1976	28.3	22.9	16.3	13.1	18.4	46.8	277	349	345	99.4	42	27.4	1285.6	108
1977	22.2	18.4	13.8	10.2	12.9	77	227	550	237	75.3	35.1	26.6	1305.5	110
1978	22.2	21	19.3	13.7	8.12	187	650	495	318	152	50.3	31.9	1968.52	165
1979	23.6	24.8	16.3	13.2	20	97.2	356	472	122	70	30.6	31.9	1277.6	108
1980	22.1	17.3	14.6	7.97	9.66	180	337	446	625	104	43.5	27.8	1834.93	153
1981	24.3	19.1	15.6	15.5	17	25.6	301	429	773	149	54.4	29	1852.5	155
1982	37	31.5	27.2	13.7	52.9	41.1	210	390	411	77.9	39.8	26.2	1358.3	114
1983	21.3	19.6	13.8	11.3	34.4	18.1	106	271	658	307	79.2	40.7	1580.4	132
1984	36.2	24.8	16.3	12.8	5.89	148	534	370	577	111	48.5	31.7	1916.19	160
1985	24.6	18.2	13.7	9.75	17.4	86.5	341	408	425	230	83.3	49.1	1706.55	143
1986	32.2	27.8	17.4	17.4	14.7	196	328	396	367	168	73	52.7	1690.2	142
1987	30.3	22.9	18.4	13.4	14.5	15.8	334	460	333	126	60.4	36.6	1465.3	123
1988	24.1	19.5	18.9	18.6	18.3	73.3	495	660	296	106	53.6	42.8	1826.1	153
1989	49.2	31.3	25	17.1	16.4	101	509	649	385	158	61.7	42.1	2044.8	172
1990	31.2	42.9	36	21.4	51.9	98.2	431	397	209	115	48.4	38.9	1520.9	128
1991	34	24.6	24.4	17.3	15.5	171	127	402	336	73.5	38.5	45.9	1309.7	109
1992	29.3	24.7	17.9	13.8	13.3	61.7	87.9	248	198	93.3	41.8	29.8	859.5	71.8
1993	25.3	21.9	28.7	20.7	18.8	58.9	179	359	339	98.8	44.9	31.3	1226.3	103
1994	27.1	25.2	18.7	15.2	13.6	105	229	288	225	72.8	39.2	29.7	1088.5	91.1
1995	25.9	23.8	19.5	14.7	15.2	114	202	288	198	85.3	40.5	27.2	1054.1	87.84
Total	922.2	763.6	619.6	473.24	524.82	3038.5	9473.9	12674	10687	4334.4	1653.9	1105.5	46270.7	3888.342
Mean	28.82	23.86	19.36	14.79	16.40	94.95	296.06	396.06	333.97	135.45	51.68	34.55	1446	121.51
SD	–	–	–	–	–	–	–	–	–	–	–	–		31.4
CV(in%)	–	–	–	–	–	–	–	–	–	–	–	–		25.8

Source: HMG of Nepal, Hydrological Records of Nepal, Stream Flow Summary, Kathmandu, April 1998.

2.5.3 Seasonal Discharge

Factors Controlling River Regimes:

Seasonal variation in the discharge of a catchment area depends primarily on the relationships between climate, vegetation, soils and rock structure, basin morphometry, and hydraulic geometry. Of these, only rock structure and, to a lesser extent, basin size can be strictly independent of the climate. It should be stressed that the features of the basin morphometry and hydraulic geometry are only of direct relevance to the seasonal regimes of the large river basins[36].

The river regime of the Rapti river comes under warm tropical climate (Cwa type) with monsoon maximum and winter minimum amount of discharge.

The seasonal distribution of the annual discharge is given in Table 2.8. About 87 percent of the annual discharge is received in the monsoon season.

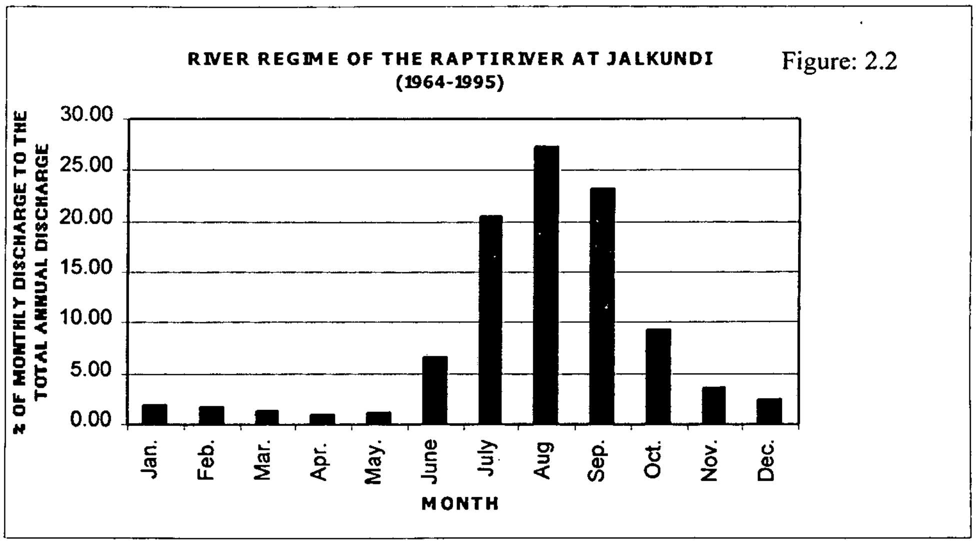
Table 2.8: Seasonal Distribution of the Annual Discharge

Season	Month	Percentage to the mean annual discharge
Winter	Jan.- Feb.	3.64
Summer	March - May	3.49
Monsoon	June – Oct.	86.91
Post Monsoon	Nov.- Dec.	5.96
Total		100

The percentage of average monthly discharge to the mean annual discharge shows that the river carries about 1 % of the annual flow during the months January to May. During the monsoon months more than 20% of the annual flow is observed in each month (Table 2.9 and Fig. 2.2).

Table 2.9: The Percentage of Average Monthly Discharge to the Mean Annual Discharge

Month	Percentage to the mean annual discharge
Jan.	1.99
Feb.	1.65
Mar.	1.34
Apr.	1.02
May.	1.13
June	6.57
July	20.47
Aug	27.39
Sep.	23.10
Oct.	9.37
Nov.	3.57
Dec.	2.39
Total	**100.00**



2.5.4 Component Separation

The river flows through both the mountainous and flat Rapti dun area with numerous affluents as, Madi, Lungri, Jhirmruk, and so on. These affluents bring huge amount of discharge to the Rapti. The total catchment area is 5150 Km^2 upto Jalkundi. The catchment gets high rainfall during the monsoon period (June to October) so that the proportion of surface flow i.e., the flood flow is considerably high in this season while in the non- monsoon period (November to May) the flow is basically, base flow i.e., the ground water (Table 2.10). In other words, the river feeds upon the effluent seepage during the non-monsoon period.

Table 2.10: Component Flow of Mean Annual Hydrograph at Jalkundi (1964-1995)

1	2	3	4	5	6
JAN	28.82	28.82	–	100	–
FEB	23.86	23.86	–	100	–
MAR	19.36	19.36	–	100	–
APR	14.79	14.79	–	100	–
MAY	16.4	16.4	–	100	–
JUNE	94.95	22	72.95	23.17	76.83
JULY	296.06	28	268.06	9.46	90.54
AUG	396.06	34	362.06	8.58	91.42
SEP	333.97	40	293.97	11.98	88.02
OCT	135.45	46	89.45	33.96	66.04
NOV	51.68	51.68	–	100	–
DEC	34.55	34.55	–	100	–
TOTAL	1446.0	359.46	1086.49	–	–
PERCENTAGE	100	24.86	75.14	–	–

1. Month, 2. Mean Monthly Discharge (in cumec), 3. Base Flow (in cumec), 4. Flood Flow (in cumec), 5. Percentage Base Flow, and 6. Percentage Flood Flow.

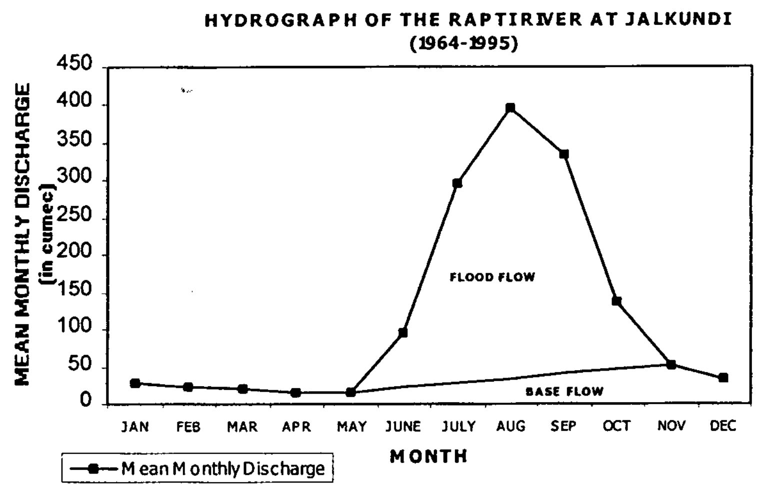


Figure: 2.3

The components of the regime of the Rapti river are separated with the help of the traditional hydrograph separation method. These are basically the flood flow and the base flow (Fig. 2.3). As a whole, the percentage of the base flow to the total mean annual discharge is 24.86 while the flood flow is 75.14, which is three times more than the base flow (Table 2.10).

2.6 Conclusion

The most prominent features of the lower Rapti flood plain are ox-bow lakes, alternative channel bars, swamp or marshes, natural levee and anabranching streams. The presence of ox-bow lakes (perennial and ephemeral) and the anabranching stream signify the low surface gradient. The Rapti river is a typical meandering stream. Low surface gradient and backwater effect of the Ghaghara river make the course of the Rapti river more sinuous in lower reaches (from Gorakhpur to Barhaj) than the upper reaches (from Balauha to Gorakhpur). The Rapti riverbed has become shallow due to siltation. Therefore, it also causes backwater effect into its tributaries i.e., the Rohini, the Ami, the Gaura and the Taraina.

The Rapti river is a foothills fed river. The upper part of the basin lies in the Siwalik of Nepal and receives heavy rainfall. Most of its annual discharge is found in the monsoon season.

References

1. Newson, M., (1992), *Land, Water and Development: River basin System and their Sustainable Management,* Routledge, London, p.43.
2. Gregory, K.J., and Walling, D.E., (1973), *Drainage Basin Form and Processes: A Geomorphological Approach,* Edward Arnold, London, p. 261.
3. Dury, G.H., (1969), " Relation of Morphometry to Runoff Frequency", in *Water, Earth and Man: A Synthesis of Hydrology, Geomorphology and Socio-Economic Geography,* edited by R.J., Chorley, Methuen & Co Ltd., London, p. 425.
4. Miller, John B., (1997), *Floods: People at Risk, Strategies for Prevention,* United Nations Publication, New York, p.79.
5. Rao, K. L., (1979), *India's Water Wealth,* Orient Longman Limited, p.70.
6. U.P. District Gazetteers, *Bahraich,* Govt. of U.P., 1988, p. 5.
7. Rao, K.L., *op. cit.,* p.70.
8. Jain, V. and Sinha, R, (2003), "River System in the Gangatic Plains and their comparison with the Siwaliks", *Current Science,* Vol. 84, No. 825, p.1025.
9. *Ibid.,* p.1026.
10. Yadav, R.P., (1999), *Floods in Eastern U. P,* Radha Publications, New Delhi-2, p.19.
11. Bose, S.C., (1972), *Geography of Himalaya,* Thomson Press Limited, New Delhi-21, p.158.
12. *Ibid.,* p.158.
13. Yadav, R.P., *op. cit.,* p.28.
14. U.P. District Gazetteers, *Bahraich, op. cit.,* p.8.
15. *Ibid.,* p.9.
16. U.P. District Gazetteers, *Gonda,* Govt. of U.P., 1989, pp. 5-6.
17. U.P. District Gazetteers, *Gorakhpur,* Govt. of U.P., 1987, p. 4.
18. *Ibid.,* p.5.
19. *Ibid.,* p.5.
20. U.P. District Gazetteers, *Basti,* Govt. of U.P., 1988, p. 9.
21. U.P. District Gazetteers, *Gorakhpur, op. cit.,* p.6.
22. Leopold, L.B., Wolman, M. G., and Miller, (1963), *FluvialGeomorphology...,* p.281.

23. Gardon, N.D., Mcmahon, T.A., & Finlayson, B. L., (1993), *River Hydrology,* John Wiley & Sons Ltd., U.K., pp.316-317.

24. Leopold, L.B., Wolman, M. G., and Miller, *op. cit.,* p.281.

25. Yadav, R.P., *op. cit.,* pp.28-46.

26. Schumm, S.A.,(1980), " Planform of Alluvial Rivers", *Proceeding of the International Workshop on Alluvial River Problems* held at Roorkee, India, pp.4 -22.

27. Knighton, David, (1998), *Fluvial From and Processes: A New Perspective,* Arnold, London, p. 236.

28. Raman, V.A.V., (2003), *PhotoGeomorphological analysis of Fluviatile Depositional Surface: A study in Ganga and Brahmaputra Alluvial Plains,* Unpublished Ph.D Thesis, submitted to the University of Delhi, p.66.

29. Gregory, K.J., and Walling, D.E., *op. cit.,* p.263.

30. Harsh, K., (2005), "Intzar Videshi Mehmano Ka", *India today*, February 14, pp. 52-53.

31. Strahler, A., and Strahler, A., (2002), *Physical Geography,* John Willey & Sons (Asia), p. 711.

32. Ward, R.C., (1978), *Principles of Hydrology,* Mc.Graw Hill, London, p. 324.

33. *Ibid.,* p.325.

34. Yadav, R.P., *op. cit.,* p.21.

35. Sharma, R.P., (1974), *Nepal: A Detailed Geographical Account,* Pustak Sagar, Bhotahity, Nepal, pp. 10-11.

36. Beckinsale, Robert P., (1969), "River Regimes," in *Water Earth and Man: A Synthesis of Hydrology, Geomorphology and Socio-Economic Geography* edited by R.J. Chorley, Methuen, London, P.455.

Chapter Three

Land Use Changes in the Lower Rapti River Basin

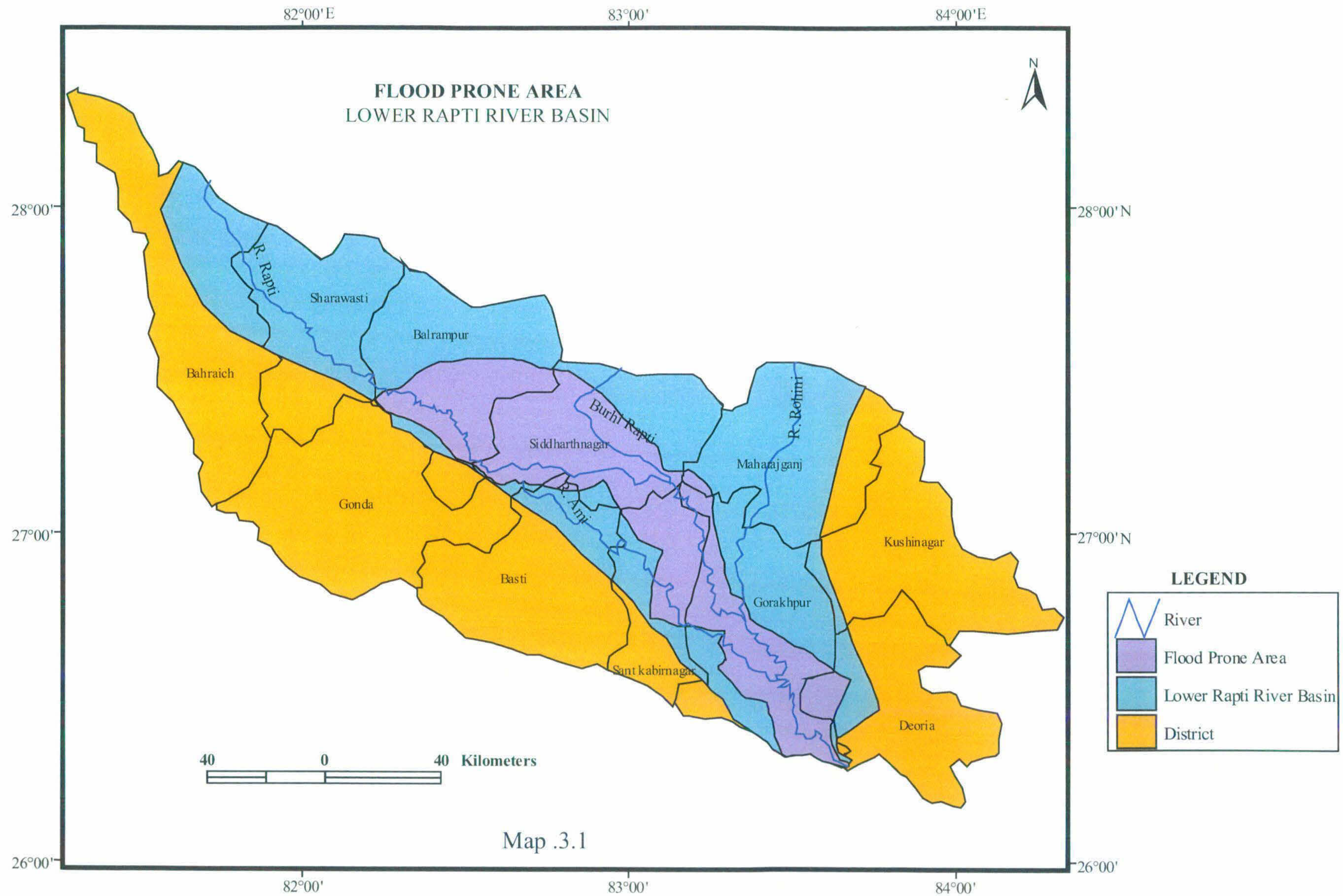
3.1 Introduction

Man has inhabited the flat and fertile land of the Rapti river basin for a long time. When man settled on the land and formed settlements, he preferred to be close to the banks of rivers for fertile agricultural land, drinking water, transportation facility and mud, which was the key building material for constructing shelter. However, early settlers took care to build their settlements on high ground and used flood plain only for crops and grazing. Later, as the civilization grew, floodplain got converted to high value land uses. The extent of man-nature interaction is manifested in the pattern of land use. In this basin, the land use presents a typical scenario of subsistence economy where agriculture is predominant activity. The land use and floods appear to be interrelated. Therefore, analysis of land use holds importance especially in case of the study of flood problem.

The Rapti river basin has potential for the urban development. Urban area is growing both geographically and demographically at an alarming rate. Process of urbanization may alter the flood hydrology. Deforestation in Nepal hills is an important cause of the frequent and severe floods in the lower Rapti river basin. The area under forest and woodland has reduced from 287.46 Km^2 to 137.65 Km^2 in the mountain and the *Tarai* regions of the upper Rapti river basin between 1991-92 and 2001-02[1]. This chapter analyses the land use pattern in order to assess the flood hazard in the basin and impact of floods on land use and vice versa. Further research will be needed in order to study the land use changes in flood prone area through remotely sensed satellite imageries and detailed hydrological data.

3.2 District-wise Flood Prone Area

Out of the total area of 14828 Km^2, flood prone area along the Rapti river is 5010 Km^2 It accounts for 33.8 percent to the total basin area. District-wise area under basin and flood prone area in the lower Rapti river basin is shown in Table 3.1. The flood prone area is demarcated through the contour, spot height, water level and personal knowledge of the area (Map 3.1).



Map .3.1

Source: SOI Toposheet Nos. 63N/1,2,5,6,7,10 and 11 and Ancillary Information

Table 3.1: District-wise Area under the Lower Rapti River Basin and Flood Prone Area (in Km^2) in the Lower Rapti River Basin.

1	2	3	4	5	6	7
Balrampur	3394	2536	17.10	74.72	1048	41.33
Bahraich	4420	933	6.29	21.11	0	0.00
Sharawasti	2458	1332	8.98	54.19	0	0.00
Siddharathnagar	2895	2895	19.53	100.00	1641	56.67
Basti	2688	503	3.39	18.71	33	6.55
Santkabirnagar	1646	1102	7.43	66.95	691	62.68
Gorakhpur	3321	2910	19.63	87.62	1380	47.44
Maharajganj	2952	2077	14.01	70.36	38	1.85
Kushinagar	2906	113	0.76	3.89	0	0.00
Deoria	2538	427	2.88	16.82	179	41.80
Total		**14828**		**100.00**	**5010**	

1. District as per 2001 census 2. Total District area 3. District area under basin 4. Percentage area to the total basin area. 5.Percentage Basin area to the total district area 6. Flood prone Area 7.Percentage Flood Prone area to the district area under Basin.

Source: 1.Survey of India toposheet Nos. 63N/1,2,5,6,7,10 and 11.
2. National Atlas of India, Vol.6, 1981.
3.Census of India, Provisional Population total, Uttar Pradesh, 2001.

3.3 Land Use as Depicted in Topographical Sheets

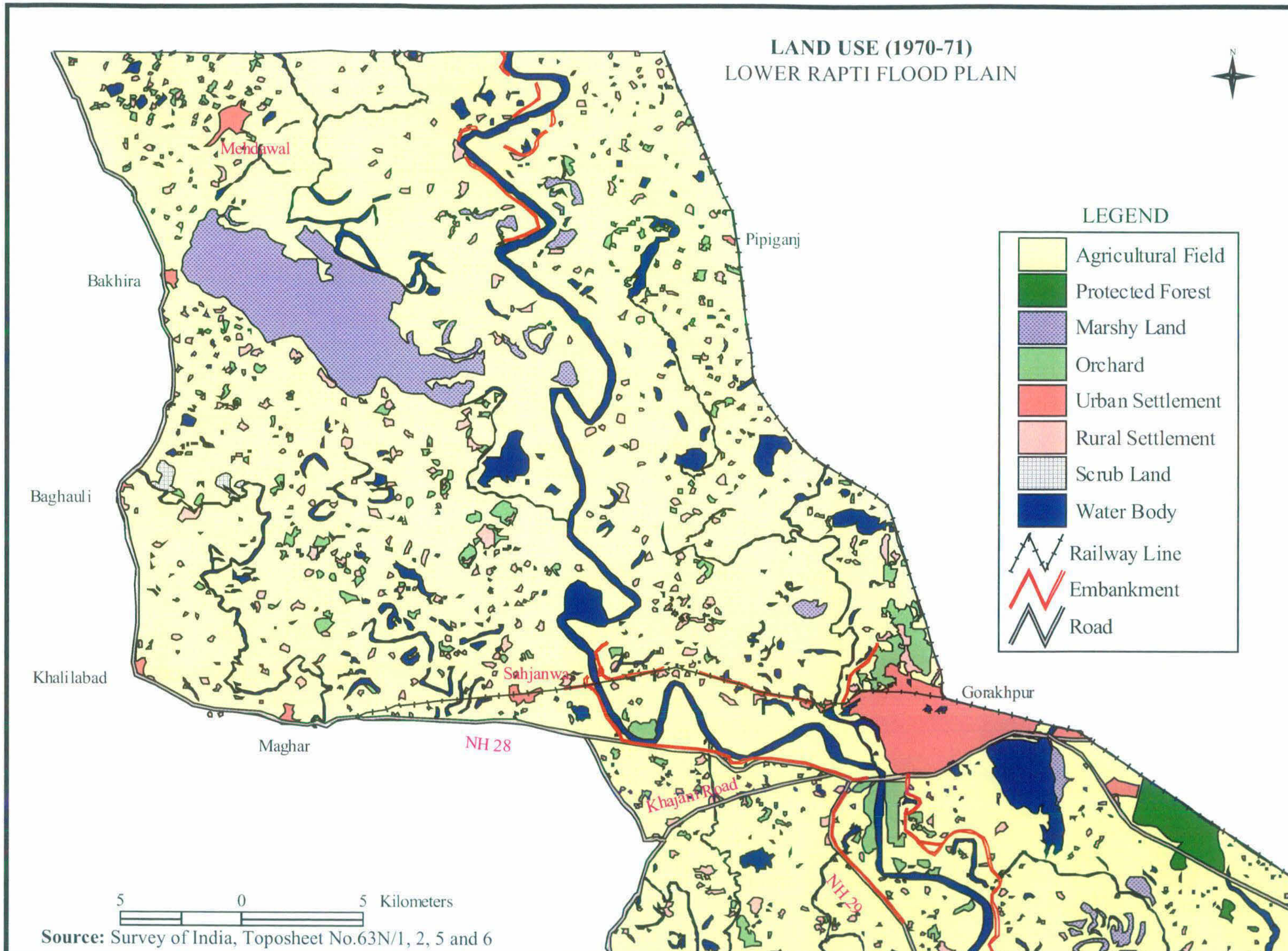
Land use in the part of the Rapti river basin has been analyzed to understand the land use pattern in the flood prone area (Map 3.2 a, b and c). Table 3.2 shows the land use categories that have been calculated from topographical sheets. In a total area of 1926 Km^2, agricultural land accounts for 85.2% (1641 Km^2) area. Water bodies, including rivers and *Tals* cover 5.8% (112 Km^2) area.

Table 3.2: Land use (in Km^2) as Depicted in Survey of India Topographical Sheets (1970-71)

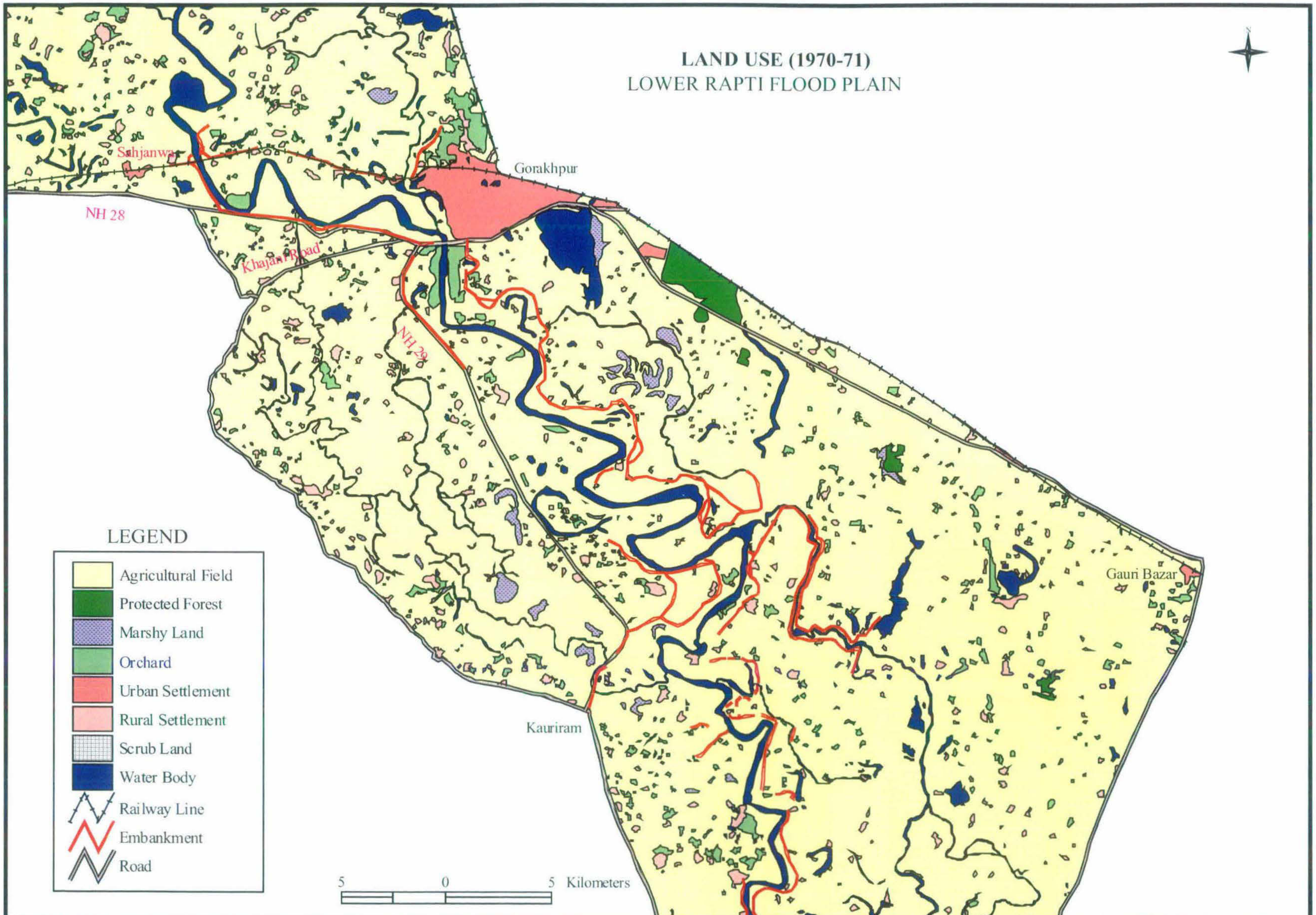
1	2	3
Agricultural Land	1641	85.2
Protected Forest	8	0.4
Marshy Land	52	2.7
Orchard	38	2.0
Buit-up Area	74	3.8
Land with Scrub	1	0.1
Water body	112	5.8
Total Area	**1926**	**100.0**

1. Land use Category 2. Area 3.Percentage area to the total area

Source: Survey of India toposheet No. 63N/1,2,5,6,7,10 and 11.

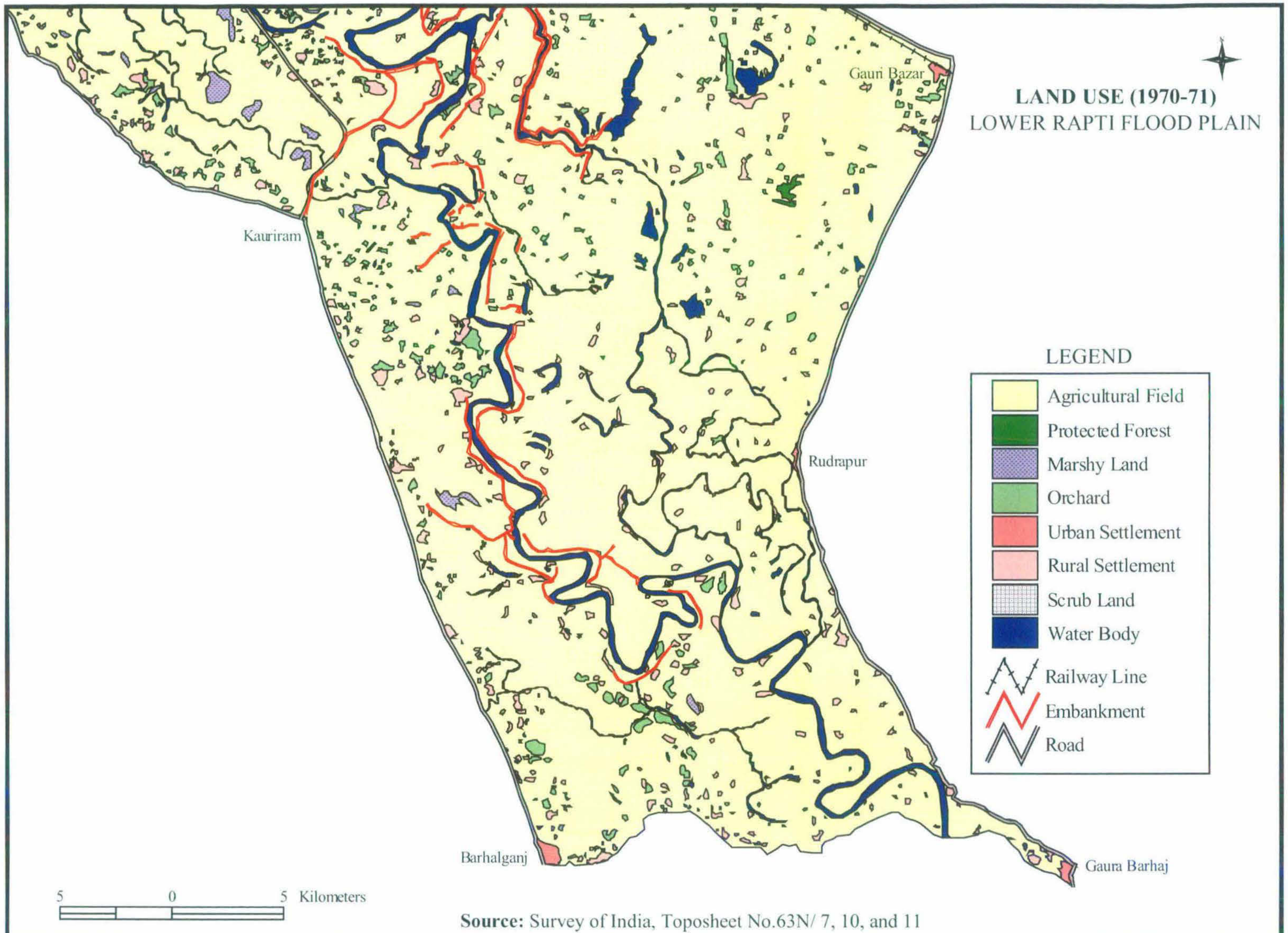

LAND USE (1970-71)
LOWER RAPTI FLOOD PLAIN
N
LEGEND
Agricultural Field
Protected Forest
Marshy Land
Orchard
Urban Settlement
Rural Settlement
Scrub Land
Water Body
Railway Line
Embankment
Road
Mehdawal
Pipiganj
Bakhira
Baghauli
Khalilabad
Sahjanwa
Gorakhpur
Maghar
NH 28
Khajani Road
NH 29
5 0 5 Kilometers
Source: Survey of India, Toposheet No.63N/1, 2, 5 and 6

Map 3.2a



Source: Survey of India, Toposheet No.63N/6, 7, 10, and 11

Map 3.2b


LAND USE (1970-71)
LOWER RAPTI FLOOD PLAIN
Gauri Bazar
Kauriram
Rudrapur
Barhalganj
Gaura Barhaj
LEGEND
Agricultural Field
Protected Forest
Marshy Land
Orchard
Urban Settlement
Rural Settlement
Scrub Land
Water Body
Railway Line
Embankment
Road
5 0 5 Kilometers
Source: Survey of India, Toposheet No.63N/ 7, 10, and 11

Map 3.2c

The built-up area including urban and rural settlements comprises 3.8% (74 Km^2) area of the total area. Protected forest, marshy land, orchard and land with scrub cover 0.4% (8 Km^2), 2.7% (52 Km^2), 2.0% (38 Km^2), and 0.1% (1 Km^2), respectively. Thus, agricultural fields, water bodies and built-up area cover a large chunk.

3.4 Land Use Changes in the Southern Part of Gorakhpur City (1970-71 to 2001)

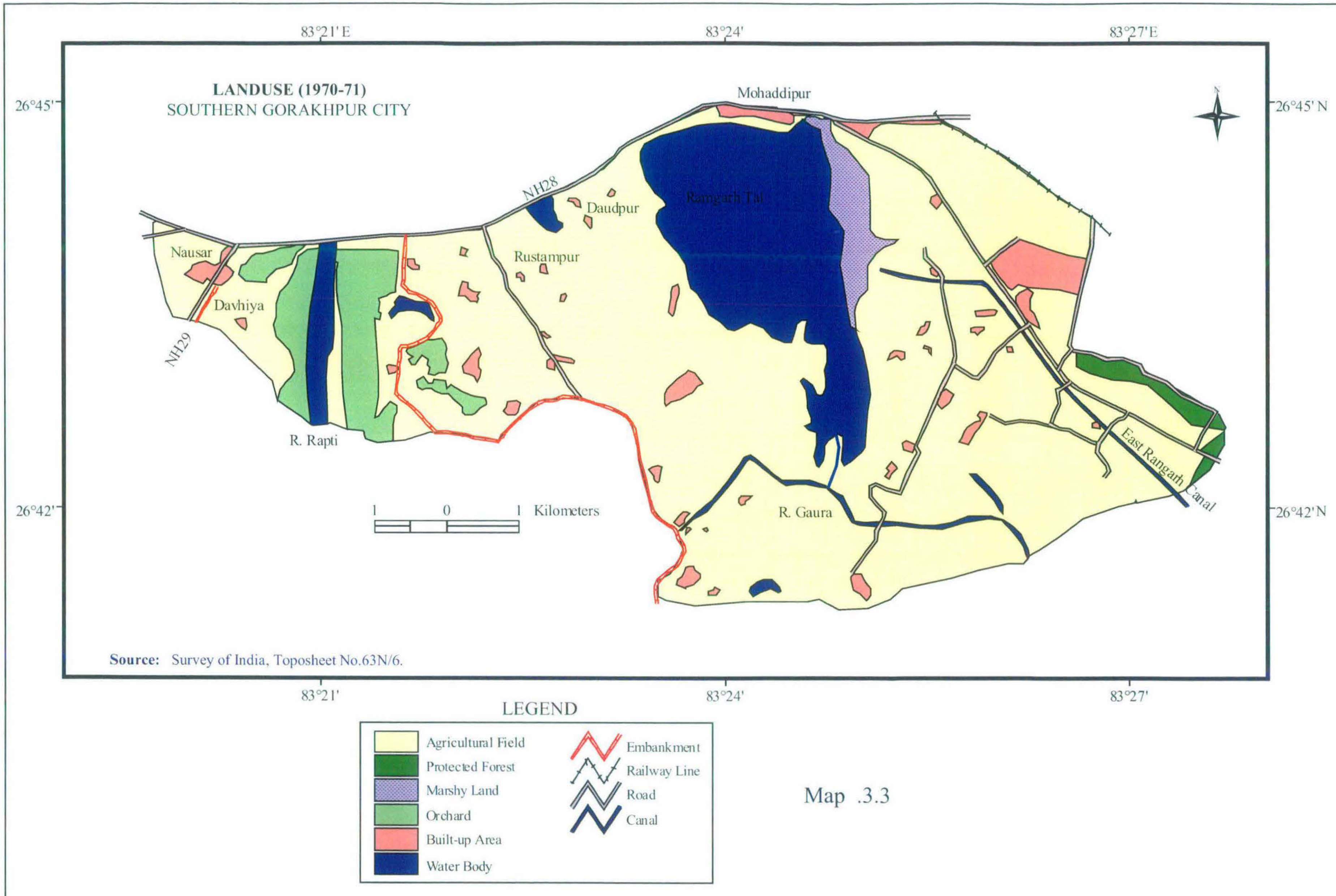
Table 3.3 and Fig. 3.1 show the land use change between 1970-71 and 2001. Total area is 52.5 Km^2. Built-up area has increased significantly due to urban development. Such changes are noticed around NH28, NH29, East Ramgarh canal and Ramgarh *Tal* (Map 3.3 and 3.4). Urban expansion has replaced the good agricultural land along the NH28, NH29 and Ramgarh *tal*. Over all, agricultural land is predominant land use practice in this area. Agricultural land has reduced from 38.1 Km^2 to 29.5 Km^2. Open space with scrub has occupied 2.5 Km^2 area along the NH 28 and Ramgarh *Tal*.

Table 3.3: Land Use Changes in the Southern Part of Gorakhpur City (1970-71 to 2001)

1	2	3	4	5
Agricultural Land	38.1	29.5	72.6	56.2
Built-up Area	2.0	9.2	3.8	17.6
Protected Forest	0.6	0.6	1.2	1.2
Marshy Land	1.0	1.2	1.9	2.4
Orchard	2.7	2.1	5.1	4.0
Open space with Scrub	0.0	2.5	0.0	4.8
Water Body	8.1	7.3	15.4	13.9
Total	**52.5**	**52.5**	**100.0**	**100.0**

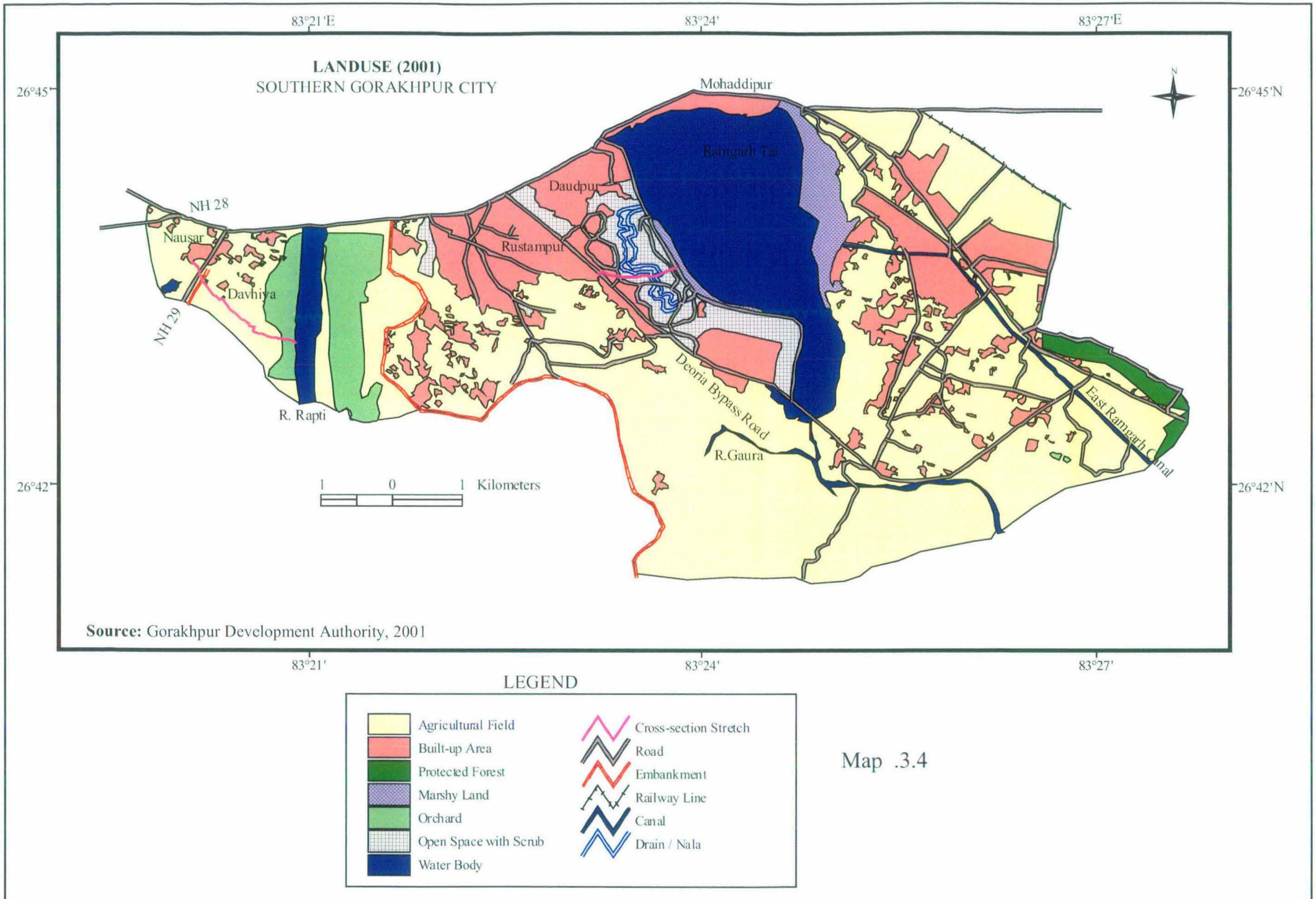
1. Land use Category 2. Area in Km^2 (1970-71) 3. Area in Km^2 (2001) 4.Percentage area to the total area (1970-71) 5.Percentage area to the total area (2001).
Source: SOI, Toposheet no. 63N/6 and Gorakhpur Development Authority, 2001.

Area occupied by water body has reduced from 8.1 sq. km to 7.3 Km^2; while marshy land has increased from 1.0 Km^2 to 1.2 Km^2. Area under forest is remained same and are located in the southeastern part of Gorakhpur city. Area under orchard has reduced from 2.7 Km^2 to 2.1 Km^2. Large road network have been constructed on both sides of Ramgarh *Tal*. Since the built-up area is increasing in this highly flood prone area, the flood damage to building, road and other public utilities is likely to increase when floods occur.



LANDUSE (1970-71)
SOUTHERN GORAKHPUR CITY
83°21' E
83°24'
83°27'E
26°45'
26°45' N
26°42'
26°42'N
Mohaddipur
NH28
Daudpur
Rangarh Tal
Nausar
Rustampur
Davhiya
NH29
R. Rapti
R. Gaura
East Rangarh Canal
1 0 1 Kilometers
Source: Survey of India, Toposheet No.63N/6.
83°21'
83°24'
83°27'
LEGEND
Agricultural Field
Protected Forest
Marshy Land
Orchard
Built-up Area
Water Body
Embankment
Railway Line
Road
Canal

Map .3.3



83°21'E
83°24'
83°27'E
LANDUSE (2001)
SOUTHERN GORAKHPUR CITY
26°45'
26°45'N
Mohaddipur
Ramgarh Tal
Daudpur
NH 28
Nausar
Rustampur
Davhiya
NH 29
R. Rapti
Deoria Bypass Road
R.Gaura
East Ramgarh Canal
26°42'
26°42'N
1 0 1 Kilometers
Source: Gorakhpur Development Authority, 2001
83°21'
83°24'
83°27'
LEGEND
Agricultural Field
Built-up Area
Protected Forest
Marshy Land
Orchard
Open Space with Scrub
Water Body
Cross-section Stretch
Road
Embankment
Railway Line
Canal
Drain / Nala

Map .3.4

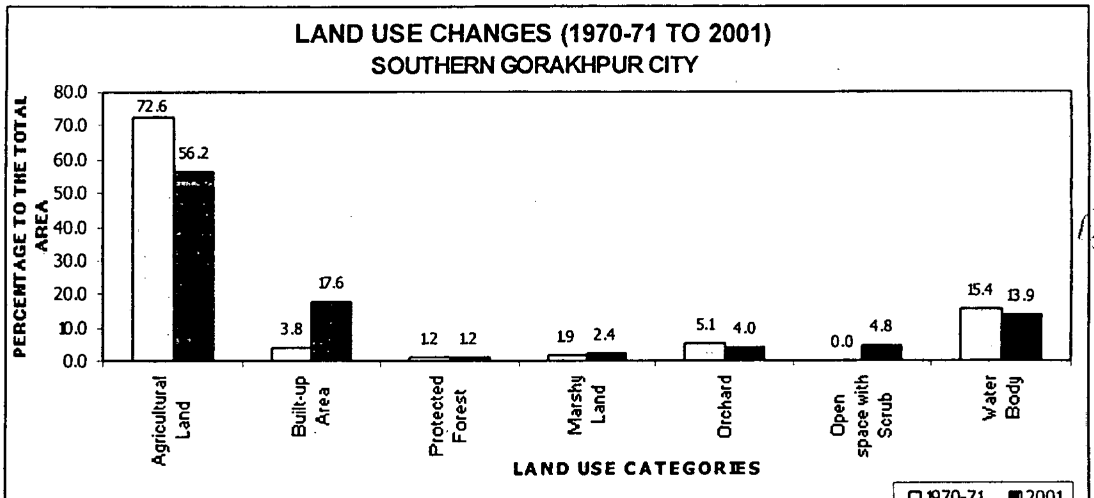


Figure-3.1

3.5 Urban Development in the Rapti River Basin (1971-1991)

Most of the urban areas have been developed near the rivers i.e., in the flood plains because of the amenities they offer including level, usually well drained land for building, access to the source of water for a variety of uses, proximity to transport routes and availability of sink into which waste can be dumped. A disaster happens once flood occurs, depending upon the amount of property damage, disruption and loss of life.

Urban area in the lower Rapti river basin is increasing at an alarming rate. Total urban area was 76.21 Km^2 in 1971, which increased to 160.41 Km^2 in 1981. Finally, in 1991 the urban area covered 287.95 Km^2 (Table 3.4).

3.5.1 District-wise Urban Area and Population in the Basin

The pace of urbanization has increased manifold in the lower Rapti river basin (Table 3.4). But the increase in urban area is not uniform in all the districts, which come under the basin. Urban area has increased by more than two times in the districts of Balrampur, Siddharthnagar and Gorakhpur between 1971 and 1991 (Fig.3.2). On the other hand, urban area has increased by one and half times in Santkabirnagar and Deoria districts.

Table 3.4: District-wise Urban Area, Number of Town and Population in the Lower Rapti River Basin

District	No. of Town			Total Urban Area(in sq.km)				Total Urban Population			
	1971	1981	1991	1971	1981	1991	% Change 1971-91	1971	1981	1991	% Change 1971-91
Shrawasti	1	1	1	1.71	1.71	1.71	0.0	9819	13307	16528	68.3
Balrampur	3	5	5	13.17	39.96	39.96	203.4	58427	96752	129620	121.8
Siddharthnagar	1	4	4	7.69	16.14	29.75	286.9	12125	40764	59508	390.8
Santkabirnagar	1	4	4	6.06	13.26	15.06	148.5	13539	55540	73442	442.4
Maharajganj	NA	4	5	NA	21.27	34.08		NA	44164	74254	
Gorakhpur	2	5	6	42.48	57.54	152.96	260.1	240158	327845	565543	135.5
Deoria	1	2	2	5.1	10.53	14.43	182.9	17943	39255	52137	190.6
Total	9	25	27	76.21	160.41	287.95	277.8	352011	617627	971032	175.9

Source: 1. General Population Tables, Uttar Pradesh, Census of India 1991, Series- 25, Part- IIA, pp. 121-127.
2. General Population Tables, Uttar Pradesh, Census of India 1981, Series- 22, Part- IIA, pp. 65-70.
3. General Population Tables, Uttar Pradesh, Census of India 1971, Series- 21, Part- IIA, pp. 52-57

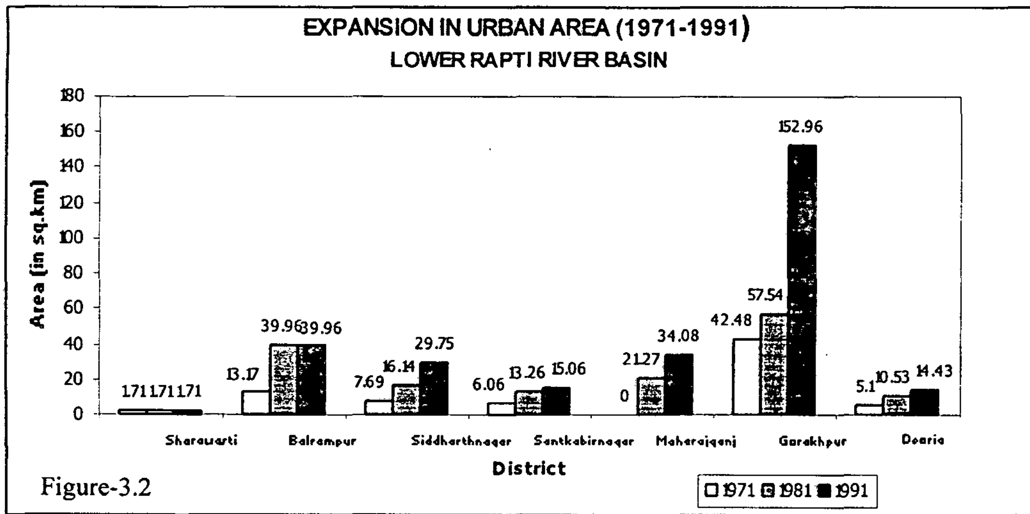


Figure-3.2

Santkabirnagar district has experienced rapid growth in urban population, which has increased by more than four times between 1971 and 1991 and same is true in the case of Siddharthnagar district where the urban population has increased by more than three times (Table 3.4). On the other hand, there are three districts i.e., Balrampur, Gorakhpur and Deoria where the urban population has increased by more than one times. But in the case of Shrawasti district the urban area has remained same but the urban population is increasing.

3.5.2 A Feed Back Model of Flooding and Urbanization

Once settlement on the flood plain is established, a cycle is initiated that affects the hydrology of flooding on the one hand and the exposure and vulnerability on the other. This is a feed back model, because one element i.e., urbanization affects flood hazard, which then affects the urban area differently (more severe or more frequent flooding).

3.5.3 The Effect of Urbanization on Flooding

There are four ways in which the process of urbanization increases flood potential. These are as follow:

1. Urbanization inhibits infiltration by creating impermeable surfaces such as roads, parking lots and rooftops. As a result, a higher proportion of precipitation enters streams and rivers as overland flow.
2. This increased run off reaches rivers and streams faster because of smoother surfaces with reduced friction and because of surface and sub surface drainage networks designed to move overland flow into channels as quickly as possible.

Together these two alterations lead to increased discharge in rivers. Thus, lag time is decreased and discharge is increased, with resulting impacts on magnitude of floods.

3. Development in flood plains along and across rivers can constrict or restrict the flow of water in the channel, and
4. Bridges across the rivers reduce the natural carrying capacity of the river and provide barriers upon which debris can accumulate. Bridges also generate array flow in the channel that causes bank erosion and slump down stream. A quick result has been observed in the form of river shift down stream from the bridge. The River Rapti is shifting towards Nausar village due to the array flow generated by Habird bridge at Gorakhpur.

Thus, these factors are illustrated in the case of Gorakhpur city. This city is located at the confluence of the Rapti and Rohini rivers. The city is situated on the high cut bank of the Rapti river. The changing course of the Rapti river has influenced the morphology of city in different time[2]. The past flood has played an important role in shaping the morphology of the city that is just like a bowl. Therefore, there is not a good natural drainage. There are three embankments to protect the city from floods. Herbert and Malauni embankments have been constructed along the Rapti river in the southwestern part of the city. While Madhopur embankment has been constructed along the Rohini river in the northwestern part of the city.

Three pumping stations have been installed by the municipal corporation in the northern part of the city in order to pump out the waters from two drains into the Ramgarh *Tal*. As a result, water logging prevails around northern part of the Ramgarh *Tal*.

During 1998 flood, Harbird bridge across the Rapti river had constricted the river flow as a result backwater from the Rapti river breached the Madhopur embankment along the Rohini river. Thus, water from the Rohini river came to Ramgarh *Tal* that was already flooded with roof top water from the city and water from the Rapti river due to wide cut in the left Herbert embankment. This situation aggravated the flood situation in the southern part of Gorakhpur city[3].

3.6 Implication of Land Use Changes on Flood Plain Morphology, Floods and Catchment

As stated earlier that land use and floods are closely related. Forests are cut down in *Tarai* region in order to make the way for agriculture and urban development. Change in land use triggers off a sequence of reactions starting with soil erosion leading to loss of fertile topsoil. Excessive soil losses make the land infertile. The eroded material may get deposited in the riverbeds, thus contributing to braiding of the river channel. Such restrictions to the flow may then possibly enhance the chances of flooding of adjacent land during high flow conditions of the river. Sand deposition in the agricultural fields makes the land barren and infertile. Such depositions are visible near Davhiya village.

3.7 Conclusion

The concept of land use is a complex and dynamic and changes over time and space. Various hydrological processes such as, infiltration, evapotranspiration, soil moisture status etc. are influenced by land use characteristics of the basin. The haphazard construction of road in the flood prone area creates waterlogging and aggravates flood situation. The built-up area is increasing at an alarming rate, as a result more and more rainfall enters into the river as overland flow. In this way, discharge increases down stream and makes the channel unstable. For instance, the Rapti river is shifting towards west down stream of Gorakhpur city due to excessive discharge and array flow generated by Habird bridge. Deforestation in the mountain and *Tarai* region of Nepal is the main cause of landslide and soil erosion resulting in siltation of riverbeds. The Rapti riverbed has become shallow due to siltation. Therefore, it causes backwater effect into its tributaries i.e., the Rohini, the Ami, the Gaura and the Taraina. Thus, floods and land use compliment each other. As the built-up area is increasing in the flood prone area, proper land use planning is necessary to minimize the flood damages. The basic counter measure against flood damages is through proper land use planning in flood prone area as well as in the basin. The conservation measures such as, infiltration and soil-plant-water relations can improve ground water recharge and reduce soil erosion and floods.

References

1. *Statistical Year Book of Nepal,* Central Bureau of Statistics, Kathmandu, Nepal, 2001-02.
2. Yadav, H.R., and Yadav, H.L., "Hierarchy of Commercial Centres in Gorakhpur City", *National Geographical Journal of India*, Vol.44, No.1-4, 1998, p.19.
3. *Flood Report of Gorakhpur district*, 2001, pp. 101-103.

Chapter Four

Causes and Occurrence of Floods in the Lower Rapti River Basin

4.1 Introduction

Lower Rapti River Basin receives more than 80 percent of its annual rainfall during the monsoon season Monsoon rainfall in the basin starts at a low key in June attains its peak in July and August, falls off in September ends by second week of October. The flood risk, therefore, goes on increasing with the advance of monsoon because of the dual effects of increased rainfall and favourable antecedent wet conditions. The reduced rainfall in September, however, does not affect this increasing trend in flood flow. This is not only because the antecedent condition is very favourable but also because of a particular feature of September rainfall. Though, the total rainfall during September is less than that during July or August, there is a significant increase in the intensity of rainfall per rainy days in September. In other words, September rainstorms are fewer in number but are more intense than their counterparts in earlier months. This section analyses the causes of floods, flood producing weather systems, rainfall characteristics, flood flow from upper reaches, monitoring of flood, floods of 1998 and flood damages in Gorakhpur district.

4.2 Causes of Floods

Floods in the Rapti river are mainly caused by intense rainfall further accentuated by geomorphological features and human activities.

4.2.1 Synoptic Meteorological Factors

There are two major synoptic meteorological factors that cause floods in the basin are 1. Low pressure area and depressions prevails over the basin, and 2. Monsoon trough passing through the basin and Break monsoon conditions.

1. Low pressure area/ upper air cyclonic circulation located over catchment with monsoon trough passing through the catchment cause heavy rainfall in the months of July and August as a result floods occur during these months.

2. During break monsoon situation, the axis of the seasonal monsoon trough, which normally passes through Sriganganagar, Delhi, Allahabad, Patna and then to Kolkata, shifts northwards from its normal position and lies close to the foothills i.e., Siwalik Himalayas. This particular situation results in causing heavy rainfall over the

northeastern and central Himalayas and their adjoining plain areas. In this particular situation, heavy rainfall occurs in foothill region as a result floods occur in the rivers of north-east and central Himalayas i.e., the Bramhaputra and its tributaries, the Teesta, the Kosi, the Gandak, the Ghaghara, the Kamala Balan, the Bagmati and the Rapti [1] while the rest of the country is relling under drought conditions with more or less no rain. Break situation generally, occurs in July and August months of summer monsoon.

A southward position of the monsoon trough to its normal position is usually an indication of well-distributed rainfall over central India and the Indo-Gangetic plains. The position of the trough is governed by the migratory and translatory systems such as tropical depression as well as upper easterly and westerly waves. The monsoon trough is not a mechanical effect of mountains. It is more closely related to the radiation balance of the earlier atmospheric system during the monsoon [2]. A detailed analysis of very heavy rainfall producing weather systems is given in a later section.

4.2.2 Geomorphological Factors

The geomorphologic factors that cause floods in the basin are 1.Breaks of slope at the junction of the two contrasting features i.e., mountain and plain, 2. High sinuosity and very low gradient in the lower reaches of the Rapti river, and 3. Backwater effect

1. The acute kink in the longitudinal profile of the Himalayan rivers at the junction of the two contrasting slopes of steep mountain and flat plain (especially *Tarai* region) is responsible for creating inundation[3]. Due to this acute kink rivers, (the Rapti river and its tributaries in upper reaches) can not carry both silt and water at the same rate. The silt gets deposited and chokes the channel and thus, water spreads in the *Tarai* region, causing floods.

2.The Rapti river is having the very high sinuosity index of 2.019 (from Belauha village to Barhaj). It certainly aggravates the flood problem, because water takes much longer period to flow downstream, as a result, water starts piling up and inundates large areas.

The Rapti river has a gradient of 15cm/Km from Dhanibazar (in the district of Siddharthnagar) to Gorakhpur city While the gradient from Gorakhpur city to Barhaj is of

6.5cm/Km[4]. Very low gradient from Gorakhpur to Barhaj results in heavy piling up of floodwater.

3. Backwater effect of the Rapti river causes flooding in its tributaries i.e., the Rohini, the Ami, the Gaura and the Taraina. The backwater effect of the Ghaghara river is the main cause of flooding in downstream.

4.2.3 Human Activity

Human activities that cause flooding in the basin are 1.Heavy deforestation in the upper reaches, 2. Obstruction of natural flow by roads, railway lines, bridges etc., 3. Improper land use especially in flood plains, 4. Increase in built up areas especially in flood plains, and 5. Breaches in embankments

1. The upper reaches of the Rapti catchment receive very high rainfall. It was previously covered with dense forest, and therefore, a considerable amount of rainfall was absorbed and thus run off was reduced and delayed to some extent. But after second quarter of 19th century people cut the forest ruthlessly to increase the agricultural area. It was even allowed by the Governments of India and Nepal both[5]. As a result, run off has suddenly increased and time lag has decreased giving rise to frequent and heavy floods in the lower reaches. Deforestation not only increased the run off but also the sediment load in the rivers, which gets deposited in the riverbed making them more and more shallow. During 2001-flood period, the Rapti riverbed was silted up by 12 metre at Birdghat G/D site. Thus, water carrying capacity of these rivers has decreased and frequent over flow is observed.

2. Man has compounded flood problem by constructing roads, bridges, railways and embankment across the natural flow, which constricts the easy flow of the rivers. During 1998 flood, Harbird bridge across the Rapti river constricted the river flow as a result back water from the Rapti river breached the Madhopur embankment along the Rohini river and aggravated the flood situation in southern part of Gorakhpur city.

3. Due to improper land use and agricultural practices on the slopes and even in the plains, the flood problem of lower Rapti river basin, have further been magnified. Wrong tillage system allows more soil to go with run off which finally retards the velocity and level of floodwater rises gradually making the situation worse.

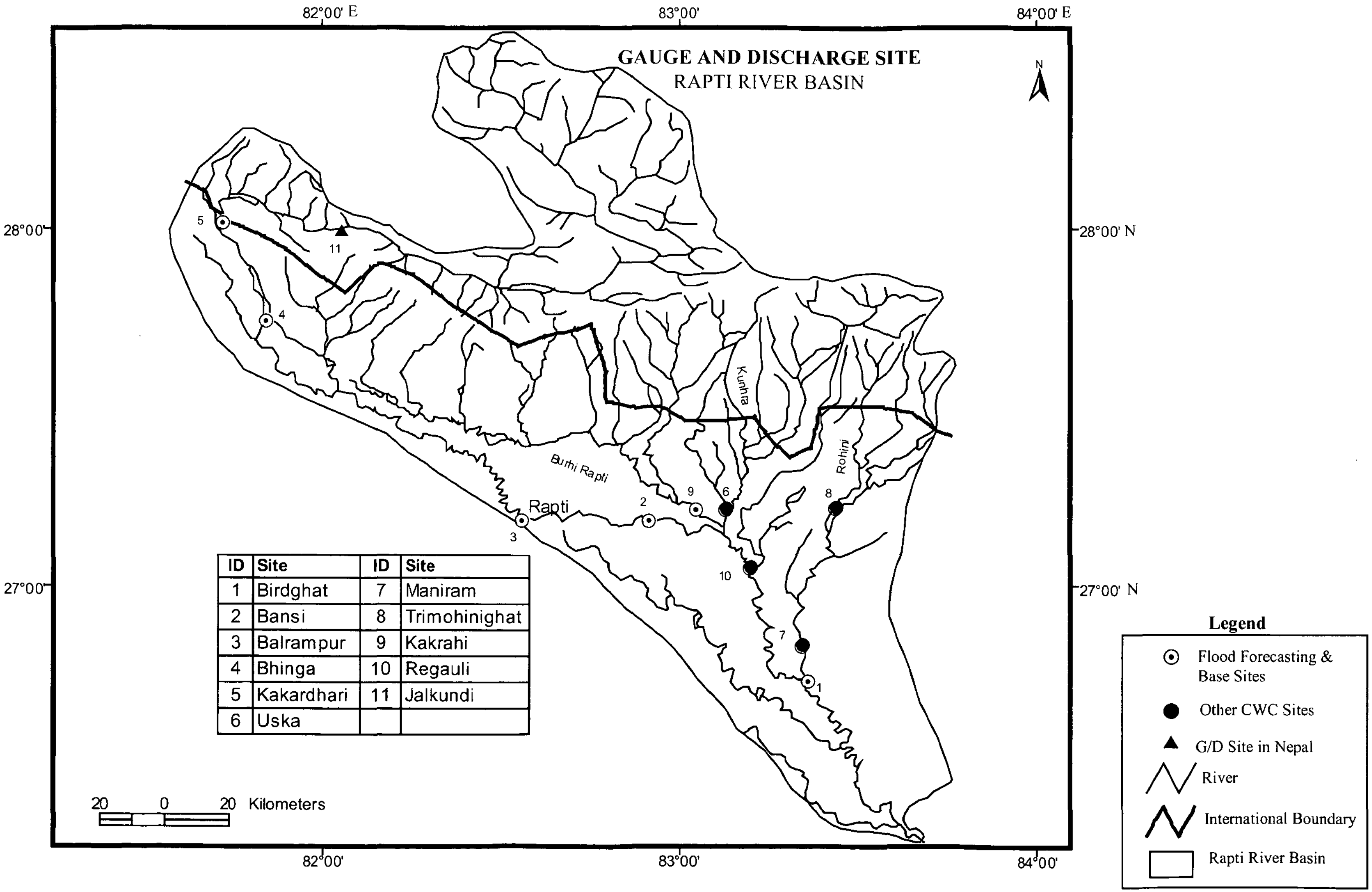
4. As stated earlier, urban area in the lower Rapti river basin is increasing at an alarming rate. Total urban area was 76.21 Km^2 in 1971, which increased to 160.41 Km^2 in 1981. Finally, in 1991 the urban area covered 287.95 Km^2. Thus, the increasing urbanization trend in the basin inhibits infiltration by creating impermeable surfaces such as roads, parking lots and rooftops. As a result, a higher proportion of precipitation enters streams and rivers as overland flow and magnifies the flood situation.

5. At present, government is mostly interested in mud embankment construction works to cope up with the flood problem but it has rather aggravated the flood problem because embankment allows silting in the riverbeds and it breaches frequently and obstructs the natural flow of the rivers at large. More over in the vicinity of urban areas the higher elevation of embankments encourages people to settle there, although there is no such provision for shops and households. The presence of *Gumati* (Small shop) and households attract more rodent population, which burrow and weaken the embankments and during floods breaches occur. Human induced cuttings either to make way for the cart or to let the water away from the inundated area are other causes for breaches in the embankments.

4.3 Monitoring of Floods in the Lower Rapti River Basin

Floods are recurrent phenomena in the lower Rapti river basin. Flood control structures are not effective in a flat densely populated terrain. Non-structural measures are also needed to cope up with the floods and to reduce the damages caused by the floods. One of the important and effective non-structural measures is flood forecasting. The National Flood Management Programme launched in 1959 and the effectiveness of structural programme to control floods, led to giving greater stress on flood forecasting, flood warning, flood fighting and flood management. Accordingly, Central Water Commission established 157 flood forecasting stations in India.

There are 10 Gauge and Discharge sites on the main river Rapti and its tributaries, out of which 6 sites are base sites for flood forecasting in the basin (Map 4.1).



ID	Site	ID	Site
1	Birdghat	7	Maniram
2	Bansi	8	Trimohinighat
3	Balrampur	9	Kakrahi
4	Bhinga	10	Regauli
5	Kakardhari	11	Jalkundi
6	Uska		

Map 4.1

4.3.1 Flood Forecast[6]

Flood forecasting may be defined as " the process of estimating the future stage or flows and its time sequence at selected points along the river during floods". Flood forecasts refers to prediction of " the crest and its time of occurrence" and logical extension to the stages of river above the warning level that is generally one metre below the danger level (D.L.).

The various steps, involved in the operation before issue of forecasts and warning, are 1. observation and collection of hydrological and meteorological data, 2.transmission and communication of data to the forecasting centers, 3. analysis of data and formulation of forecasts, and 4. dissemination of forecasts and warning to the administrative and engineering authority of the states.

1. Observation and collection of hydrological data are done by field formation functioning under Member (RM), Central Water Commission. Flood Meteorological Offices (FMO) of India Meteorological Department collect and transmit the meteorological data. River Management Wing of CWC is responsible for planning of river gauge/ discharge network, collection of gauge and discharge data and communication of the data to its flood forecasting centers. FMO is responsible for planning of rain gauge network and for collection and transmission of rainfall data including warning and general synoptic situation and weather forecast to the flood forecasting centers.

2. Transmission of data on real time basis from the hydrological and hydro-meteorological sites to the flood forecasting sub-division/ division is a very vital factor in flood forecasting. The common modes of data transmission to the flood forecasting centers are telephone/ telegram, wireless and Fax (Fig. 4.1).

3. The flood forecasting centers are using different forecasting models, based on availability of hydrological and hydro meteorological data and basin characteristics, computational facilities available at the forecasting centers, warning time required and purpose of forecast. Some of the common methods being used by various centers are:

a. Simple correlation based on stage discharge data.
b. Co-axial correlation based on stage, discharge and rainfall data.
c. Routing by Muskingum method.

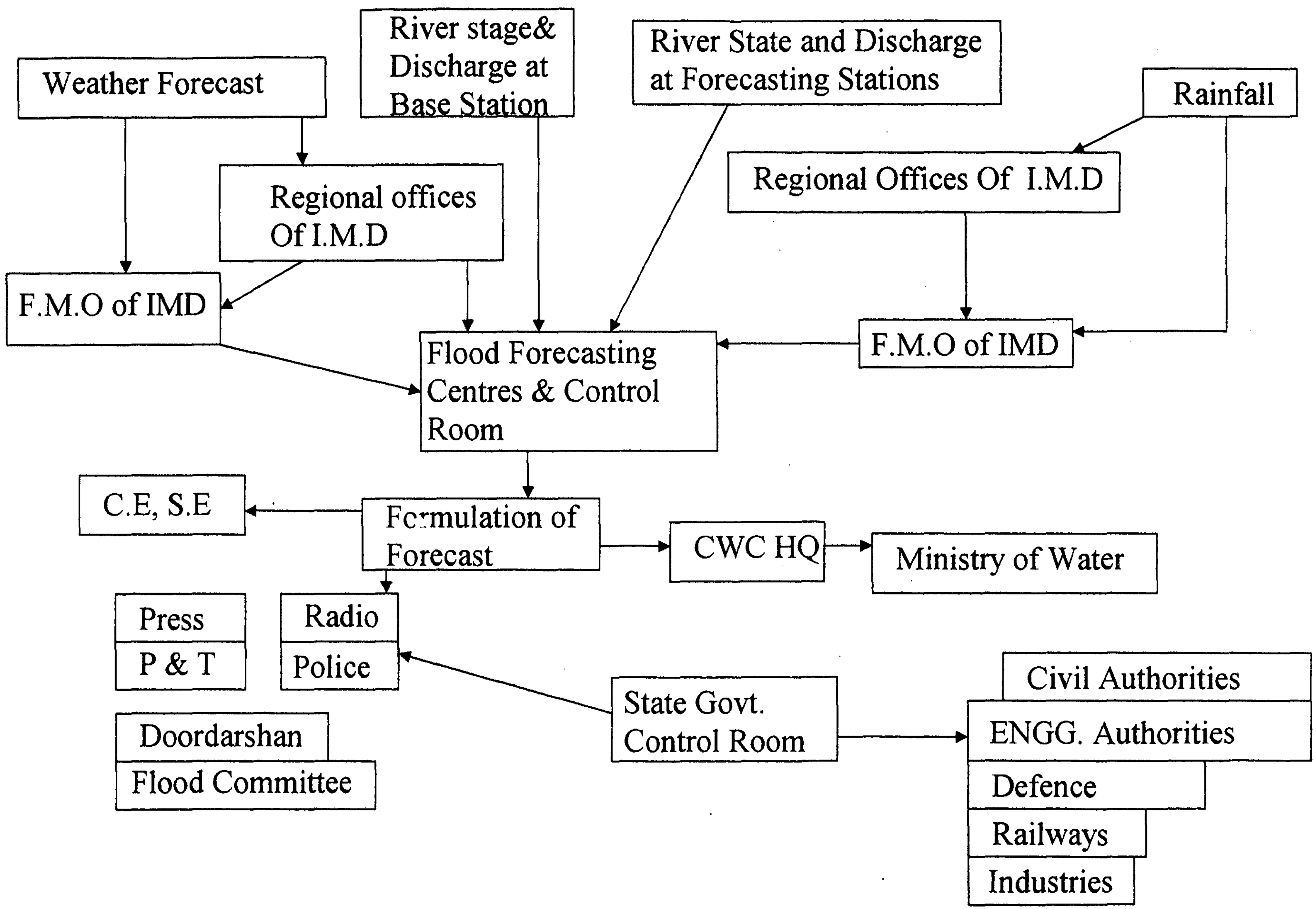


Figure: 4.1 Flood Forecasting System in India

d. Successive routing through sub reaches and

e. Hydrological models such as Stream flow Synthesis and Reservoir Regulation Model (SSARR), Hydrologic Engineering Centre (HECIF), NAMS11F, Non Linear Cascade (NLC) and Central Water Commission Flood Forecast (CWCFF1) are being used at some places.

Flood forecast methods are being constantly reviewed and further improvements are being made with the assistance from UNDP, USAID, Denmark, and etc. Flood forecasting methods are being reviewed by the Ministry of Water Resources.

4. The final forecast are being communicated to the Administrative and engineering authorities concerned of the state and other agencies connected with the flood protection and management work on telephone or by special messenger/ telegram/ wireless depending upon local factors like vulnerability of the area and availability of communication facilities etc.

In flood forecasting operations, the correct observation of the river stages is over emphasized at G/D sites. There are various types of gauges in use and the most commonly used are:

1. Manually operated Gauges: a. Staff Gauge, b. Slopping or Stepped Gauge (installed at Birdghat),

c. Cantilever Gauge and d. Gauge wells provided in major hydraulic structures.

2. Continuous River Stage Records: a. Float Type and b. Pneumatic Type.

Sloping or stepped gauge has been installed at Birghat G/D site, where the banks are quite stable. This is generally made of concrete blocks fixed along the slope of the banks and provided with steps for reading the gauges, painting them, etc. the marking of the slope gauge is to be made with precise leveling. These gauges are to be checked every year before the floods for possible disturbances. The water levels can be read with greater degree of accuracy because of enlarged scale.

4.4 Occurrence Of Floods

The maximum water level data available for the years 1986 through 1999 (except 1995) at the G/D sites Balrampur, Bansi and Birdghat and for 1986-1989 at the site

Jalkundi in Nepal are used to study the occurrence of floods in the lower Rapti river basin.

4.4.1 Flood Flow from the Upper Rapti

Floods in the lower Rapti river basin are associated with the high rainfall in upstream as well as downstream. During the four years (1986-1989) occurrences of simultaneous flood at all the four sites were noticed in 3 years. Only in 1986 the maximum water level at the four sites was noticed on different dates. Generally, the flood crest takes one day to reach from Jalkundi to Balrampur in high floods. The flood crest may take less than a day to travel between the two points as in the year 1989. During low flood, the travel time is 3 days as in the year 1987. The travel time of flood crest between Balrampur to Birdghat varies from 2 to 5 days. In the year 1989, although the flood level was high at Jalkundi and Balrampur, the highest water level at Birdghat noticed after 5 days. Probably, no additional flow reached Rapti in this section during this period (Table 4.1 and 4.2).

Table 4.1: Maximum Water Level in the Rapti River

Jalkundi		Balrampur		Bansi		Birdghat(Gorakhpur)	
Gauge height(in meter)	Date	MWLA (in meter)	Date	MWLA (in meter)	Date	MWLA (in meter)	Date
6.6	19.6.86	103.26	20.6.86	83.46	15.9.86	74.6	17.9.86
6.36	11.8.87	104.21	14.8.87	84.37	15.8.87	74.76	16.8.87
6.78	17.8.88	104.55	18.8.88	85.07	18.8.88	75.86	21.8.88
9.2	15.7.89	105.07	15.7.89	85.47	18.7.89	76.45	20.7.89

Table 4.2: Lag Time (in days)

Year	Jalkundi to Balrampur	Jalkundi to Bansi	Jalkundi to Birdghat	Balrampur to Bansi	Balrampur to Birdghat	Bansi to Birdghat
1986	1					2
1987	3	4	5	1	2	1
1988	1	1	3	0	3	3
1989	0	3	5	3	5	2

Source: 1. HMG of Nepal, Hydrological Records of Nepal, Stream Flow Summary, Kathmandu, April 1998 and 2.Flood Forecasting and Warning Network Performance Appraisal, 1986 to 1991, Central Water Commission, New Delhi.

4.4.2 Occurrence Of Floods in the Lower Rapti River Basin

Flood crest occurs 7 times at all stations during the years 1987, 1988, 1989, 1990, 1992, 1997 and 1998. Flood crest occurs 5 times at Balrampur but not at Bansi and Gorakhpur/ Birdghat during the years 1986, 1991, 1993, 1996 and 1999. Flood crest occurs only one time at Balrampur and Bansi but not at Birghat during 1994 flood season. Flood crest occurs 11 times at Bansi and Gorakhpur (Table 4.3 and 4.4). Flood crest occurs 2 times at Bansi but not at Birdghat during 1994 and 1996. floods season. Thus, flood crest occurs at bansi is also seen at Birdghat.

Table 4.3: Occurrence of Flood Crest in the Lower Rapti River Basin (1986-1999)

Condition	**Frequency**
1. Flood crest occurs at all the sites	7
2. Flood crest occurs at Balrampur but not at Bansi and Gorakhpur	5
3. Flood crest occurs at Balrampur and bansi but not at Gorakhpur	1
4. Flood crest occurs at different dates on all sites	Nil
Total	13
Condition	**Frequency**
5. Flood crest occurs at Bansi and Gorakhpur	11
6. Flood crest occurs at Bansi but not at Gorakhpur	2
Total	13

Source: 1.Flood Forecasting and Warning Network Performance Appraisal, 1986 to 2000, Central Water Commission, New Delhi.
2. Water and Related Statistics, Information System Organization, Water Planning and Project Wing, 1998 to 2001,CWC, New Delhi.

Table 4.4: Maximum Water Level in the Rapti River

Balrampur			Bansi			Gorakhpur (Birdghat)		
Date	MWLA	DL	Date	MWLA	DL	Date	MWLA	DL
20.6.86	103.26	104.62	15.9.86	83.46	84.9	17.9.86	74.6	74.98
14.8.87	104.21	104.62	15.8.87	84.37	84.9	16.8.87	74.76	74.98
18.8.88	104.55	104.62	18.8.88	85.07	84.9	21.8.88	75.86	74.98
15.7.89	105.07	104.62	18.7.89	85.47	84.9	20.7.89	76.45	74.98
12.7.90	104.23	104.62	16.7.90	84.42	84.9	17.7.90	74.81	74.98
29.8.91	103.83	104.62	17.9.91	83.6	84.9	19.9.91	74.06	74.98
28.8.92	103.58	104.62	29.8.92	83.4	84.9	29.8.92	72.92	74.98
31.8.93	104.6	104.62	9.9.93	85.55	84.9	15.9.93	76.59	74.98
16.8.94	103.86	104.62	17.8.94	84.07	84.9	22.9.94	75.07	74.98
16.7.96	104.5	104.62	22.7.96	85.05	84.9	24.8.96	75.92	74.98
14.8.97	104.61	104.62	19.8.97	84.7	84.9	20.8.97	74.88	74.98
19.8.98	104.93	104.62	21.8.98	85.82	84.9	23.8.98	77.54	74.98
4.9.99	104.42	104.62	31.8.99	84.66	84.9	1.9.99	75.95	74.98

Source: 1.Flood Forecasting and Warning Network Performance Appraisal, 1986 to 2000, Central Water Commission, New Delhi.
2. Water and Related Statistics, Information System Organization, Water Planning and Project Wing, 1998 to 2001,CWC, New Delhi.

MAXIMUM WATER LEVEL IN THE RAPTI RIVER
(1986-1999)

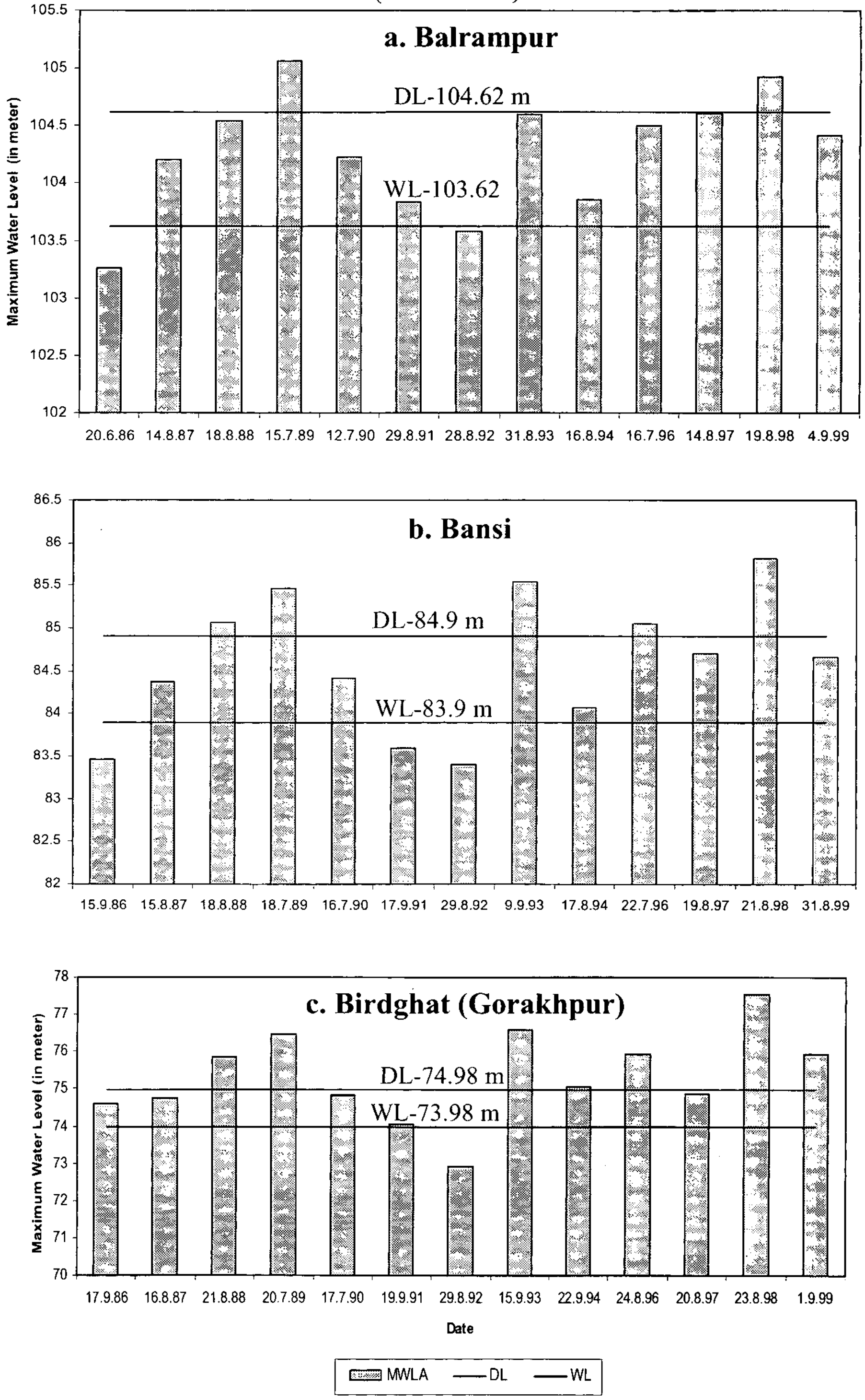


Figure:4.2

The water level reaches the warning level almost every year at all the sites (Fig. 4.2). The year 1992 witnessed very low water level at all sites. Maximum water level at Balrampur, Bansi and Birdghat crosses danger level 2, 5 and 7 times respectively, in the years (1986 to 1999). Thus, the occurrence of flood is increasing from upstream to downstream due to the drainage congestion and water from Nepal carried by the Rohini, Burhi Rapti, Kunhara rivers etc.

4.4.3 Recurrence Interval Analysis

Return period is the recurrence interval of specified events such as the flooding of a particular magnitude.Return period is the expected frequency of occurrence in years of a discharge of a particular magnitude. The data needed to determine the return period are the series of annual floods, i.e., the maximum flood peak of each year, whereby the second and the lower- order events of each year are ignored, even if they are greater than the peaks of other years. Such a series is a true distribution series to which a distribution function may be fitted, and is therefore acceptable for rigorous analysis. In some empirical methods, the use of all floods above a selected datum makes it possible to incorporate floods which are only second or third highest in a given year but which may be significantly higher than the peaks of other years. These floods make up a partial duration series which is not a true distribution series because flood is not defined in terms of its occurrence in time, but according to its magnitude. When this series is used, it should be established that two consecutive events in any one-year are independent. Therefore, only one peak per complex storm is listed[7].

In this study the annual series i.e., maximum discharges recorded at Bhinga and Birdghat (Gorakhpur) G/D sites located on the Rapti river are used to compute the return period. Maximum discharges are arranged in decreasing order and ranked from the highest to downwards. The Weibull formula is used to calculated return period[8]:

$$F = (n + 1 / m)$$

Where, n is the total number of items in the series and m is the rank in the array numbering from the highest (1) downwards.

The return period (F), the period of time in which a given event is likely to be equaled or exceeded once. The resultant frequency curve shows the average time interval within which a flood of a given size will occur as an annual maximum.

The formula used to compute the percentage exceedence probability is:

$$P = (m/n+1) \times 100.$$

The steps for flood frequency analysis through log Pearson type III method are as follows[9]:

1. At the very fist stage, discharge values are put into the descending order. The lognormal value for each discharge value is calculated.
2. The average lognormal is computed.
3. The variance is computed using the formula:

$$\frac{\sum_{i}^{n} (\log Q - avg(\log Q))^{\wedge} 2}{n-1}$$

4. Standard deviation is computed using the formula:

$$\sigma \log Q = \sqrt{\mathrm{var}\,iance}$$

5. Skewness coefficient (cs) is computed in order to know the inequality in the discharges. The formula is as follows:

$$\frac{n \times \sum_{i}^{n} (\log Q - avg(\log Q))^{\wedge} 3}{(n-1)(n-2)(\ \sigma \log Q)^{\wedge}3}$$

6. The K value is the function of return period and Skewness coefficient. This constant determines the shape of the flood frequency curve. The K value is found using the frequency factor table.

7. Discharge associated with each return period is computed through the formula:

$$\log QTr = avg(\log Q) + [K\ (Tr, Cs)] \times \sigma \log Q$$

Table 4.5 shows the maximum discharge, return period, and percentage exceedence probability at Bhinga and Birdghat G/D sites based on data for the period 1978-2002. As the magnitude increases, the probability of occurrence decreases. Figure 4.3 and 4.4 show the maximum discharge against the return period at Bhinga and Birdghat G/D sites. The down stream station i.e., Birdghat (Gorakhpur) always shows a higher peak discharge than at upstream station (Bhinga) for the same return period.

Table 4.5: Maximum Discharge, Return Period and Percentage Exceedence Probability at Bhinga and Birdghat G/D Sites (1978-2002)

1	2	3	4
26.0	3.8	3217.88	6512.5
13.0	7.7	2973.78	6172.15
8.7	11.5	2755.8	5811.1
6.5	15.4	2621.4	5377.88
5.2	19.2	2532.56	5346.5
4.3	23.1	2502.51	4217.43
3.7	26.9	2358.03	4154.7
3.3	30.8	2201.5	3781.56
2.9	34.6	2044.3	3747.73
2.6	38.5	2010.38	3648.3
2.4	42.3	1982.58	3607.45
2.2	46.2	1908.56	3163.46
2.0	50.0	1819.5	2903.87
1.9	53.8	1490.52	2798.05
1.7	57.7	1322	2775.56
1.6	61.5	1317.78	2668.98
1.5	65.4	1193.32	2667.98
1.4	69.2	1119.51	2537.45
1.4	73.1	1064.66	2491.45
1.3	76.9	1013.48	2416.45
1.2	80.8	999.8	2326.75
1.2	84.6	958.96	2163.82
1.1	88.5	713.77	1311.67
1.1	92.3	692.81	1239.33
1.0	96.2	640.38	789.61

1. Return Period (in Years), 2. Percentage Probability, 3. Max. Discharge (m^3/sec) at Bhinga, and 4. . Max. Discharge (m^3/sec) at Birdghat

Source: CWC, Lucknow, Uttar Pradesh.

Table 4.6 shows the statistics of the log Pearson type-III method. The discharges associated with the return period 2, 5, 10, 25, 50, 100 and 200 years for Binga and Birdghat G/D sites are depicted in Table 4.7. This is fairly normal situation and reflects the tributary influence which is responsible for enhancing the flood peak at Birdghat (Gorakhpur) G/D site. The major tributaries such as, the Burhi Rapti and the Rohini join the Rapti river between Bhinga and Gorakhpur reach. They carry enormous amount of discharge during the monsoon season. Therefore, the susceptibility of flood at Birdghat is more than upstream site i.e., Bhinga.

Table 4.6: Statistics of Log Pearson Type-III Method.

Statistics	Bhinga	Birdghat
Av.Log(Q)/ Discharge	3.195	3.482
Varience	0.044	0.0487
Standard deviation	0.210	0.2207
Skewness (cs)	-0.3	-0.8

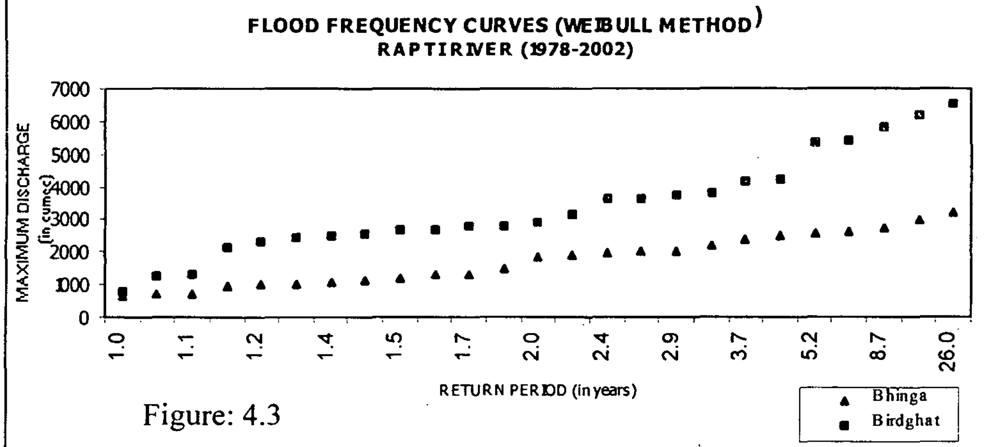


Figure: 4.3

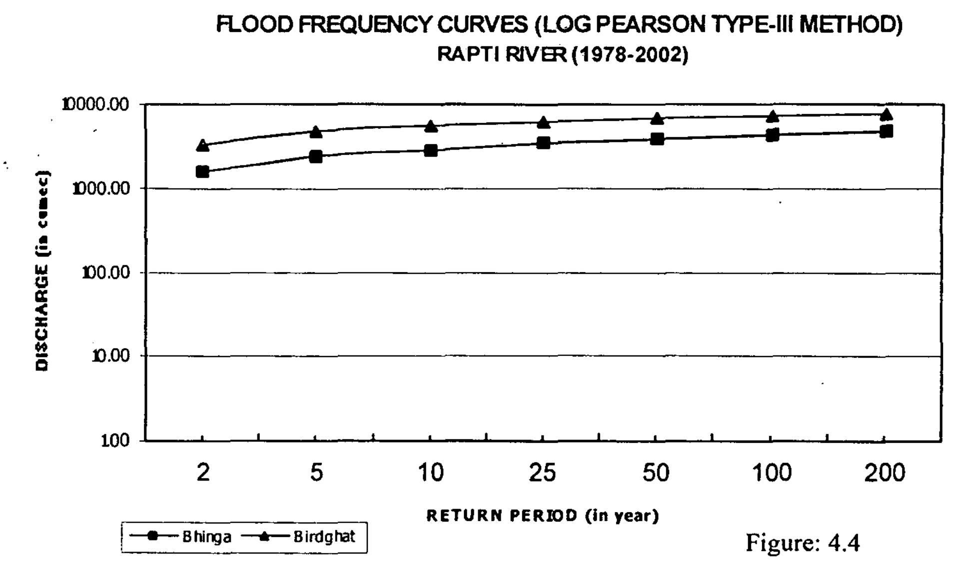


Figure: 4.4

Table 4.7: Discharge Associated with the Return Period (Computed through Log Pearson Type-III Method).

Return Period(tr)	Bhinga Log(Q)	Bhinga Q	Birdghat Log(Q)	Birdghat Q
2	3.206	1606.94	3.511	3243.39
5	3.374	2365.91	3.670	4677.35
10	3.456	2857.59	3.739	5482.77
25	3.540	3467.36	3.801	6324.12
50	3.592	3908.40	3.835	6839.12
100	3.637	4335.100	3.872	7447.32
200	3.677	4753.350	3.886	7691.30

Q= Discharge (in m^3 / sec.)

Maximum discharge computed through the log Pearson type-III method would be of value while planning any engineering structure on the Rapti river and for managing flood plain.

4.5 Floods in 1998: A Case Study

During 1998-monsoon season i.e., July to September, the river Rapti experienced moderate to high flood events followed by unprecedented flood events recorded at Bansi and Birdghat G/D sites in second half of August. This section analyses the rainfall characteristics of 1998 monsoon season, the synoptic weather systems that caused rain spells, the relation between daily water level and rainfall at Bansi and Gorakhpur and average areal rainfall over lower Rapti river basin, separately.

4.5.1 Rainfall Characteristics during 1998 Monsoon Season

1998 was the year of especially high and intense rainfall, which caused the highest flood so far recorded in the lower Rapti river basin at Bansi and Birdghat G/D sites. This section analyses the rainfall data recorded at 1. Bahraich, 2. Bansi, and 3. Gorakhpur. Table 4.8 shows the monsoon rainfall, annual rainfall, and percentage departure from normal, one-day maximum rainfall, rainy days and normal rainy days.

During 1998, the annual rainfall at Bahraich was 1329.2 mm and was 13 % more than the normal rainfall (1176.5 mm). The annual rainy days were 59 against normal 49.8 days. On the other hand, the departure of monsoon rainfall from normal was only 8%

while there were 42 rainy days against the normal 39.1 days. The departure of rainfall from the normal was –51% and –41% in the months of June and September, respectively. There were 4 rainy days in June and 5 in September against normal 6 and 8 days, respectively. On the other hand, the departure of rainfall from the normal was 13% and 18% in the months of July and August, respectively. There were 15 rainy days in July and 18 in August as against normal 12.2 and 12.9 days, respectively.

During 1998, the annual rainfall at Bansi was 2434.6 mm and was 82 % more than the normal rainfall (1340.2 mm). The annual rainy days were 64 against normal 54.7 days. On the other hand, the departure of monsoon rainfall from normal was 85% while there were 49 rainy days against the normal 44 days. The departure of rainfall from the normal was –25% and 10% in the months of June and September, respectively. There were 8 rainy days in June and 7 in September against normal 7.6 and 7 days, respectively. On the other hand, the departure of rainfall from the normal was 153% and 108% in the months of July and August, respectively. There were 16 rainy days in July and 18 in August as against normal 14 and 13.8 days, respectively.

During 1998, the annual rainfall at Gorakhpur was 1527.5 mm and was 21 % more than the normal rainfall (1259.3 mm). The annual rainy days were 60 against normal 57.4 days. On the other hand, the departure of monsoon rainfall from normal was 29 % while there were 47 rainy days against the normal 46.7 days. The departure of rainfall from the normal was -92% and –86 % in the months of June and September, respectively. There were 3 rainy days in June and 4 in September against normal 7.6 and 10 days, respectively. On the other hand, the departure of rainfall from the normal was 79% and 110% in the months of July and August, respectively. There were 19 rainy days in July and 21 in August as against normal 14 and 15.1 days, respectively.

Table 4.8: Monsoon Season and Annual Rainfall (in mm) and Percentage Departure from Normal during 1998 Monsoon Season in the Lower Rapti River Basin

Bahraich						
Month	Jun.	July.	Aug.	Sept.	Monsoon Total	Annual
Rainfall (mm)	76.4	361.3	527.4	132.9	1098	1329.2
Normal Rainfall (mm)	155.5	318.5	313.2	226.8	1014	1176.5
% Departure	-51	13	68	-41	8	13
One day max. Rainfall	29.5 (15th)	56.2 (16th)	93.6 (3rd)	62.2 (1st)		
Rainy days	4	15	18	5	42	59
Normal Rainy days	6	12.2	12.9	8	39.1	49.8
Bansi						
Rainfall (mm)	139	1074.2	699.8	245.6	2158.6	2434.6
Normal Rainfall (mm)	185.9	423.9	336	223.5	1169.3	1340.2
% Departure	-25	153	108	10	85	82
One day max. Rainfall	33.2 (23rd)	218 (7th)	180.4 (19th)	117.4 (20th)		
Rainy days	8	16	18	7	49	64
Normal Rainy days	7.6	14	13.8	8.6	44	54.7
Gorakhpur						
Rainfall (mm)	13.3	641.7	725.7	33.5	1414.2	1527.5
Normal Rainfall (mm)	160.8	358.7	345.9	231.4	1096.8	1259.3
% Departure	-92	79	110	-86	29	21
One day max. Rainfall	4.2 (27th)	224.7 (9th)	99.4 (18th)	46.8 (29th)		
Rainy days	3	19	21	4	47	60
Normal Rainy days	7.6	14	15.1	10	46.7	57.4

Source: IMD, Pune-5.

Table 4.9: Classification of Rain Spell by Quantum of Rainfall during 1998 Monsoon Season

Rain spell	LR	MR	RH	H	VH	Total
Bahraich						
June		2				2
July	2	2	1	1		6
August		2		1		3
September		2		1		3
Total	2	8	1	3		14
Bansi						
June	2	2				4
July			1	1	1	3
August		3	1		1	5
September	2	1		2		5
Total	4	6	2	3	2	17
Gorakhpur						
June	3					3
July		1	1	1	1	4
August		2	1	4		7
September	3		1			4
Total	6	3	3	5	1	18

LR= Light rain (2.5 -7.5 mm), MR= Moderate rain (7.6 -34.9 mm), R= Rather high rain (35 - 64.9 mm), H= High rain (65 – 124.9 mm), and VH= Very high rain (> 125 mm.)

Source: IMD, Pune-5.

Table 4.9 shows the classification of rain spells by the quantum of rain during 1998 monsoon season. It is observed that the 1998 monsoon season started with a low amount of rainfall in light rain spells in the month of June and reached to its peak in the months of July and August.

Thus, rainfall was mainly concentrated in moderate, rather high, high and very high rain spells in the months of July and August. The excessive rainfall in the month of August was the primary reason of the unprecedented floods recorded on 21 and 23 August 1998 at Bansi and Birdghat G/D sites, respectively.

4.5.2 Depth Duration Curve

The cumulative average areal rainfall in each rainstorm has been plotted against the day. The maxima of cumulative average areal rainfall have been taken to draw the enveloping curve from 15th June to 29th September 1998 (Table 4.10). The enveloping curve is receding after 5 day that means the rainstorm of 5 days duration produced most of the rainfall in the basin (Fig. 4.5).

Table 4.10: Cumulative Rainfall in Rainstorms and Enveloping Curve in the Lower Rapti River Basin (15th June to 29th September, 1998)

Rain Stroms	Day1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
RNSTM 1	4.2	8.8	20					
RNSTM 2	9.4	23.1	31.9	47.4	67.1	76.4	79	81.8
RNSTM 3	4	19.1	107.4	184.6	252.4			
RNSTM 4	14.1	41.4	57.6	73.9	151	203.7		
RNSTM 5	26.9	62.4	86.9	92.9				
RNSTM 6	5.3	47	54.3	77.9	81.3			
RNSTM 7	42.4	82	85.9	104.4	118.3			
RNSTM 8	14.6	30.9	89.4	112.1	124.1	166.3		
RNSTM 9	5.2	93.9	175.4					
RNSTM 10	3.4	22.2	37.7	55				
RNSTM 11	3	27.6	33.8	67.9	74.2			
RNSTM 12	2.6	7.6	26.5					
RNSTM 13	3.7	8						
RNSTM 14	59.4	77.6						
RNSTM 15	3	6						
Enveloping curve	59.4	93.9	175.4	184.6	252.4			

Source: IMD, Pune-5.

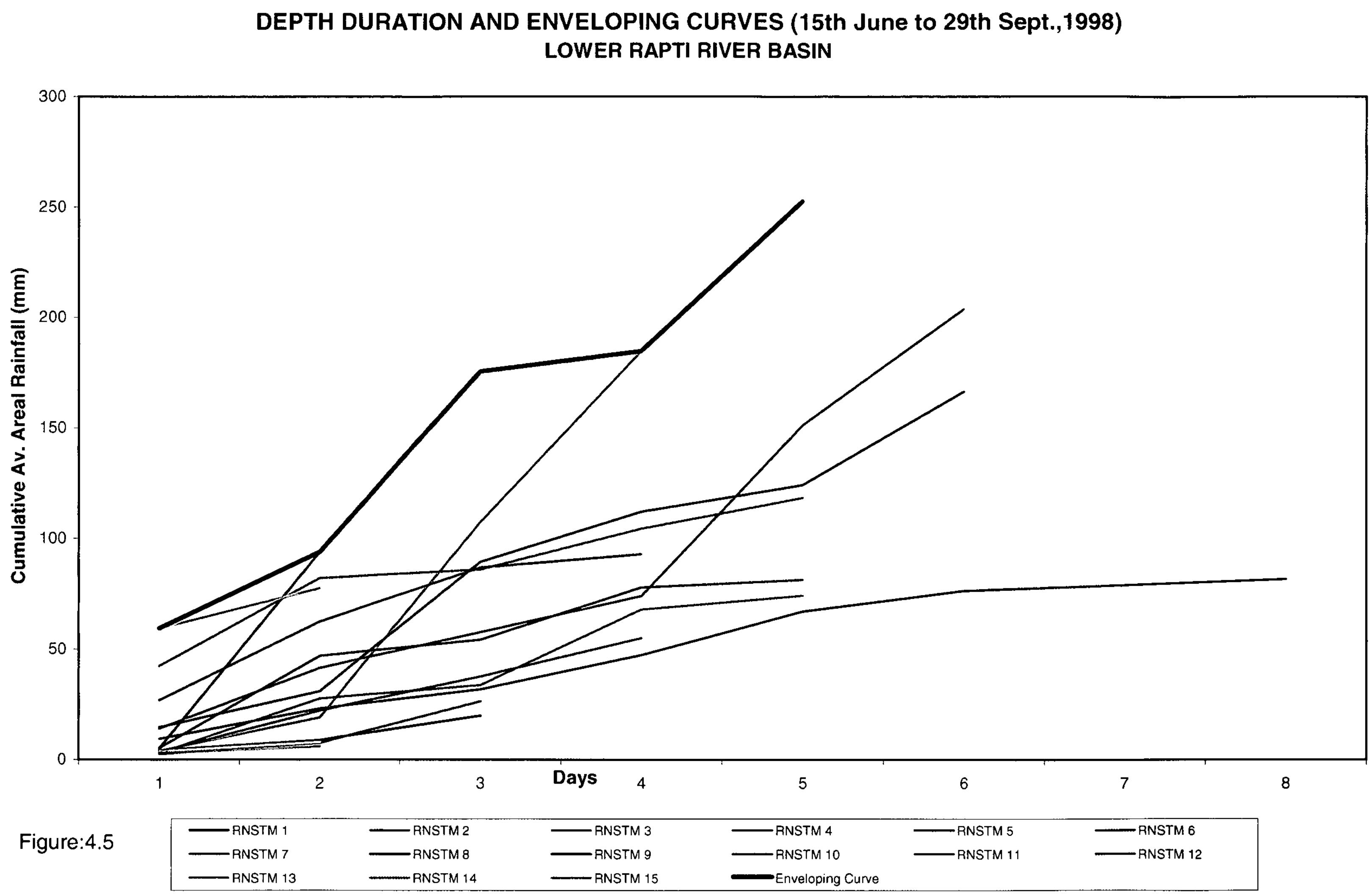

DEPTH DURATION AND ENVELOPING CURVES (15th June to 29th Sept.,1998)
LOWER RAPTI RIVER BASIN
Cumulative Av. Areal Rainfall (mm)
300
250
200
150
100
50
0
1
2
3
Days
4
5
6
7
8
RNSTM 1
RNSTM 2
RNSTM 3
RNSTM 4
RNSTM 5
RNSTM 6
RNSTM 7
RNSTM 8
RNSTM 9
RNSTM 10
RNSTM 11
RNSTM 12
RNSTM 13
RNSTM 14
RNSTM 15
Enveloping Curve

Figure:4.5

4.5.3 Synoptic Weather Systems

As discussed earlier, the main cause of floods in the lower Rapti river basin is very intense rainfall caused by the passage of favourable weather systems in the vicinity of the basin. Using synoptic meteorological approach empirical relationship can be established between the amount of rainfall and the associated weather systems. This can be used for quantitative precipitation forecasting (QPF). An attempt is made in this section to do such an analysis for the 1998 monsoon season. Identification of weather systems has been done on the basis of Indian Daily Weather Reports. Daily rainfall data for four stations Bahraich, Balrampur, Bansi and Gorakhpur for the 1998 monsoon season are also included in this analysis. Since the lower Rapti river basin is flat, the average areal rainfall for the whole basin has been calculated by the arithmetic mean method.

The major synoptic systems, which prevailed over or near to the basin during 1998 monsoon season, are as follows[10]:

S1: A low pressure area/ upper air cyclonic circulation located outside the catchment over north bay and adjoining Bangladesh.

S2: A low pressure area/ upper air cyclonic circulation located outside the catchment over Bihar plains and adjoining northeast Madhya Pradesh.

S3: A low pressure area/ upper air cyclonic circulation located outside the catchment over southwest Uttar Pradesh and adjoining north Madhya Pradesh.

S4: A low pressure area/ upper air cyclonic circulation located near and moving towards the catchment.

S5: A low pressure area/ upper air cyclonic circulation located over the catchment.

S6: An elongated axis of monsoon trough with embedded upper air cyclonic circulation south of the catchment.

S7: An elongated axis of monsoon trough with embedded upper air cyclonic circulation passing through the catchment.

S8: An elongated axis of monsoon trough with embedded upper air cyclonic circulation, close to the foothills of Himalayas.

S9: Rainfall occurs due to thunderstorm.

S10: None of these conditions are present.

The daily average areal rainfall and synoptic conditions prevailed over the basin from 15th June to 29th September. Different categories of rainfall ranges have been categorized by using Indian Daily Weather Report, 1998. The rainstorms less than 2.5 mm have been ignored and higher ranges of rainfall i.e., 2.5 – 10 mm, 11 – 25 mm, 26 – 50 mm and > 51 mm have been considered for matching with different categories of synoptic situations.

Table 4.11: Synoptic Systems and Rainstorm Affecting Lower Rapti River Basin during 1998 Monsoon Season.

Av. Areal rainfall Range (in mm)	Synoptic System	No. of Rainstorms	Percentage to the total
2.5-10 (Low)	S1	2	6.9
	S3	5	17.24
	S4	1	3.45
	S6	7	24.14
	S8	2	6.9
	S9	9	31.03
	S10	3	10.34
Total		29	100
Av. Areal rainfall Range (in mm)	Synoptic System	No. of Rainstorms	Percentage to the total
11-25 (Moderate)	S1	1	4.17
	S2	5	20.83
	S3	7	29.17
	S5	5	20.83
	S6	5	20.83
	S7	1	4.17
Total		24	100
Av. Areal rainfall Range (in mm)	Synoptic System	No. of Rainstorms	Percentage to the total
26-50 (High)	S3	1	12.5
	S6	2	25
	S7	3	37.5
	S8	2	25
Total		8	100
Av. Areal rainfall Range (in mm)	Synoptic System	No. of Rainstorms	Percentage to the total
> 51 (Very High)	S5	4	44.44
	S7	2	22.22
	S8	3	33.33
Total		9	100

Source: IMD, Pune-5 and Indian Daily Weather Report (June to September, 1998), IMD, Pune-5

Table 4.11 shows the average areal rainfall, synoptic systems, and number of rainstorms in each system and their percentage to the total number of rainstorms occurring in each range during 1998 monsoon season. It is observed that out of 29 occasions the systems like S1 and S3, which were away from the catchment had accounted for 24.14% occasions when the realized rainfall was in 2.5-10 mm. The contribution of systems like S4 and S6 was 27.59%, whereas the contribution of systems S8 and S9 was found to be 37.93%. Out of 24 occasions of rainstorms in the range of 11-25 mm, systems like S1, S2 and S3 had accounted for 54.17% whereas S5 and S6 and S7 had accounted for 25% and 20.83%, respectively. Out of 8 occasions of rainstorms, in the range of 26-50 mm, S3 and S6 had accounted for 37.5% whereas S7 and S8 had contributed 62.5%. Out of 9 occasions in the range of >51mm, the systems i.e., S5, S7 and S8 which were basically located in the basin area contributed 100%.

Table 4.12 shows synoptic conditions, number of Rainstorms, average areal rainfall, Percentage of rainfall to the total, average areal rainfall per rainstorm during 1998 monsoon season. Synoptic systems like S5, S7 S8 and S9 produced 66.17% rainfall to the total average areal rainfall. The average areal rainfall per rainstorm was 21.46 mm for the whole lower Rapti river basin. The average areal rainfall per rainstorm was 47 mm for S7, which indicates a very high intensity of rainfall in this particular synoptic system followed by S8 (42.51mm) and S5 (41.94 mm) synoptic systems.

Table 4.12: Synoptic System, Number of Rainstorm, Average Areal Rainfall, Percentage of Average Areal Rainfall to the Total and Average Areal Rainfall per Rainstorm in the Lower Rapti River Basin during 1998 Monsoon Season.

1	2	3	4	5
S1	3	31.9	2.12	10.63
S2	5	87.8	5.84	17.56
S3	13	180.4	12.01	13.88
S4	1	4.0	0.27	4.00
S5	**9**	**377.5**	**25.13**	**41.94**
S6	14	194.0	12.91	13.86
S7	**6**	**282.0**	**18.77**	**47.00**
S8	**7**	**297.6**	**19.81**	**42.51**
S9	9	37.0	2.46	4.11
S10	3	10.0	0.67	3.33
Total	**70**	**1502.2**	**100.00**	**21.46**

1. Synoptic Weather Systems, 2. Number of Rainstorm, 3. Average areal rainfall (in mm), 4. Percentage of rainfall to the total, 5. Average areal rainfall per rainstorm.

Source: IMD, Pune-5 and Indian Daily Weather Report (June to September, 1998), IMD, Pune-5

Thus, it has been found that the systems, which were away from the catchment predominantly, produced rainfall in the low and moderate ranges and the system near the catchment area or located over it or active monsoon trough with a tendency to move towards foothills of Himalayas produced rainfall generally in high ranges.

Table 4.13 shows the monthly average areal rainfall, total number of rainy days in each month and monthly average areal rainfall per rain day during the 1998 flood season. The average areal rainfall of 124.2 mm, which was mainly concentrated in the low and moderate ranges in the month of June, was sufficient for saturation of soil moisture in the lower Rapti river basin and the intensity of average areal rainfall per rain day was only 10.35mm. But in the months of July and August, basin received 637.4mm and 603.7mm average areal rainfall that was mainly concentrated in moderate, high and very high ranges, while the intensity of average areal rainfall per rain day was 28.97mm and 23.22mm, respectively. In the month of September, basin received 136.9mm average areal rainfall that was concentrated in moderate and very high ranges with an intensity of 13.69 mm per rain day.

Table 4.13: Monthly Average Areal Rainfall and Rainy Days during 1998 Monsoon Season

Av. Areal Rainfall Range (in mm)	June	July	August	Sept.
2.5 -10 (Low)	41.7	33.1	42.5	22.7
11 - 25 (Moderate)	82.5	109.8	174.2	54.8
26 - 50 (High)	Nil	131.4	158.3	Nil
> 51 (Very High)	Nil	363.1	228.7	59.4
Total Rainfall	**124.2**	**637.4**	**603.7**	**136.9**
No. of Raindays	12	22	26	10
Av. Areal rainfall per Rainday	**10.35**	**28.97**	**23.22**	**13.69**

Source: IMD, Pune-5.

Thus, the monsoon season started with a low amount of rainfall in the month of June and attained its peak in the months of July and August. The very high intensity of rainfall in the months of July and August caused flooding in the basin.

4.5.4 Daily Rainfall, and Water Level at Bansi and Birdghat and Average Areal Rainfall Over the Lower Rapti River Basin

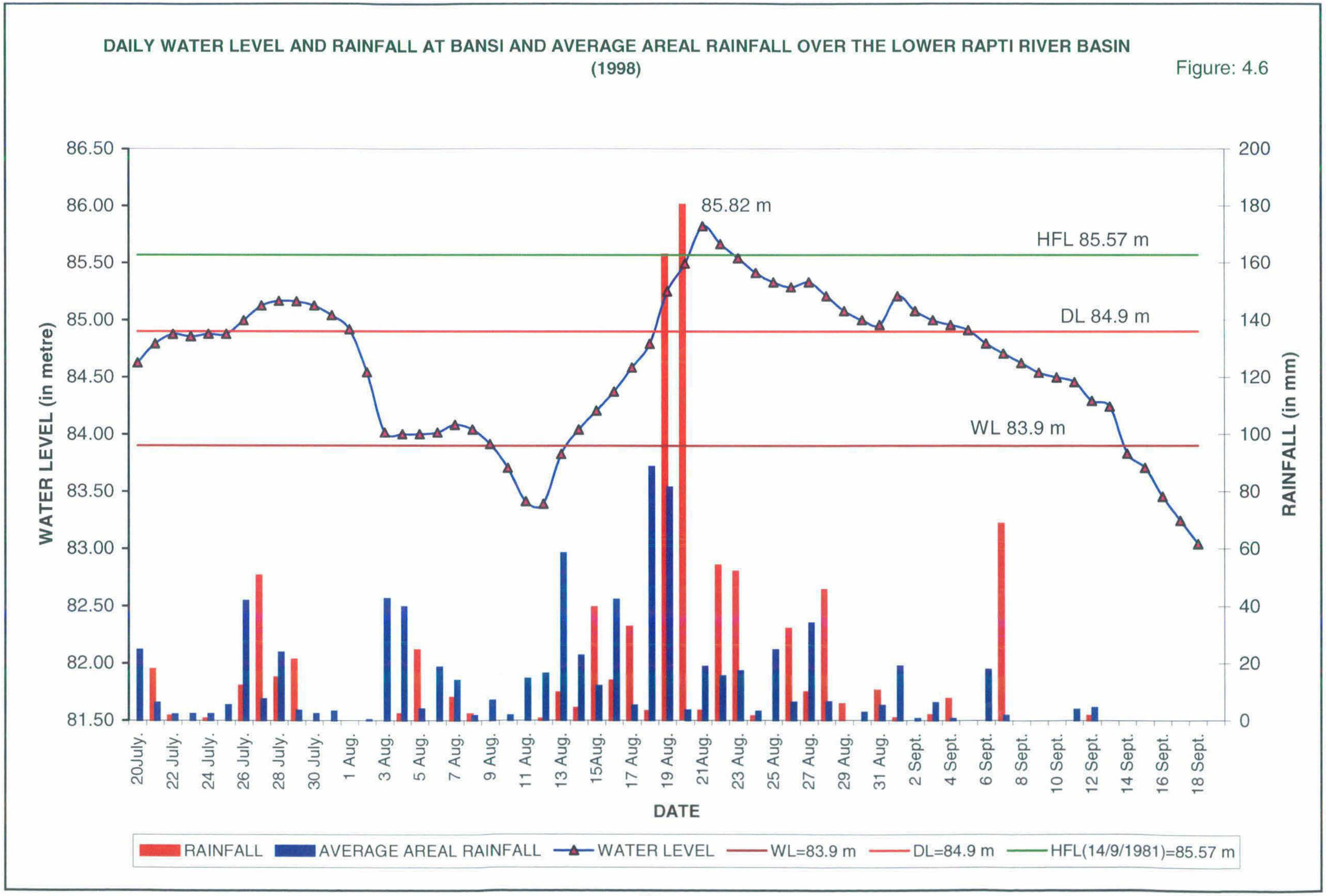
In the upstream site at Bansi, water level remained between warning and danger level from 20/7/98 to 25/7/98 (Table 4.14 and Fig. 4.6). At this time, total rainfall amount was 32 mm against the average areal rainfall of 42 mm. the major synoptic conditions, which produced rainfall during this period, were S8 and S7 that were located over the basin. S7 system produced more that 50 percent of rainfall.

Table 4.14: Rainfall at Bansi and Average Areal Rainfall under Various Synoptic Systems over the Lower Rapti River Basin during 1998 Monsoon Season.

1	2	3	4	5	6
20 July - 25 July	s6	2.2	6.9	12.2	29.0
	s7	17.8	55.6	24.5	58.3
	s8	12.0	37.5	5.3	12.6
	Total	32.0	100.0	42.0	100.0
26 July - 1Aug.	s3	0.0	0.0	0.0	0.0
	s6	36.2	41.7	37.3	46.0
	s8	50.7	58.3	41.7	51.4
	s9	0.0	0.0	2.1	2.6
	Total	86.9	100.0	81.1	100.0
2 Aug. - 12 Aug.	s1	8.0	17.0	18.5	11.6
	s2	11.8	25.1	30.1	18.9
	s3	0.4	0.9	24.7	15.5
	s6	0.0	0.0	4.0	2.5
	s7	26.8	57.0	82.0	51.5
	Total	47.0	100.0	159.3	100.0
13 Aug.- 21 Aug.	s5	53.4	10.8	34.6	10.4
	s6	90.4	18.3	64.4	19.3
	s7	184.6	37.3	140.0	42.0
	s8	166.2	33.6	93.9	28.2
	Total	494.6	100.0	332.9	100.0
22 Aug. - 5 Sept.	s3	42.0	25.1	30.8	21.9
	s5	1.4	0.8	17.3	12.3
	s6	108.4	64.8	71.1	50.5
	s9	15.6	9.3	21.4	15.2
	s10	0.0	0.0	0.0	0.0
	Total	167.4	100.0	140.6	99.8
6 Sept. - 13 Sept.	s5	68.8	97.7	17.7	64.6
	s9	1.6	2.3	9.7	35.4
	s10	0.0	0.0	0.0	0.0
	Total	70.4	100.0	27.4	100.0

1.Date 2. Synoptic System 3. Rainfall (in mm) at Bansi, 4. Percentage Rainfall to the total 5. Average Areal Rainfall over the basin 6. Percentage average areal rainfall to the total.

Source: 1. IMD, Pune-5 and 2. Indian Daily Weather Report (June to September, 1998), IMD, Pune-5


DAILY WATER LEVEL AND RAINFALL AT BANSI AND AVERAGE AREAL RAINFALL OVER THE LOWER RAPTI RIVER BASIN (1998)
Figure: 4.6
WATER LEVEL (in metre)
RAINFALL (in mm)
DATE
85.82 m
HFL 85.57 m
DL 84.9 m
WL 83.9 m
RAINFALL
AVERAGE AREAL RAINFALL
WATER LEVEL
WL=83.9 m
DL=84.9 m
HFL(14/9/1981)=85.57 m

The water level remained above the danger level from 26/7/98 to 1/8/98. The rainfall amount was 86.9 mm against the average areal rainfall of 81.1 mm. The major synoptic systems were S6 and S8 but more than 50 percent of rainfall occurred in S8 system during this specific period.

Again, the water level remained between warning and danger level from 2/8/98 to 9/8/98 and it remained below the warning level from 10/8/98 to 13/8/98. The rainfall amount at this site was 47 mm against the average areal rainfall of 159.3 mm. The major synoptic systems were S7 and S2 but more than 50 percent of rainfall was produced by S7 system. Thus, the low rainfall at Bansi pushed the water level below the warning level.

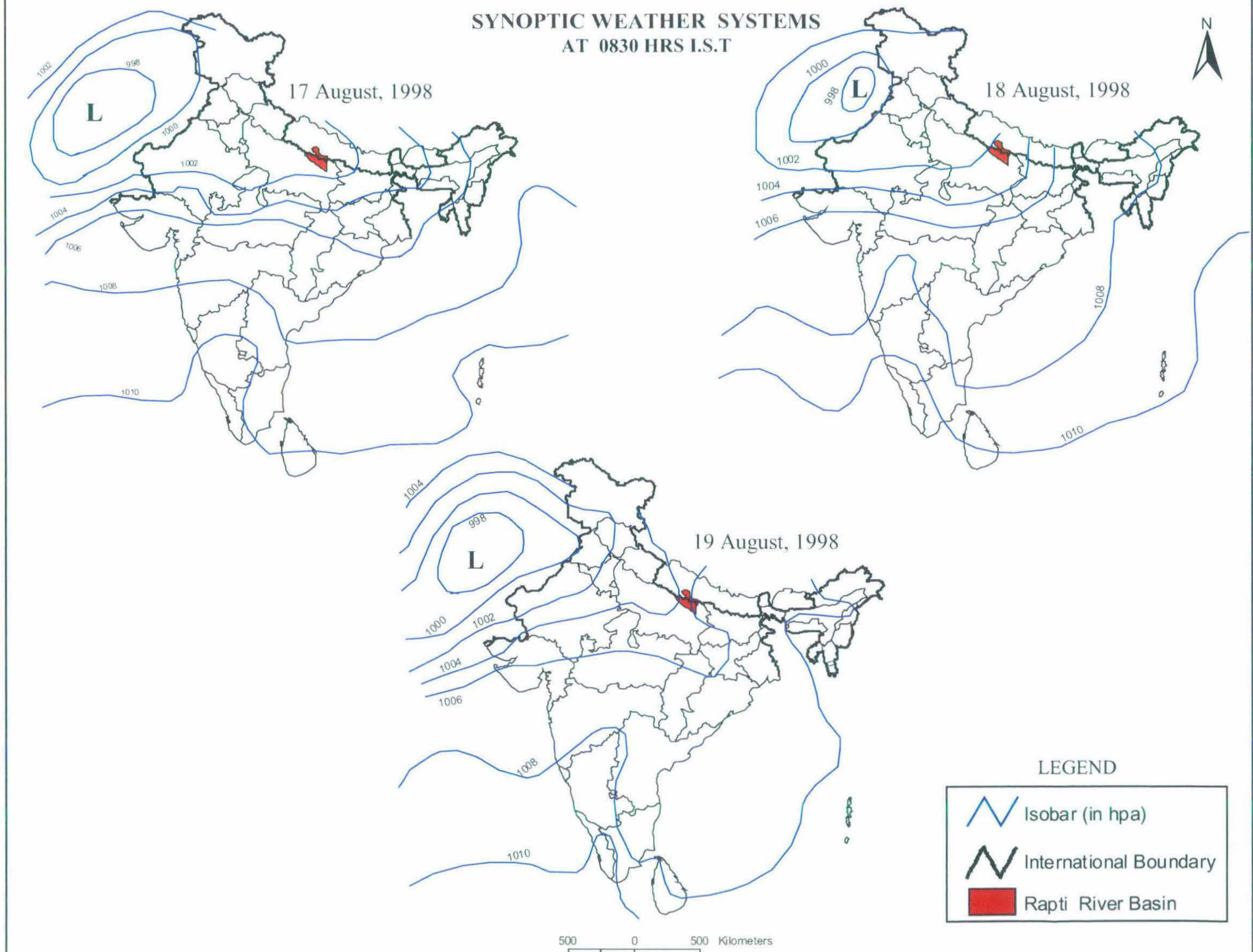
The water level was continuously increasing from 14/8/98 to 21/8/98. As a result, it surpassed its previous highest flood level (HFL) of 85.57m (14/9/1981) on 21/8/98 when it attained a new HFL of 85.82 m exceeding the previous level by 25 cm. It remained above the previous HFL for two days i.e., on 21/8/98 and 22/8/98. The rainfall amount was 494.6 mm against the average areal rainfall of 332.9 mm from 13/8/98 to 21/8/98. The major rain producing synoptic systems were S5, S7 and S8 that were located over the basin. S7 and S8 systems collectively produced more than 70 percent of rainfall during this specific time. The monsoon trough located near the foothills of Himalayas from 17/8/98 to 18/8/98 and it passed through the basin on 19/8/98 (Map 4.2). Thus, the break monsoon condition caused the unprecedented flood at Bansi.

After this unprecedented flood, the water level remained above the danger level from 22/8/98 to 5/9/98. The rainfall amount was 167.4 mm against the average areal rainfall of 140.6 mm. the major synoptic systems, which produced the rainfall, were S6, S9 and S3. S6 system produced more than 50 percent of rainfall during this period.

Again, the water level remained between warning and danger level from 6/9/98 to 13/9/98. The rainfall amount was 70.4 mm against the average areal rainfall of 27.4 mm during this specific period and the major rain producing synoptic systems were S5 and S9.

Finally, the water level came down below the warning level from 14/9/98 to 18/9/98. The rainfall amount was zero during this period.

SYNOPTIC WEATHER SYSTEMS
AT 0830 HRS I.S.T



Source: Indian Daily Weather Report, IMD Pune, 1998

Map 4.2

Table 4.15: Rainfall at Birdghat and Average Areal Rainfall under Various Synoptic Systems over the Lower Rapti River Basin during 1998 Monsoon Season.

1	2	3	4	5	6
9 Jully - 10 July	s2	0.7	0.3	0.8	1.1
	s5	**224.7**	**99.7**	**67.8**	**98.9**
	Total	**225.4**	100.0	**68.5**	100.0
11 July - 22July	s3	83.1	27.6	73.9	24.7
	s6	3.8	1.3	8.0	2.7
	s7	**35.7**	**11.8**	**60.0**	**20.1**
	s8	**178.8**	**59.3**	**156.7**	**52.5**
	Total	**301.4**	100.0	**298.5**	100.0
23 July - 25 July	s6	1.0	100.0	4.0	43
	s8	**0.0**	**0.0**	**5.3**	**57**
	Total	1.0	100.0	9.3	100
26 July - 31 July	s6	49.0	43.5	37.3	47.0
	s8	**55.2**	**49.0**	**40.0**	**50.4**
	s9	**8.5**	**7.5**	**2.1**	**2.7**
	Total	112.7	100.0	79.4	100.0
1Aug - 9 Aug.	s1	20.5	10.6	18.5	14.6
	s2	13.0	6.8	13.9	10.9
	s3	25.4	13.2	8.5	6.7
	s6	1.0	0.5	4.0	3.1
	s7	**132.6**	**68.9**	**82.0**	**64.7**
	Total	192.5	100.0	126.7	100.0
10Aug -23Aug.	s2	20.0	4.8	16.3	4.1
	s3	36.3	8.7	16.2	4.1
	s5	**112.7**	**27.1**	**51.9**	**13.0**
	s6	59.2	14.2	79.9	20.1
	s7	**87.9**	**21.1**	**140.0**	**35.2**
	s8	**100.0**	**24.0**	**93.9**	**23.6**
	Total	416.1	100.0	398.2	100.0
24 Sept - 2 Sept.	s3	9.6	7.8	30.8	30.5
	s6	71.4	57.7	55.5	54.9
	s9	**42.8**	**34.6**	**14.8**	**14.6**
	Total	123.8	100.0	101.2	100.0
3Sept. - 14 Sept.	**s5**	**1.8**	**10.7**	**17.7**	**52.2**
	s9	**15.1**	**89.3**	**16.2**	**47.8**
	s10	0.0	0.0	0.0	0.0
	Total	16.9	100.0	34.0	100.0

1. Date 2. Synoptic System 3. Rainfall (in mm) at Gorakhpur, 4. Percentage Rainfall to the total 5. Average Areal Rainfall over the basin 6. Percentage average areal rainfall to the total.

Source: 1. IMD, Pune-5, and 2. Indian Daily Weather Report (June to September, 1998), IMD, Pune-5

At down stream site i.e., Birdghat (Gorakhpur), the Rapti river crossed danger level on 11th July 1998 and remained above danger level for almost next two months i.e., till 9th Sepetember 1998 (Table 4.15).

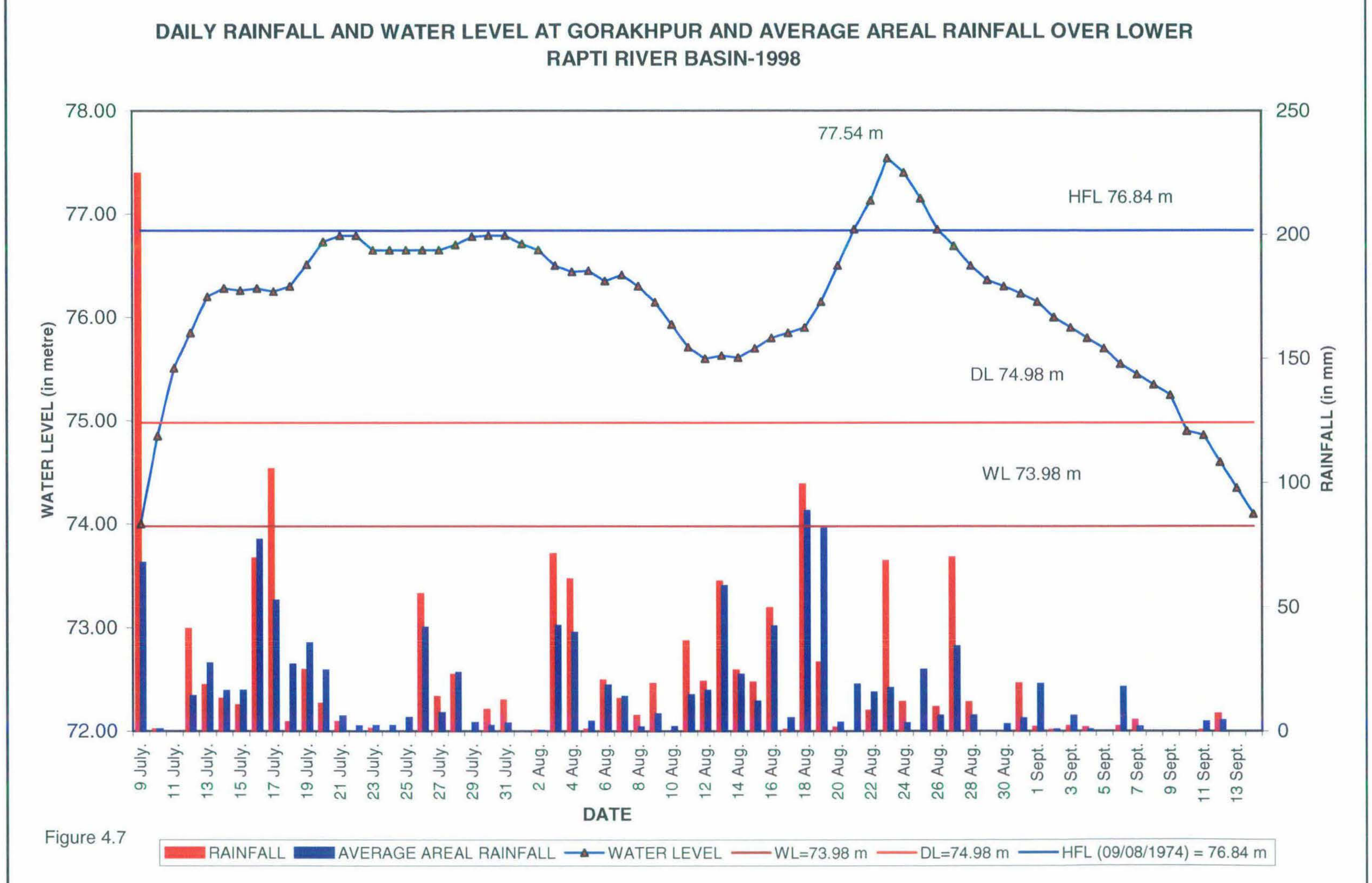

DAILY RAINFALL AND WATER LEVEL AT GORAKHPUR AND AVERAGE AREAL RAINFALL OVER LOWER RAPTI RIVER BASIN-1998
WATER LEVEL (in metre)
RAINFALL (in mm)
DATE
78.00
77.00
76.00
75.00
74.00
73.00
72.00
250
200
150
100
50
0
77.54 m
HFL 76.84 m
DL 74.98 m
WL 73.98 m
9 July.
11 July.
13 July.
15 July.
17 July.
19 July.
21 July.
23 July.
25 July.
27 July.
29 July.
31 July.
2 Aug.
4 Aug.
6 Aug.
8 Aug.
10 Aug.
12 Aug.
14 Aug.
16 Aug.
18 Aug.
20 Aug.
22 Aug.
24 Aug.
26 Aug.
28 Aug.
30 Aug.
1 Sept.
3 Sept.
5 Sept.
7 Sept.
9 Sept.
11 Sept.
13 Sept.
RAINFALL
AVERAGE AREAL RAINFALL
WATER LEVEL
WL=73.98 m
DL=74.98 m
HFL (09/08/1974) = 76.84 m

Figure 4.7

The water level remained between warning and danger level for two days i.e., on 9/7/98 and 10/7/98. The rainfall amount of 224.7 mm at Gorakhpur on 9/7/98 raised the water level of Rapti above danger level on 11/7/98 with 2 days lag time. More than 90 percent of rainfall was mostly produced by the S5 synoptic system between 9/7/98 and 10/7/98.

The water level was continuously rising above the danger level from 11/7/98 to 22/7/98 (Fig. 4.7). The rainfall amount was 301.4 mm against the average areal rainfall of 298.5 mm during this specific period. Thus, the rainfall at Gorakhpur and average areal rainfall over basin was more or less same. S8 Sytem produced more than 50 percent of rainfall.

The water level did not keep the earlier pace of rising. It remained 1.67 m above the danger level from 23/7/98 to 27/7/98. The rainfall amount was 1 mm against the average areal rainfall of 9.3 mm from 23/7/98 to 25/7/98. The major synoptic system was S6.

Again, the water level started rising from 28/7/98 to 31/7/98. The rainfall amount was 112.7 mm against the average areal rainfall of 79.4 mm between 26/7/98 and 31/7/98. The major rain producing synoptic systems were S8 and S6 but 50 percent of the rainfall was produced by S8 system.

From 1/8/98 to 9/8/98, the water level remained above the danger level. But it receded as compared to the earlier period (27/7/98 to 31/7/98). The rainfall at Gorakhpur was 192.5 mm against the average areal rainfall of 126.7 mm from 1/8/98 to 9/8/98. The S7 synoptic system produced more than 65 percent of rainfall during this specific period. Thus, the excess rainfall at Gorakhpur maintained the water level above the danger level.

The very high rainfall of 416.1 mm at Gorakhpur against the average areal rainfall of 398.2 mm was produced by S5, S7, and S8 synoptic systems between 10/8/98 and 23/8/98 and flood flow from the upstream caused the unprecedented flood at Gorakhpur. Three systems viz., S5, S7, and S8 collectively produced more than 70 percent of rainfall. The flood crest occurred at Bansi on 21/8/98 reached Gorakhpur on 23/8/98 with two days lag time. As a result, the water level surpassed its previous highest flood level of 76.84 m (9/8/1974) on 21/8/98 and attained a new HFL of 77.54 m on 23/8/98. Thus, it exceeded the previous HFL by 70 cm. It remained above previous HFL from 21/8/98 to 26/8/98. The monsoon trough located near the foothills of Himalayas from 17/8/98 to 18/8/98 and it passed through the basin on 19/8/98 (Map 4.2) produced very high rainfall over the basin as well as at Gorakhpur. Thus, the break monsoon condition caused the unprecedented flood at Birdghat/Gorakhpur.

After 23/8/98, the water level started receding. But it remained above the danger level by more than 1 m from 27/8/98 to 2/9/98. The rainfall was 123.8 mm against the average areal rainfall of 101.2 mm. S6 and S9 were the major rain producing systems during this period. The water level of the Rapti river had receded quickly between 3/9/98 and 14/9/98 due to very low rainfall.

Thus, excessive rainfall, mainly produced by the synoptic systems like S8, S7 and S5, was primary reason for the 1998 flood in the lower Rapti river basin. Since 42 % area of the Rapti river basin lies in Nepal from where no rainfall data is available, it could be reasonably presumed that there might be similar or even high rainfall situation in the upper reaches of the basin.

4.5.5 Flood Events of 1998 Monsoon Season

The flood events in the lower Rapti river basin has been classified into five categories on the basis of 61 and 68 forecasts issued by CWC for Bansi and Birdghat (Gorakhpur), respectively at 100% accuracy during 1998 monsoon season[11]. They are as follows:

1. Unprecedented Flood Event: It occurs when a river crosses its previous HFL.
2. High Flood Event: It occurs when a river approaches within 0.5 m of its HFL.
3. Moderate Flood Event: It occurs when a river crosses the danger level but remains below its HFL.
4. Low Flood Event: It occurs when a river crosses its warning level but remains below its danger level.
5. Flood Free Events: It occurs when a river remains below its warning level.

The frequency of unprecedented, high and moderate flood events at downstream site Birdghat (Gorakhpur) was more than upstream site Bansi. The downstream site Gorakhpur experienced only 7 low flood events but the upstream site Bansi experienced 27 low flood events. Flood free events were observed at Bansi but not at Gorakhpur (Table 4.16 and Fig. 4.8).

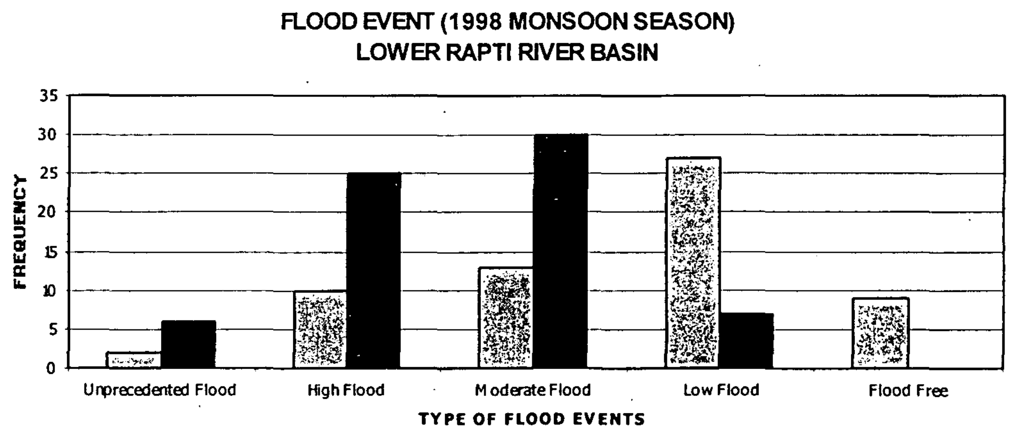


Figure: 4.8

Table 4.16: Frequency of Flood Events in the Lower Rapti River Basin during 1998 Monsoon Season

Flood Events	Bansi	Gorakhpur
Unprecedented Flood	2	6
High Flood	10	25
Moderate Flood	13	30
Low Flood	27	7
Flood Free	9	0
Total	**61**	**68**

The major causes of such type of flood events at Gorakhpur are the significant contribution of water from the Burhi Rapti and Rohini rivers etc. to the Rapti. These are the major tributaries of the Rapti and join it from left bank between Bansi - Gorakhpur reach and drainage congestion due to low gradient.

4.5.6 Sediment Size Analysis

The sediment sample of 1998 and 2001 flood season have been collected from Davhiya village (83° 20′ 53″ E and 26° 43′ 37″N) located near the right bank of the Rapti river and Birdghat G/D site, (83° 21′ 13″ E and 26° 43′ 77″N) which is located at the left bank of the Rapti river, respectively.

Sediment size analysis has been done with the help of sieve nest and shaker machine. The particle size distribution of the sediment has been ascertained by passing a dried sample of known weight through a series of sieves (1000, 500, 250, 125, 90, 63 and 45 micron). The weight retained in each sieve has been calculated in terms of percentage. Table 4.17 shows the description of particle size.

Table 4.17: Description of Particle Size

Description	Range of particle diameter (mm)
Very coarse sand with nodular limestone	Above 1.0
Coarse sand	0.5 – 1.0
Medium sand	0.25 – 0.50
Fine sand	0.125 – 0.25
Very fine sand	0.063 – 0.125
Coarse silt	0.045 – 0.063
Fine silt with clay	Less than 0.045

Source: Gregory and Walling, 1973, p. 64 [12].

The percentage weight to the total weight has been graphically represented through histograms (Fig. 4.9 and 4.10).

Sediment deposition in agricultural field near Davhiya village during 1998 flood season is still visible as a direct result; most of the fields are converted into the barren land. But there was no such type of deposition at Birdghat G/D site during 1998 flood season. This G/D site was raised up to 12m during 2001-flood season due to sand and silt deposition.

Table 4.18: Percentage of Weight to the Total Sediment Weight in the Lower Rapti River Basin

Sediment	1	2	3	4
Very Coarse Sand	2.8	1.43	4.6	4.84
Coarse Sand	0.6	0.31	0.6	0.63
Medium Sand	0.2	0.10	1.2	1.26
Fine Sand	34.8	17.76	12.4	13.04
Very Fine Sand	136.2	69.49	45.92	48.28
Coarse Silt	10.2	5.20	18.4	19.34
Fine Silt with clay	11.2	5.71	12	12.62
Total	196	100.00	95.12	100.00

1.Sediment weight (in gram) deposited near Davhiya village during 1998 monsoon season, 2. Percentage of weight to the total sediment weight deposited near Davhiya village during 1998 monsoon season, 3. Sediment weight (in gram) deposited at Birdghat G/D site during 2001monsoon season, 4. Percentage of weight to the total sediment weight deposited at Birdghat G/D site during 2001monsoon season.

The contribution of very fine sand to the total is 69.49 % and 48.28 % in 1998 and 2001 monsoon season, respectively (Table 4.18). The contribution of coarse silt and fine silt with clay to the total has increased from 1998 to 2001 monsoon seasons. A significant increase in very coarse, coarse and medium sand is observed in 2001monsoon season as compared to 1998monsoon season (Fig. 4.9 and 4.10). This signifies deforestation in upper reaches of the Rapti river. As a result, Deforestation not only increased the run off but also the sediment load in the rivers, which gets deposited in the riverbed making them shallow as well as in agriculture fields converting them into barren land.

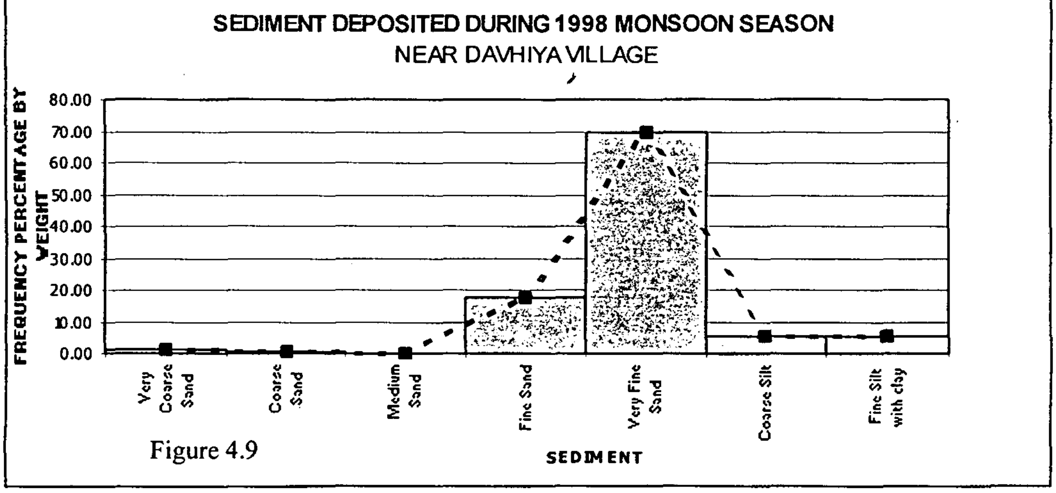


Figure 4.9

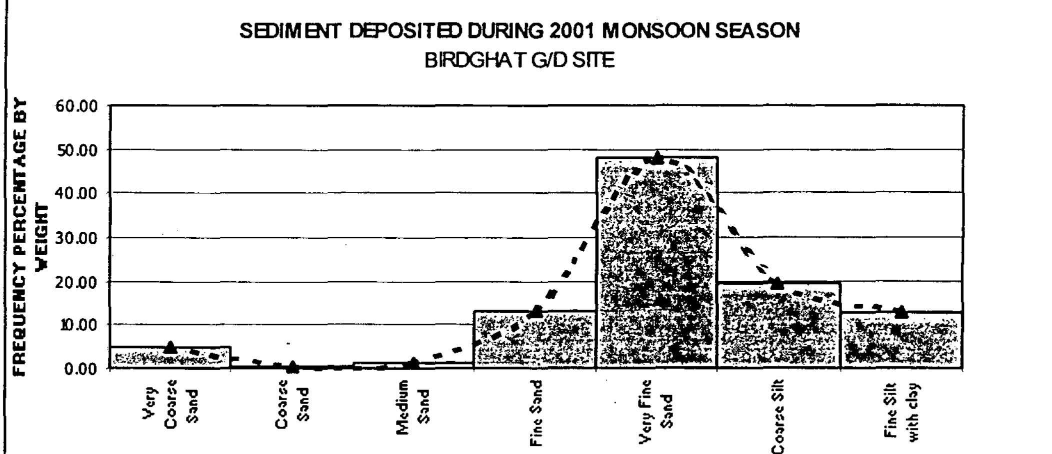


Figure 4.10

4.5.7 Impact of 1998 Floods in Gorakhpur District

Since the river Rapti at Birdghat (Gorakhpur) remained above the danger level for almost 2 months i.e., from 11/7/98 to 9/7/98 and caused heavy losses to property in the Gorakhpur city and adjoining areas. The total damage due to floods was 352.25 crores Rs. District economy is based on agriculture. During 1998, agricultural department was severely affected by floods due to sand casting in agricultural fields followed by public works and other departments (Table 4.19 and Fig. 4.11).

Figure: 4.11

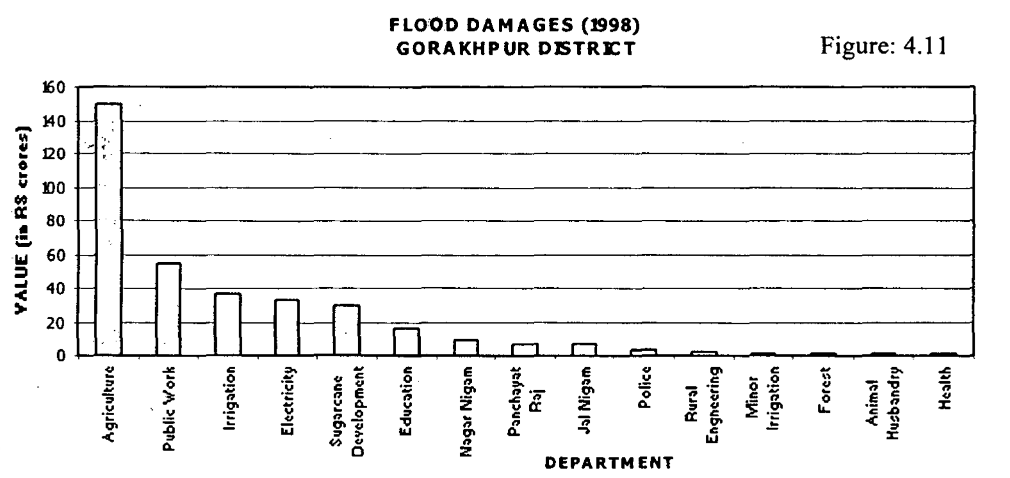


Table 4.19: Flood Damages in Gorakhpur District during 1998

Department	Damage (in crores)
Agriculture	149.3
Public Work	55.38
Irrigation	36.91
Electricity	33.23
Sugarcane Development	29.94
Education	15.65
Nagar Nigam	8.74
Panchayat Raj	7.13
Jal Nigam	6.83
Police	3.34
Rural Engneering	1.84
Minor Irrigation	1.39
Forest	1.24
Animal Husbandry	0.70
Health	0.63
Total	352.25

Source: The Troubled Water: A Report on the 1998 Floods in Eastern Uttar Pradesh, Poorvanchal Gramin Vikas Sansthan, Gorakhpur.

4.6 Flood Frequency in Gorakhpur District

The frequency of flood crest has been analysed on the basis of warning level because flood damage starts at this level. The maximum water level data of the year 1995 is missing. The flood crest occurred three times above the warning level between 1987 and 1989 and also between 1996 and 1998 while it occurred two times between 1990 and 1992 and also between 1993 and 1994 (Fig. 4.2 c).

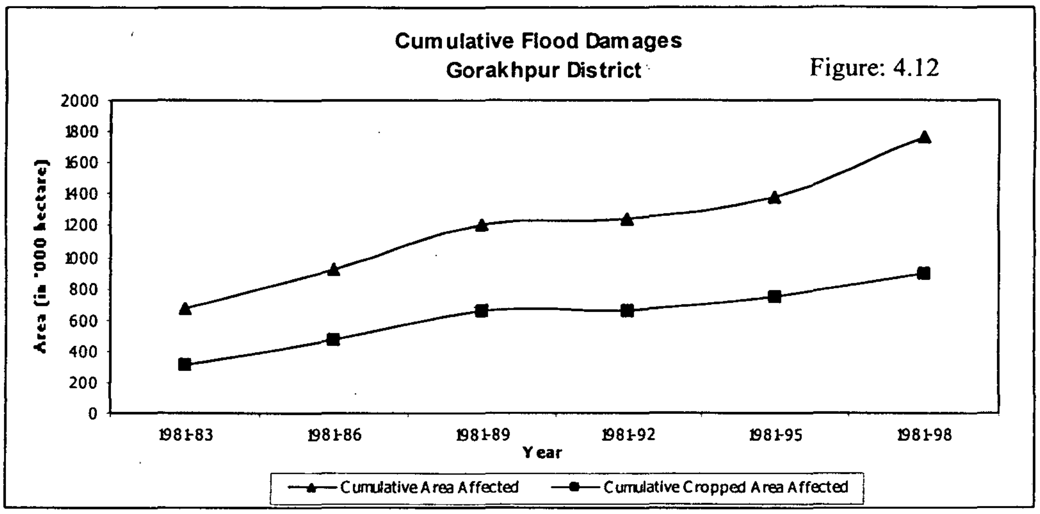
4.7 Flood Damages in Gorakhpur District (1981-1998)

This section analyses the flood damages to total area and cropped area from 1981 to 1998 and their relation to the maximum water level of the Rapti river recorded at Birdghat. Maximum water level, flood affected area and cropped area are positively correlated (Table 4.20). The trend of flood damages is determined by using cumulative value of three years.

Table 4.20: Correlation between Maximum Water Level, Total Area and Cropped Area Affected by Floods in Gorakhpur District (1986 to 1998).

	Max. Water Level	Total Area	Cropped Area
Max. Water Level	1.00	0.811*	0.710*
Total Area		1.00	0.908*
Cropped Area			1.00

* Correlation is significant at the 0.01 level.



The curves of cumulative total area and cropped area affected by floods show an increasing trend. It is observed that whenever the water level crosses the warning level with a great difference the flood damages to both the area are the maximum. Both of the curves are parallel to the x-axis between 1989 and 1992 because during this span of time the flood crest occurred only two times (Table 4.21 and Fig. 4.12).

Table 4.21: Cumulative Flood Damages in Gorakhpur District.

Year	Cumulative Area Affected	Cumulative Cropped Area Affected
1981-83	670.434	313.926
1981-86	915.176	475.185
1981-89	1209.221	653.511
1981-92	1241.644	661.244
1981-95	1377.552	748.829
1981-98	1761.618	890.143

Area in '000 hectare

Source: Flood Report of Gorakhpur district- 2001, p.180

4.8 Conclusion

Excessive rainfall and drainage congestion are the main factors, which cause floods in the lower Rapti river basin. Clustering of synoptic weather systems in the basin is responsible for the floods. Major synoptic systems, responsible for the floods in the basin are break monsoon situation, passage of monsoon trough through the basin and low pressure systems, which prevailed over the basin during 1998. One catastrophic weather system (monsoon trough located near the foothills of Himalayas) amongst the clustered synoptic weather systems was solely responsible for the unprecedented flood in the basin. The rainstorms of 5 days duration produced most of rainfall during 1998-flood season.

A significant increase in very coarse, coarse and medium sand is observed during 2001-monsoon season as compared to 1998-monsoon season. This signifies deforestation in upper reaches of the Rapti river basin. As a result, deforestation not only increased the run off but also the sediment load in the rivers, which gets deposited in the riverbed making them shallow as well as in agriculture fields converting them into barren land. The flood damages to total area and cropped area are showing an increasing trend in Gorakhpur district. This indicates that more and more area other than agricultural land is affected by the floods.

References

1. Dhar, O.N. and Nandargi, S., (2003), " Hydrometeorological Aspects of Floods in India", *Natural Hazards*, Vol. 28, No..., pp. 7-9.
2. Das, P.K., (1968), *The Monsoons,* National Book Trust of India, New Delhi, pp. 53-55.
3. Yadav, R.P., (1999), *Floods in Eastern Uttar Pradesh,* Radha Publications, New Delhi,p. 46
4. *Ibid.,* p. 28.
5. *Draft Proposal of Task Force on Land use and Erosion Control,* National Planning Commission, Secretarial, Government of Nepal, August 1974, pp....
6. *Manual on Flood Forecasting,* CWC, River Management Wing, March 1989, New Delhi p.4.

7. De. Wiest, R.J.M., (1965), *Geohydrology,* John Wiley & Sons, New York, pp. 99-106.
8. Jones, J.A.A., (1997), *Global Hydrology: Processes, Resources and Environment Management*, Addison Wesley Longman Limited, England, p.106.
9. Kumar, A., (1965), *Flood Control and Settlement Planning,* Mohit Publications, New Delhi, pp.78-84.
10. Kumar, A., and Ram, L.C., (1995), " Semi-Quantitative Precipitation Forecast for Rapti Catchment by Synoptic Analogue Method", *Mausam,* Vol. 46, No. 1, January, pp. 97-99.
11. *Flood forecasting and Warning network Performance Appraisal*, Central Water Commission, April 2000, New Delhi, pp.36-37.
12. Gregory, K.J., and Walling, D.E., (1973), *Drainage Basin Form and Processes: A Geomorphological Approach,* Edward Arnold, London, p. 64.

Chapter Five

Approaches to Flood Management

5.1 Introduction

The numerous advantages that flood plain offers for the economic activities, particularly in urban and rural areas, encourage the people to settle down with certain amount of protection against the flood. The reduction of damage from flooding requires a combination of three different strategies. They are as follows:

1. Keep the flood away from the people includes structural measures
2. Keep the people out of the way of flood includes non-structural measures, and
3. Clean up afterwards.

The extensively adopted measures for flood control in lower Rapti river basin are construction of embankments and ring bunds. This section analyses the measures for flood management and people perception about floods in the basin.

5.2 Structural Measures for Flood Control

The most popular method of protection is through structural controls. They are embankments and flood wall, dam and reservoirs, natural detention basins, channel improvements, emergency flood, river diversions, Inter basin Transfer, Bank stabilization and anti erosion measures, Ring bund, and under ground storage reservoir [1]. Detailed description of the structural measures for flood control is given in following section.

5.2.1Embankments

The construction of embankment on riverbanks in a Jirection parallel to the flow of the river is a most common method of flood control. It gives immediate tangible protection to the adjoining area but it has many side effects. It prevents the silt in floodwaters settling down on flood plain. The deposition of sediments on bed reduces the bearing capacity of the river due to raised bed as well as the valley storage. They prevent the natural drainage causing water logging and drainage congestion on the countryside and at confluence of the tributaries. They accelerate the velocity of stream as a result the accelerated velocity of water erodes the riverbanks and engulfs the adjoining agricultural fields. Settlements located over the embankments, rat holes and human induced cutting in the embankment are the cause of breach and seepage during the high peak flow. Thus, embankments give the false security and encourage high value land use in flood plain.

Dams, reservoirs, sediment detention basin and soil conservation measures help in reducing the magnitude of floods and make the embankment durable for a long time by reducing sand and silt.

5.2.2 West Rapti High Dam

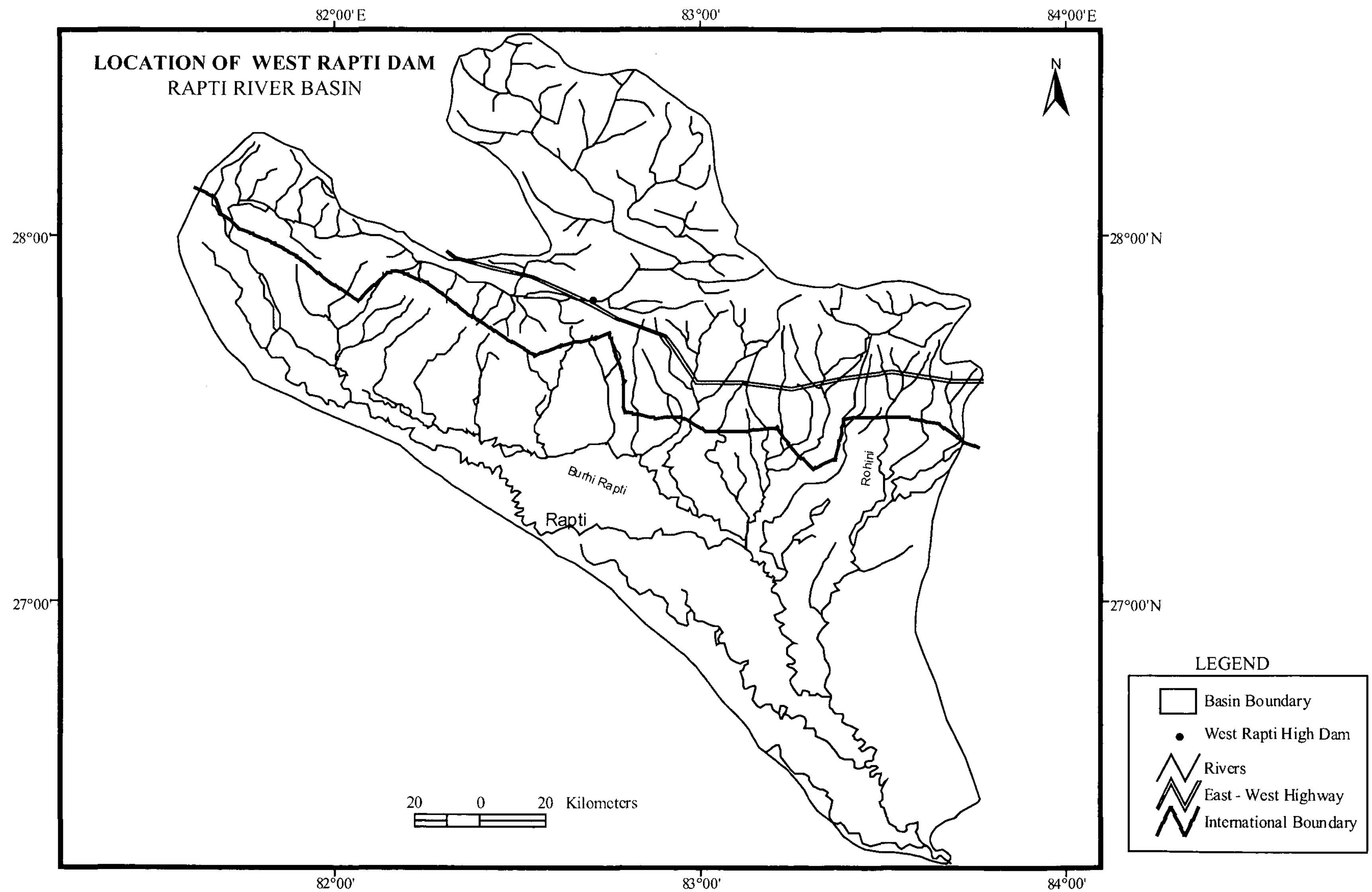
The most important structure that controls floods is the reservoirs behind the dam. The West Rapti high dam has been proposed to construct at Bhalubang located close to the point where the east-west highway crosses the West Rapti river (Map 5.1). The Rapti river is known as West Rapti in Nepal. The proposed Bhalubang site is suitable to build a dam up to 120m in height. The height of dam would correspond to the highest reservoir water level at an elevation of 420m (MSL). At this height the total storage capacity of the reservoir would have been 3000 million cubic metre[2]. Thus, this dam will save the lower Rapti river basin from most of floods but not from the extreme floods.

5.2.3 Laxmanpur Barrage[3]

This barrage is constructed for harnessing the Rapti river in Laxmanpur village of Bahraich district of Eastern Uttar Pradesh. The barrage is located 10 km south of Nepal border. Construction of barrage started in 1981 and was completed in 1985.

The barrage is 284 metre long with 5000 cumec water exit capacity. It accumulates discharge from all affluents of the Rapti river during the monsoon season. Bahraich, Shrawasti, Siddharthnagar, and Gorakhpur districts of Eastern Uttar Pradesh get twin benefits of flood control and irrigation. On the other hand, Bardia, Banke, and Dangdeukhuri districts of Nepal are bearing devastating floods in paddy belt of the Rapti Dun.

Laxmanpur barrage is a controversial issue between India and Nepal. The paddy belt of Rapti Dun will gradually change into the infertile barren land due to constant silting, which is particularly caused by the Barrage. Regional co-operation between India and Nepal should be necessary in order to combat the floods and its adverse consequences. Proper site assessment before the construction of barrage, dams and



Source: The Orient Longman School Atlas for Nepal, 2002

Map 5.1

reservoirs at Indo-Nepal border is necessary for the betterment of people of India and Nepal.

5.2.4 Reservoirs

There are fifteen reservoirs in the lower Rapti river basin for irrigation and flood control. The proposed link canals under the Saryu Command Area Project will also control floods and facilitate irrigation to Gonda, Bahraich, Shrawasti, Balrampur, Sidhharthnagar, Basti, and Gorakhpur districts of Eastern Uttar Pradesh (Map 5.2).

5.2.5 Afforestation

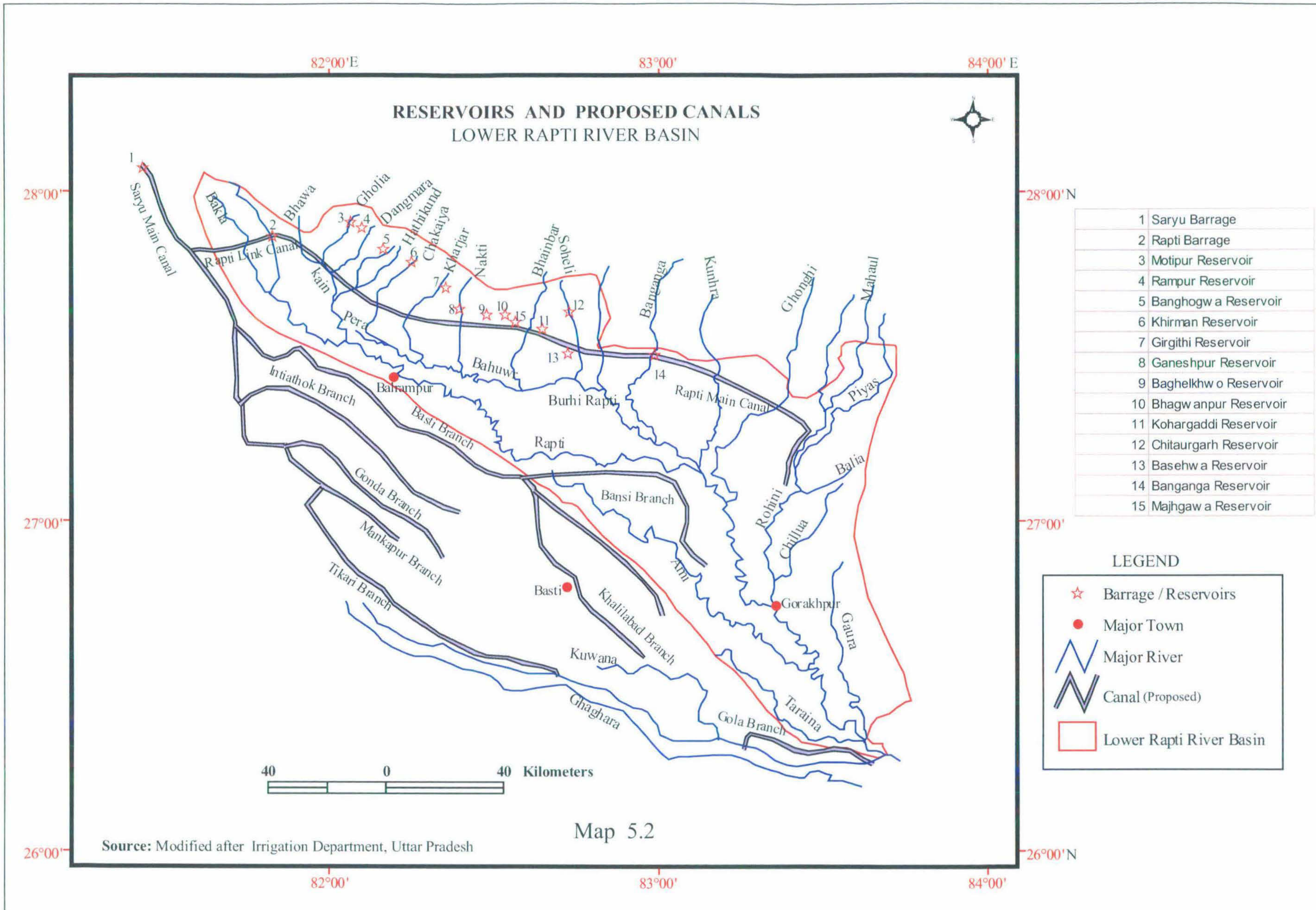
Afforestation measures basically minimize soil loss and reduce sediment load in streams and rivers, thus moderating the floods and controlling the meandering tendency of rivers, thereby minimizing the erosion of banks and embankments. However, the effect of afforestation is insignificant for catastrophic floods. People's participation in afforestation efforts not only helps in reducing the soil erosion but it also improves the socio-economic condition of community. In the case of the Rapti river basin, it is very essential to keep more and more area under forest in mountain, *Tarai,* and plain regions to retard the surface runoff [4] and also to reduce siltation in riverbed.

5.2.6 Sediment Detention Basin

A large number of big natural depressions occur in lower Rapti river basin, locally called *Tal*. Some of these depressions may be used as detention basins where the sediment laiden surface runoff may be allowed to accumulate and after settling of the sediment, the clear water should be allowed to flow into streams. Layered wells and dykes should be constructed in the *Tarai* region of Nepal and India to minimize the sediment load in lower reaches of the basin.

5.3 Non-Structural Measures for Flood Control

Non-structural measures, if implemented efficiently, can be very effective for flood management. They basically include flood forecasting and warning, flood proofing,



Map 5.2

Source: Modified after Irrigation Department, Uttar Pradesh flood plain zoning and emergency measures like evacuation, public health and relief services.

5.3.1 Flood Forecasting and Warning System

Since, Rapti river is a trans-boundary river so, the regional co-operation between India and Nepal is necessary for combating floods and the betterment of people in the basin. The dissemination of flood forecast from Nepal to India should be encouraged in order to make flood warning in proper time. This can minimize the flood damage. In lower Rapti River Basin, there are 10 G/D sites out of which 6 sites are the base sites for the flood forecasting in the basin. Jalkundi G/D site is located in Nepal (Map 4.1 and Fig. 4.1 of Chapter IV).

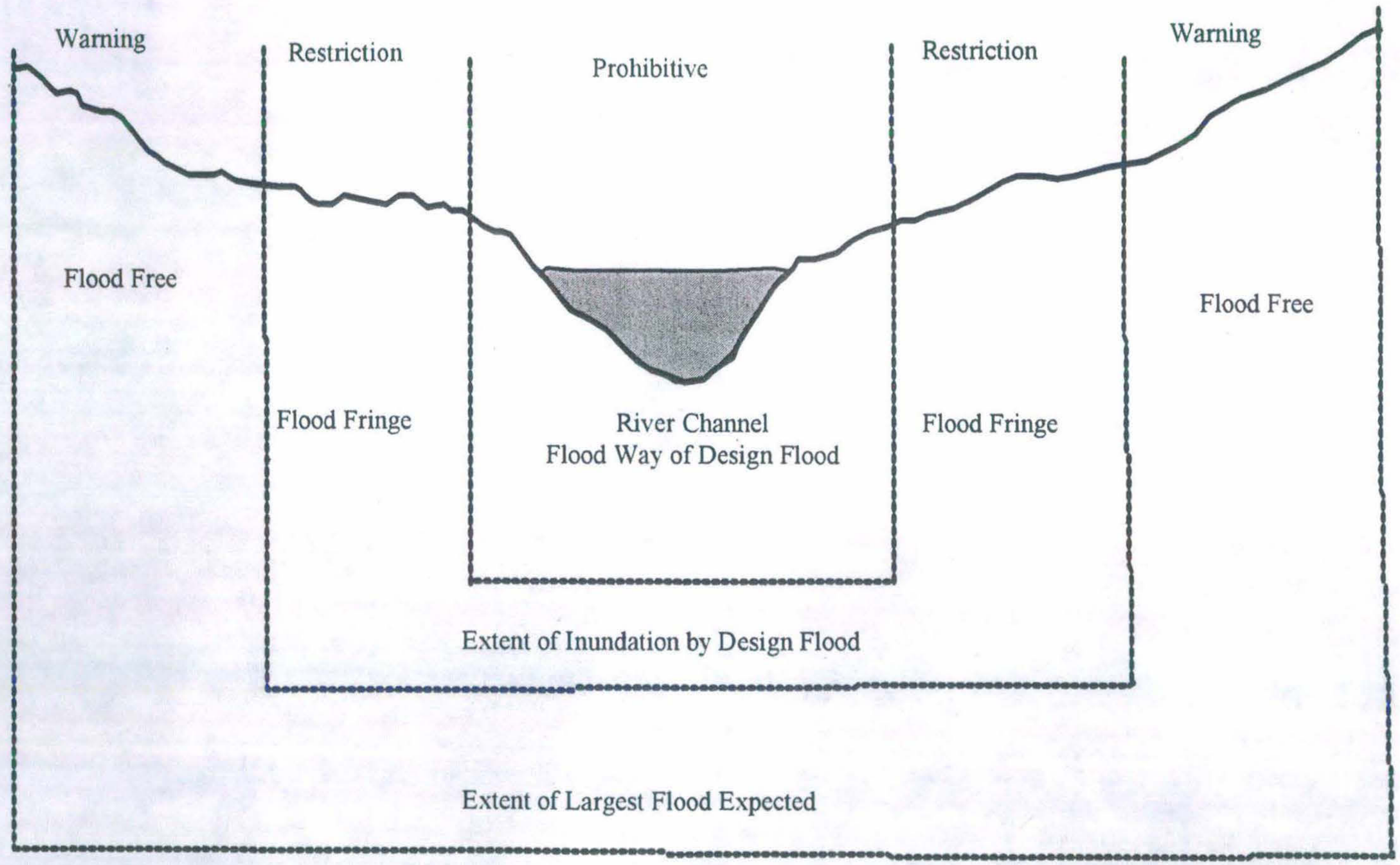
Flood booth should be established for a group of six or seven flood prone villages in order to disseminate the flood forecast and warning during flood season[5].

5.3.2 Flood Plain Zoning[6]

The need for flood plain zoning had received recognition in the seventies and model draft bill for flood plain zoning legislation was circulated by the Union government in 1975 to all the states. In fact the progress achieved in enactment and enforcement of legislation for flood plain zoning is tardy. A task force for the purpose is required to be considered.

The basic concept of flood plain zoning lies into the regulation of land use in flood plain in order to minimize the damage by floods, which are bound to occur from time to time with different magnitude and frequency. Flood plain can be divided into three zones i.e., flood way, flood fringe and flood free or Bhanger land on the basis of frequency of flood (Fig. 5.1). Encroachment into the flood plain and high value land use in flood hazard zones have resulted in the increasing flood damages. Therefore, there is an urgent need to regulate the land use in flood plain.

FLOOD PLAIN ZONES



Source: Central Water Commission, New Delhi

Figure:5.1

5.3.2.1 Regulating Land Use in Different Flood Zones

The different types of buildings and utility services can be grouped under priorities indicated below from the point of view of the damage likely to occur.

1. First priority: land is used for essential services such as hospitals, electrical installations, water supply, telephone exchange, aerodromes, railway stations, commercial centres, defence installations, industries, etc,
2. Second priority: residential areas, public institution, government offices, universities, public libraries, and
3. Third priority: parks and playgrounds.

The following regulation in respect of the above can be considered:

1. Building for priority-1 should be located in such a fashion that they are above the levels corresponding to a 100 year frequency or the maximum observed flood levels. Similarly, they should also be above the levels corresponding to a 50 year rainfall and the likely submersion due to drainage congestion.
2. Priority-2 should be for a 25 year flood or a 10 year rainfall stipulation that all buildings are on stilts or higher levels.
3. Playgrounds and parks can be located in areas vulnerable to frequent floods.

5.3.2.2 Regulations for Future Buildings

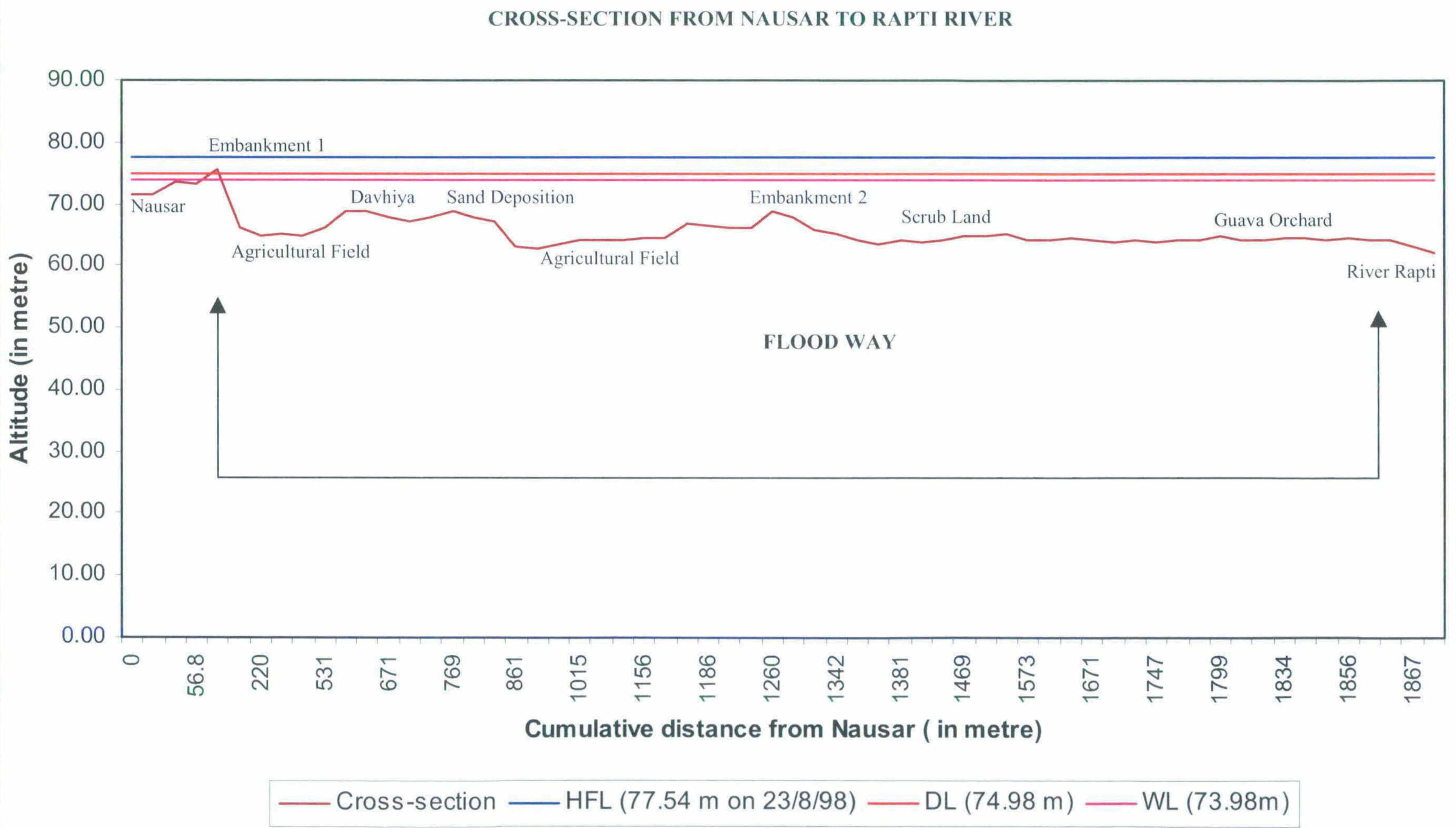
1. Plinth levels of all buildings should be nearly 0.75 to 1 metre above the drainage/flood submersion lines.
2. In the areas liable to floods, all the buildings should preferably be double/multi storeyed.
3. Wherever there are single storey buildings, a stairway should invarialbly be provided to the roofs so that temporary shelter can be taken there.

5.3.2.3 Application of GPS in Flood Plain Zone Mapping

The delineation of flood prone area and flood plain zoning means assessment of land relative to its susceptibility of flooding. Such zoning would also refer to a relative scale of flood risk with a particular geomorphic area. Flood prone area demarcation with the help of topographic maps and GPS data with integration of GIS has become an integral part of modern decision support system for mitigation of flood.

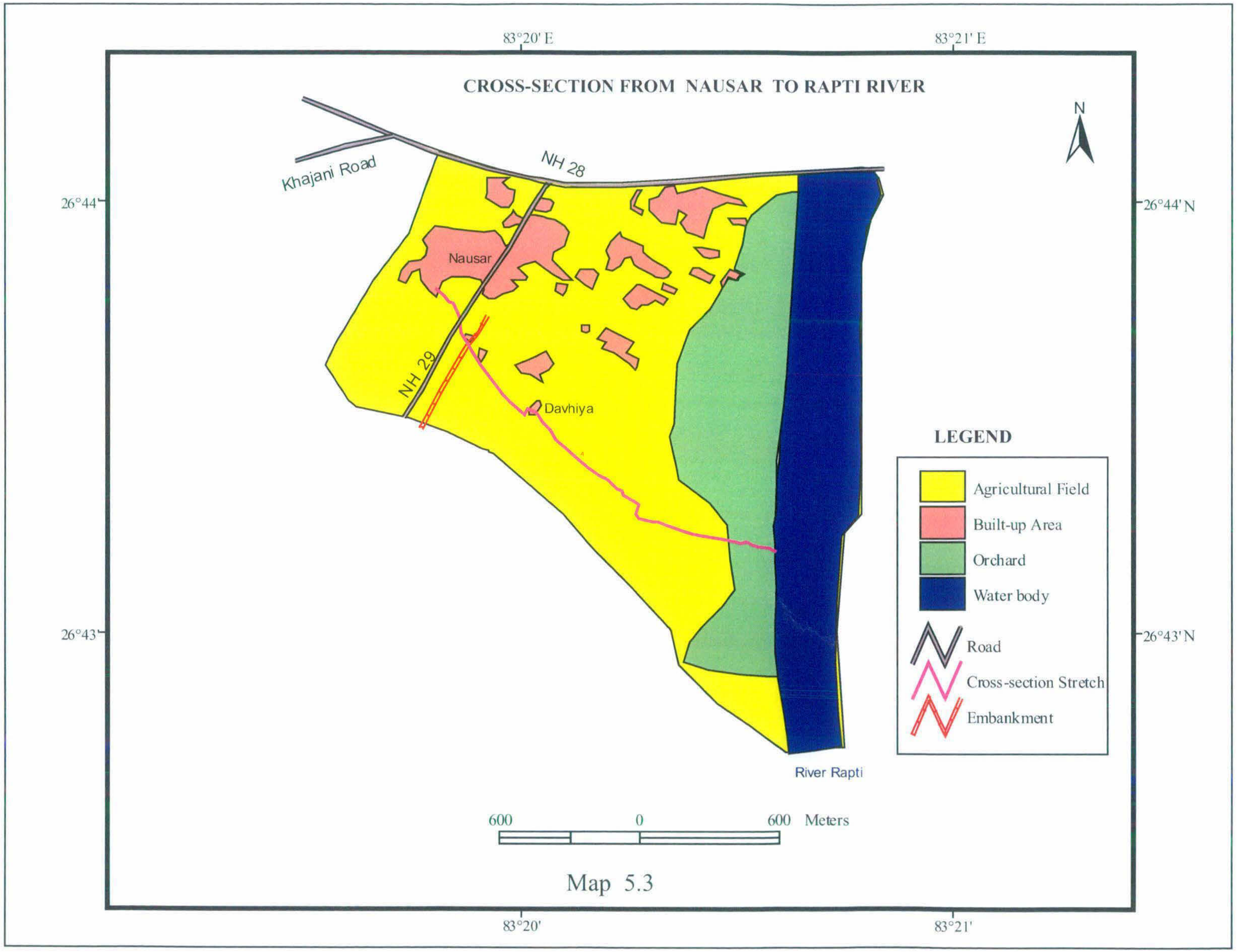
Cross-sections from Nausar to the Rapti river and from Ramgarh Tal to Deoria bypass road have been constructed with the help of Garmin GPS-76 in order to understand the topography and Altitude. The Garmin GPS 76 is designed to provide precise GPS positioning using correction data obtained from the Wide Area Augmentation System (WAAS). This unit features a built-in quad helix antenna for superior reception and can provide position accuracy to less than three meters when receiving WAAS correction that is obtained only in USA. The Garmin GPS 76 provides 1 megabyte of internal user memory to be used for storing waypoint information. Data processing has been done with the help of MAP SOURCE, ARC GIS-9, ARCVIEW 3.2a and SPSS-10 software. The cross-sections are prepared through waypoint location and altitude. The distance between waypoints has been calculated with the help of ARC VIEW GIS 3.2a software. The altitude calculated by Garmin GPS 76 is 14m less than the benchmark located at the Birdghat G/D site. Thus, during the data processing 14m units have been added to the altitude calculated through GPS 76.

Cross-section from Nausar to the Rapti river has been drawn by plotting the cumulative distance from Nausar to the Rapti on x-axis and altitude on y-axis. The total length of the cross-section is 1869.32 m (Table 5.1). The area plotted on the graph was fully submerged during 1998 flood. The altitude of embankments (1and 2) is quite low relative to the maximum water level of 77.54 m recorded on 23/08/1998 at Birdghat G/D site. Embankment-1 was cut due to the high water pressure and flow as a result a natural lake was made to the left side of NH29 (Map 5.3 and Plate 1 to 5). Flood plain zone i.e., Flood way has been marked on the cross-section by plotting the water level. The altitude of embankment-2 is quite low relative to the danger and warning level while the altitude of embankment-1, which protects the Nausar village, is quite high relative to danger and warning level (Fig.5.2).



CROSS-SECTION FROM NAUSAR TO RAPTI RIVER
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Altitude (in metre)
Embankment 1
Nausar
Davhiya
Sand Deposition
Embankment 2
Scrub Land
Guava Orchard
Agricultural Field
Agricultural Field
River Rapti
FLOOD WAY
0
56.8
220
531
671
769
861
1015
1156
1186
1260
1342
1381
1469
1573
1671
1747
1799
1834
1856
1867
Cumulative distance from Nausar (in metre)
Cross-section
HFL (77.54 m on 23/8/98)
DL (74.98 m)
WL (73.98m)

Figure 5.2


83°20' E
83°21' E
CROSS-SECTION FROM NAUSAR TO RAPTI RIVER
N
Khajani Road
NH 28
NH 29
Nausar
Davhiya
26°44'
26°44' N
26°43'
26°43' N
LEGEND
Agricultural Field
Built-up Area
Orchard
Water body
Road
Cross-section Stretch
Embankment
River Rapti
600 0 600 Meters
83°20'
83°21'

Map 5.3

Table 5.1: GPS Data from Nausar Village to the Rapti River

Way point	Date	Time	Lat.	Long.	Distance (m)	Cumulative Distance	Altitude (m)
1	22-Dec-04	14:19	N26.72810	E83.33527	0	0	71.62
2	22-Dec-04	14:19	N26.72793	E83.33547	28.36	28.36	71.62
3	22-Dec-04	14:18	N26.72782	E83.33556	15.64	44	73.45
4	22-Dec-04	14:18	N26.72774	E83.33565	12.83	56.83	73.15
5	22-Dec-04	14:18	N26.72761	E83.33584	24.22	81.05	75.59
6	22-Dec-04	13:09	N26.72707	E83.33611	67.45	148.5	66.13
7	22-Dec-04	13:10	N26.72643	E83.33619	71.6	219.6	64.91
8	22-Dec-04	13:11	N26.72571	E83.33664	91.69	311.29	65.22
9	22-Dec-04	13:12	N26.72535	E83.33690	48.17	359.46	64.91
10	22-Dec-04	13:14	N26.72403	E83.33781	171.8	531.26	66.13
11	22-Dec-04	13:14	N26.72377	E83.33809	40.97	572.23	68.88
12	22-Dec-04	13:17	N26.72330	E83.33865	75.92	648.15	69.00
13	22-Dec-04	13:18	N26.72345	E83.33880	22.63	670.78	68.00
14	22-Dec-04	13:18	N26.72334	E83.33908	31.04	701.82	67.00
15	22-Dec-04	13:18	N26.72310	E83.33928	33.22	735.04	68.00
16	22-Dec-04	13:19	N26.72288	E83.33951	33.9	768.94	69.00
17	22-Dec-04	13:19	N26.72271	E83.33961	20.93	789.87	68.00
18	22-Dec-04	13:20	N26.72236	E83.33980	43.12	832.99	67.05
19	22-Dec-04	13:21	N26.72221	E83.34003	27.89	860.88	63.09
20	22-Dec-04	13:21	N26.72204	E83.34019	25.48	886.36	62.78
21	22-Dec-04	13:22	N26.72154	E83.34076	79.03	965.39	63.39
22	22-Dec-04	13:23	N26.72124	E83.34113	50	1015.39	64.00
23	22-Dec-04	13:24	N26.72096	E83.34149	46.96	1062.35	64.00
24	22-Dec-04	13:24	N26.72074	E83.34187	45.63	1107.98	64.00
25	22-Dec-04	13:25	N26.72043	E83.34221	48.21	1156.19	64.61
26	22-Dec-04	13:25	N26.72031	E83.34239	21.11	1177.3	64.61
27	22-Dec-04	13:26	N26.72026	E83.34241	5.85	1183.15	66.74
28	22-Dec-04	13:26	N26.72024	E83.34243	2.92	1186.07	66.44
29	22-Dec-04	13:26	N26.72021	E83.34247	5.24	1191.31	66.13
30	22-Dec-04	13:27	N26.71988	E83.34291	57.17	1248.48	66.13
31	22-Dec-04	13:27	N26.71984	E83.34301	11.1	1259.58	68.88
32	22-Dec-04	13:28	N26.71943	E83.34297	45.54	1305.12	67.96
33	22-Dec-04	13:28	N26.71926	E83.34314	25.44	1330.56	65.83
34	22-Dec-04	13:29	N26.71924	E83.34325	11	1341.56	65.22
35	22-Dec-04	13:29	N26.71921	E83.34336	11.54	1353.1	64.00
36	22-Dec-04	13:29	N26.71919	E83.34344	8.32	1361.42	63.39
37	22-Dec-04	13:29	N26.71915	E83.34363	19.57	1380.99	64.00
38	22-Dec-04	13:29	N26.71913	E83.34374	11.08	1392.07	63.70
39	22-Dec-04	13:30	N26.71906	E83.34409	35.72	1427.79	64.00
40	22-Dec-04	13:30	N26.71892	E83.34448	41.66	1469.45	64.91
41	22-Dec-04	13:31	N26.71881	E83.34470	25.36	1494.81	64.91
42	22-Dec-04	13:31	N26.71870	E83.34504	35.87	1530.68	65.22
43	22-Dec-04	13:32	N26.71860	E83.34545	42.4	1573.08	64.30
44	22-Dec-04	13:32	N26.71856	E83.34573	28.07	1601.15	64.30
45	22-Dec-04	13:32	N26.71848	E83.34608	36.07	1637.22	64.61
46	22-Dec-04	13:33	N26.71843	E83.34642	34.27	1671.49	64.00
47	22-Dec-04	13:33	N26.718[illegible]	E83.34671	29.09	1700.58	63.70
48	22-Dec-04	13:34	N26.71833	E83.34698	27.07	1727.65	64.30
49	22-Dec-04	13:34	N26.71834	E83.34717	18.99	1746.64	63.70
50	22-Dec-04	13:34	N26.71828	E83.34738	21.85	1768.49	64.00
51	22-Dec-04	13:34	N26.71824	E83.34752	15.14	1783.63	64.30
52	22-Dec-04	13:34	N26.71822	E83.34768	15.61	1799.24	64.91
53	22-Dec-04	13:35	N26.71822	E83.34780	12	1811.24	64.30
54	22-Dec-04	13:35	N26.71819	E83.34790	10.7	1821.94	64.00
55	22-Dec-04	13:35	N26.71816	E83.34802	12.28	1834.22	64.61
56	22-Dec-04	13:35	N26.71813	E83.34813	11.73	1845.95	64.61
57	22-Dec-04	13:35	N26.71812	E83.34817	4.25	1850.2	64.30
58	22-Dec-04	13:35	N26.71811	E83.34823	6.28	1856.48	64.61
59	22-Dec-04	13:35	N26.71807	E83.34828	6.58	1863.06	64.30
60	22-Dec-04	13:35	N26.71805	E83.34829	2.37	1865.43	64.00
61	22-Dec-04	13:36	N26.71804	E83.34831	1.95	1867.38	63.09
62	22-Dec-04	13:36	N26.71803	E83.34832	1.94	1869.32	62.17

Source: Collected by author through Garmin GPS-76 during field survey.

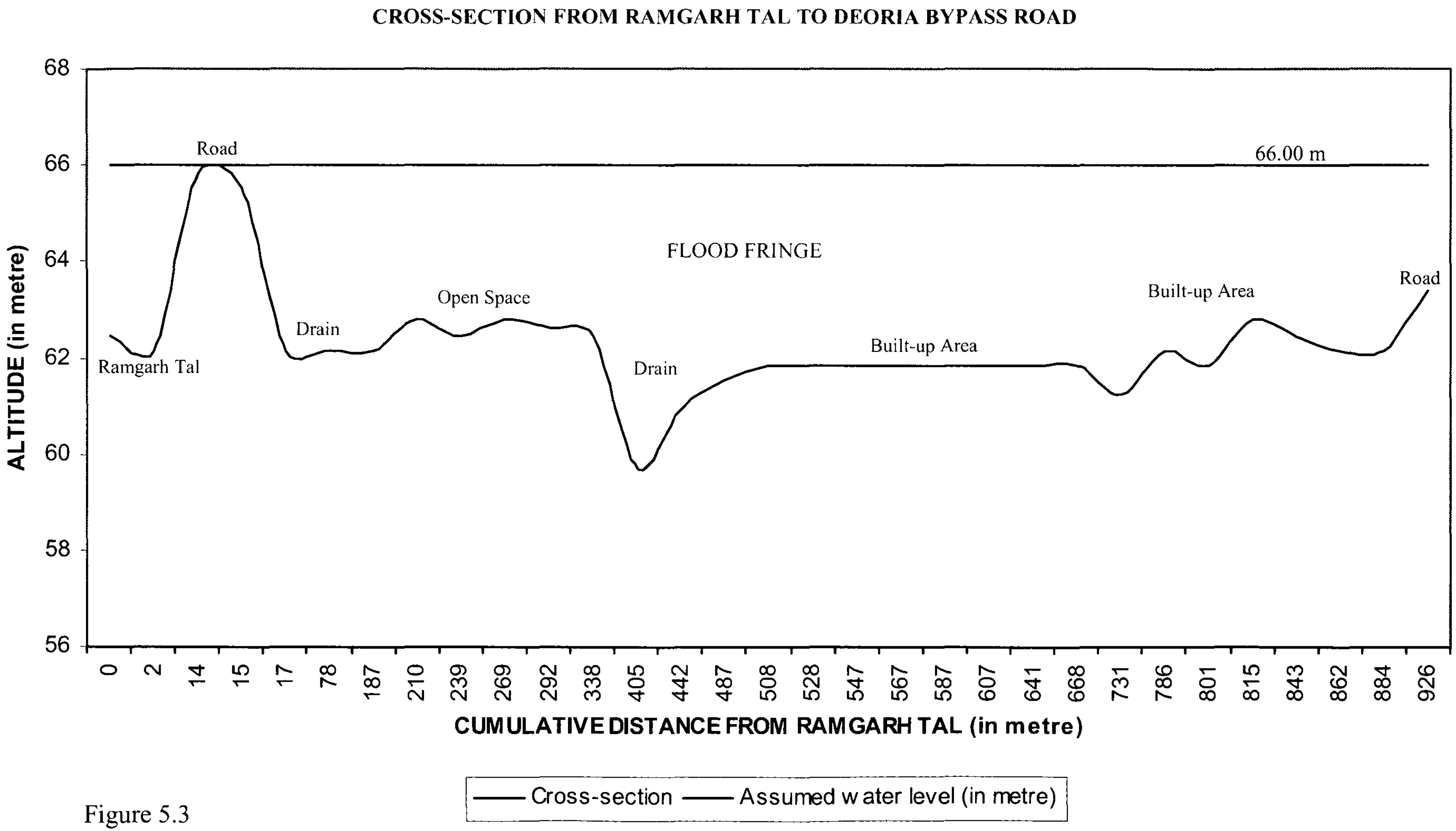
Thus, cross-section stretch from the Rapti river to embankment-1 is frequently flooded from 1986 to 1999. Nausar village, which is located in flood fringe zone, has experienced floods in 1974 and 1998. Davhiya village, which is located in flood way, experiences damage due to floods every year. Therefore, relocation of Davhiya village either horizontally or vertically is necessary. The sand deposited on the agricultural field is still visible near Davhiya village that is confined between two embankments (1 and 2). The area between embankment and the Rapti river is covered with scrub and guava orchard.

Another cross- section has been constructed from Ramgarh *Tal* to Deoria bypass road. The total length of this cross-section is 925.95 m (Table 5.2). Open space with Scrub is mostly located near the Ramgarh tal. The open space with scrub has been raised by the filling. The built- up area is 528m to 926m away from Ramgarh *Tal* in the west direction (Map 5.4 and Fig.5.3). The altitude near the built-up area is 61.87m that is quite low relative to the Ramgarh *Tal* level (62.17m) Thus, area along the Ramgarh *Tal* is highly flood prone due to back water effect of *Tal* and the Gaura river and water logging during monsoon season as mentioned by the dwellers. If the water level rose up to 66m the whole area will be flooded. This situation happened in 1998-flood season. Therefore, restriction on high value land use such as, built-up area and public utilities is necessary (Plate 6 to 7).

Table 5.2: GPS Data from Ramgarh *Tal* to Deoria Bypass Road

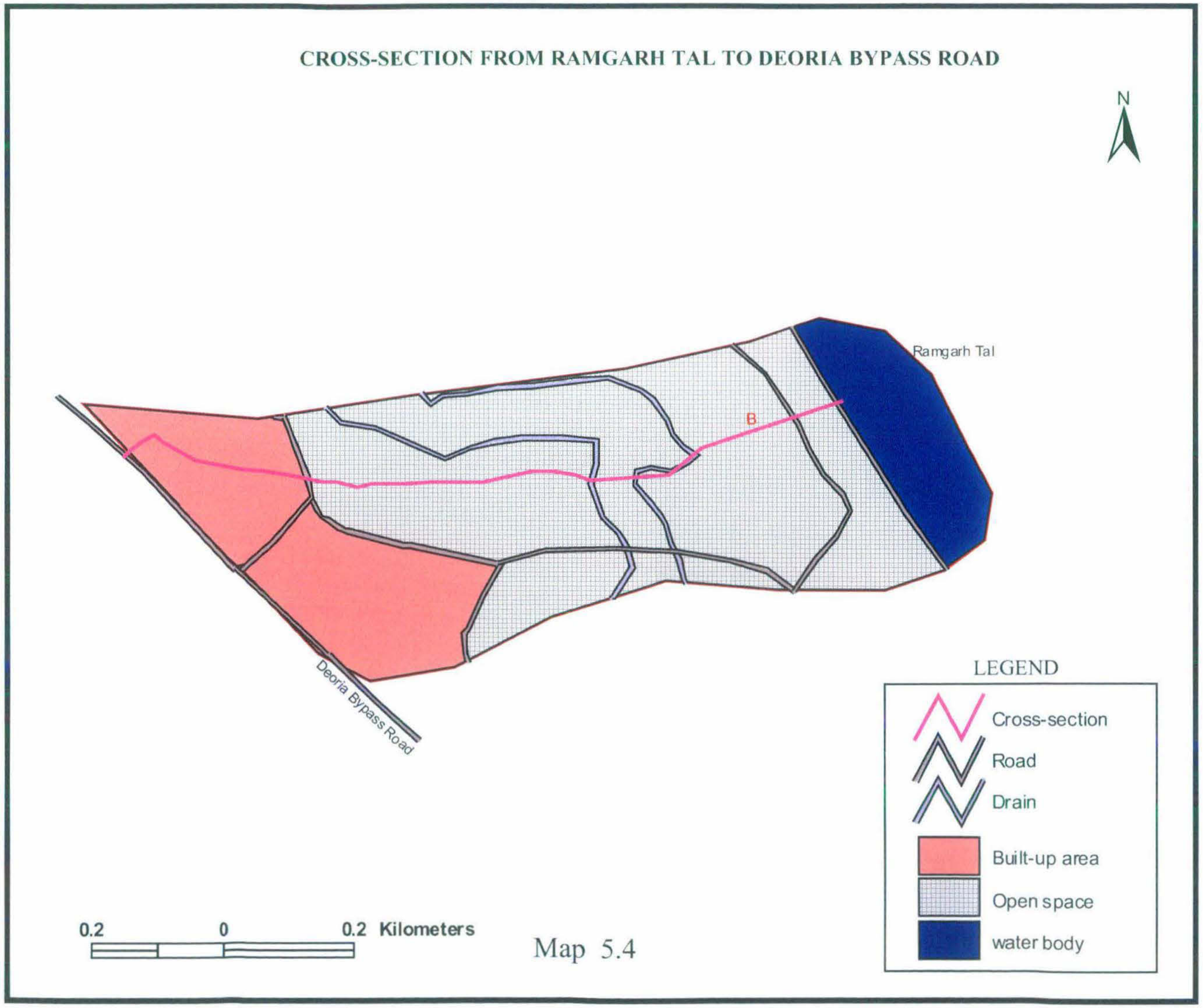
Way point	Date	Time	Lat.	Long.	Distance (m)	Cummulative Distance	Altitude (m)
1	23-Dec-04	12:30	N26.72688	E83.39508	0	0	62.48
2	23-Dec-04	12:32	N26.72688	E83.39506	1.98	1.98	62.17
3	23-Dec-04	12:33	N26.72682	E83.39496	12.02	14	65.83
4	23-Dec-04	12:33	N26.72682	E83.39495	1.01	15.01	65.52
5	23-Dec-04	12:35	N26.72680	E83.39496	2.42	17.43	62.17
6	23-Dec-04	12:35	N26.72644	E83.39451	60.57	78	62.16
7	23-Dec-04	12:36	N26.72636	E83.39342	108.59	186.59	62.17
8	23-Dec-04	12:36	N26.72643	E83.39320	23.38	209.97	62.78
9	23-Dec-04	12:36	N26.72647	E83.39291	29.04	239.01	62.48
10	23-Dec-04	12:36	N26.72648	E83.39261	29.81	268.82	62.78
11	23-Dec-04	12:39	N26.72645	E83.39238	22.88	291.7	62.63
12	23-Dec-04	12:39	N26.72630	E83.39195	45.88	337.58	62.48
13	23-Dec-04	12:39	N26.72634	E83.39128	67.32	404.9	59.73
14	23-Dec-04	12:39	N26.72630	E83.39090	37.54	442.44	60.95
15	23-Dec-04	12:40	N26.72629	E83.39045	45.02	487.46	61.56
16	23-Dec-04	12:40	N26.72628	E83.39024	20.73	508.19	61.87
17	23-Dec-04	12:40	N26.72630	E83.39004	20.03	528.22	61.87
18	23-Dec-04	12:40	N26.72633	E83.38986	18.47	546.69	61.87
19	23-Dec-04	12:40	N26.72636	E83.38965	20.79	567.48	61.87
20	23-Dec-04	12:40	N26.72638	E83.38946	19.34	586.82	61.87
21	23-Dec-04	12:40	N26.72642	E83.38926	20.56	607.38	61.87
22	23-Dec-04	12:40	N26.72648	E83.38893	33.66	641.04	61.87
23	23-Dec-04	12:40	N26.72652	E83.38866	26.92	667.96	61.87
24	23-Dec-04	12:40	N26.72663	E83.38804	62.68	730.64	61.26
25	23-Dec-04	12:40	N26.72689	E83.38757	55.08	785.72	62.17
26	23-Dec-04	12:40	N26.72696	E83.38744	14.99	800.71	61.87
27	23-Dec-04	12:41	N26.72691	E83.38731	14.46	815.17	62.78
28	23-Dec-04	12:41	N26.72673	E83.38711	28.17	843.34	62.48
29	23-Dec-04	12:41	N26.72662	E83.38696	18.9	862.24	62.17
30	23-Dec-04	12:41	N26.72649	E83.38680	22.01	884.25	62.17
31	23-Dec-04	12:41	N26.72623	E83.38650	41.7	925.95	63.39

Source: Collected by author through Garmin GPS-76 during field survey.



CROSS-SECTION FROM RAMGARH TAL TO DEORIA BYPASS ROAD
ALTITUDE (in metre)
68
66
64
62
60
58
56
Road
66.00 m
FLOOD FRINGE
Open Space
Road
Built-up Area
Drain
Ramgarh Tal
Drain
Built-up Area
0
2
14
15
17
78
187
210
239
269
292
338
405
442
487
508
528
547
567
587
607
641
668
731
786
801
815
843
862
884
926
CUMULATIVE DISTANCE FROM RAMGARH TAL (in metre)
Cross-section
Assumed water level (in metre)

Figure 5.3


CROSS-SECTION FROM RAMGARH TAL TO DEORIA BYPASS ROAD
N
Ramgarh Tal
B
Deoria Bypass Road
LEGEND
Cross-section
Road
Drain
Built-up area
Open space
water body
0.2
0
0.2 Kilometers

Map 5.4

5.3.3 Selection of Paddy Varieties During Flood

Though the requirement of water is crucial for the growth of paddy but the excess of water retards the growth of paddy plant. It has been found that after crossing a limit, the stagnant water strives to certain diseases. On the basis of available soil, means of irrigation and flood depth, the following varieties of paddy should be selected in flood affected area for the high production of paddy.

a. Cross 116, T-110, Jal-Lakshmi, and Masuri paddy varieties are suitable for low-lying area where the flood depth remains between 30 cm and 45cm.
b. Chakiya-59 paddy variety is suitable for waterlogged area where flood depth remains between 45 cm to 120 cm.
c. Jalnidhi, Jalpriya, and Jalmagan paddy varieties are suitable for an area where the flood depth remains above 120cm.
d. Madhukar paddy variety is suitable for flood prone area.

If an area is flooded in last week of August, paddy varieties like Saket-4, Narendra-118, Narendra-80 and 97, and Pant-12 should be transplanted in the month of June in order to minimize the damage to paddy because these paddy varieties take hardly three months to harvest[7]. As it is mentioned in Table 4.4 in chapter IV that maximum flood in lower Rapti river occurs during the middle and last week of August. Therefore, aforesaid varieties of paddy seem to be most suitable for the cultivation in the lower Rapti river basin.

When flood completely retreats from the agricultural fields, the mustard varieties like TA-9, Bawani, PT-303, 30 and 507 should be sown in order to compensate the flood damages to the *Kharif* crops.

5.3.4 Flood Proofing

This is a means of protecting individual structures from the effects of flooding. There are five basic approaches to flood proofing[8]:

a. Relocation: moving away from the flood prone area.
b. Elevation: raising the building above the flood level, either on piles or on a mound.

c. Flood walls: concrete or steel walls to keep the flood out.
d. Dry flood proofing: making the building water tight.
e. Wet proofing: allowing the basement and ground floor to flood while keeping the habitable portion of the building above flood level.

The flood proofing measures such as, raising of flood-prone villages above a predetermined flood level and connecting them to nearby roads and embankments have taken in the lower Rapti river basin.

5.4 Disaster Preparedness

Disaster preparedness is designed to minimize loss of life and damage to property and to organize and facilitate timely and effective rescue, relief and rehabilitation. Disaster preparedness can be classified into three categories: actions before, during and after the flood[9].

5.4.1 Pre-Flood Arrangement

1. Convening a meeting of the district Level Committee on Natural Calamities, 2. Functioning of the Control Rooms, 3. Closure of past breaches in river and canal embankments and guarding of weak points, 4. Rain recording and submission of rainfall reports, 5. Communication of gauge readings and preparation of maps and charts, 6. Dissemination of weather reports and flood bulletins issued by meteorological centers. CWC and Flood Forecasting organization, 7. Deployment of boats at strategic points, 8. Use of power boats, 9. Installation of temporary Police Wireless Stations and Temporary Telephones in flood-prone areas, 10. Arrangement for keeping Telephone and Telegraph lines in order, 11. Storage of food in interior, vulnerable strategic and key areas, 12. Arrangements dry foodstuff and other necessities of life, 13. Arrangement for keeping the drainage system desilted and properly maintained, 14. Agricultural measures, 15. Health measures, 16. Veterinary measures, 17. Selection of flood shelters, 18. Advance arrangements for army assistance, 19. Training in flood relief work, 20. Organisation of relief parties, 21. Other precautionary measures, and 22. Alternative drinking water supply arrangements.

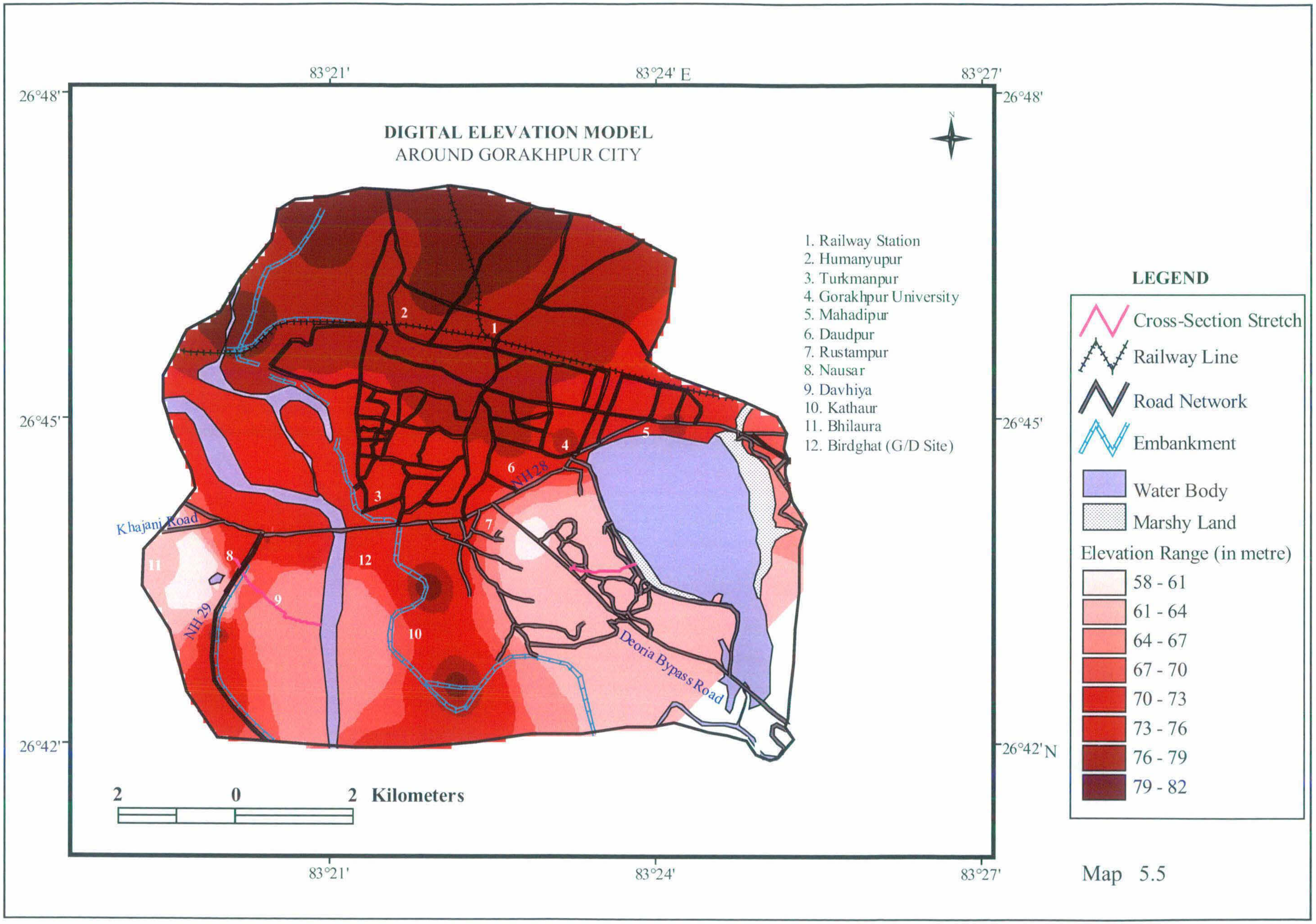
5.4.2 Arrangements During and After Floods

1. Organising shelter for people in distress in case the efforts of the civil authorities are considered inadequate, army assistance should be requisitioned, 2. Relief measures by non-official and voluntary organizations may be enlisted as far as possible, 3. Arrangements of relief camps, 4. Provision of basic amenities like drinking water, sanitation and public health care and arrangements of cooked food in the relief camps, 5. Making necessary arrangements for air dropping of food packets in the marooned villages through helicopters, 6. Organising enough relief parties to the rescue of the marooned people within a reasonable time limit, 7. Establishing alternative communication links to have effective communication with marooned areas, 8. Organising controlled kitchens to supply foods initially at least for 3 days, 9. Organising cattle camps, if necessary, and provide veterinary care, fodder and cattle feed for the affected animals, 10. Grant for emergency relief to all the affected people, 11. Submission of daily reports and dissemination of correct information through mass media to avoid rumours, 12. Rehabilitation of homeless people, 13. Commencement of agricultural activities such as desiltation, resowing etc, 14. Repair and reconstruction of infrastructure facilities such as roads, embankments, resettlement of flood prone areas and 15. Health measures.

5.5 Human Responses to Flood Based on the Short Field Survey

A fields survey was conducted during 19-24th December 2004 in Gorakhpur city and in the nearby villages. Some of the people who were affected by floods in the year 1998 were interviewed. The gauge and discharge site at Birdghat was visited and observations were made along the left embamnkment of the Rapti river for a distance of 10 Km from NH28 to Kathaur village. Bhilaura, Kathaur, Nausar, and Davhiya villages were visited (Map 5.5). The results are summarized below.

Mr. S.N. Pandey, the owner of the petrol pump located near Habird Bridge, was interviewed. The floods in 1998 was so severe that he vividly remembered the havoc caused by floods. Water came to the petrol pump on 21st August and the water depth was 6-8 inches. After two days i.e., on 23rd August the water level raised and the depth of water became 1m. At that time, this petrol pump was 1.5 m below the NH28. Water also rose from the ground with such a force that the under ground petrol tanks were lifted and



83°21'
83°24' E
83°27'
26°48'
26°45'
26°42'
26°42' N
83°24'
DIGITAL ELEVATION MODEL
AROUND GORAKHPUR CITY
N
1. Railway Station
2. Humanyupur
3. Turkmanpur
4. Gorakhpur University
5. Mahadipur
6. Daudpur
7. Rustampur
8. Nausar
9. Davhiya
10. Kathaur
11. Bhilaura
12. Birdghat (G/D Site)
Khajani Road
NH 28
NH 29
Deoria Bypass Road
2 0 2 Kilometers
LEGEND
Cross-Section Stretch
Railway Line
Road Network
Embankment
Water Body
Marshy Land
Elevation Range (in metre)
58 - 61
61 - 64
64 - 67
67 - 70
70 - 73
73 - 76
76 - 79
79 - 82

Map 5.5

shifted 100m. As a result, the petrol pump was closed for four months (Plate 8). There was no transport at NH28 for two months. Gorakhpur city is just like a bowl where the water is collected in short time. The breach in NH28 nearby Nausar circle and the backwater from the Ramgarh *Tal* aggravated the flood situation. The air force station nearby Mohadipur was threatened. The villages Bhilaura, Nausar, Bichhora, Harraiya, Kathaur, Ekla etc and Rustampur area of Gorakhpur city were severely affected by the floods.

The agricultural lands were filled by sand and silt as a result, there was a lot of damage to the Kharif crops. Flood theft was practiced in all the flood-affected wards of Gorakhpur. Sickness due to impure water spread in flood affected areas. The most common diseases were diarrhea, jaundice and so on.

Mr. Pandey elaborated the causal factors of the breaches in embankments. One of the most important factor is the rat holes. There is no provision for *Gumti*, temporary shop and settlements along the embankments. Shops and settlements on the embankments are the main cause for the formation of rat hole as a result there is seepage from these holes during the flood season weakening the embankments (Plate 9).

Bhilaura Village is located along Khajani Road. The water depth in the agricultural field as well as in village was 4 to 5 feet. A shop owner showed the mark on the wall of his shop left by the floodwaters. Crops were destroyed due to the deposition of sand and silt in the agricultural fields. Structural changes were incorporated in house design. The foundation of recently constructed houses has been raised by 2 to 3 feet above the 1998 flood level. One of the villagers told that the 1998 flood is more severe than the 1974 flood. The maximum water level of River Rapti at Birdghat was 76.84 m on 09/08/1974 while it was 77.54 m on 23/8/1998. Thus, it was 70 cm above from the previous level of 1974.

The sand was subsequently removed from the agricultural lands for construction work. Crops *(Rabi and Kharif)* are growing in the flood-affected lands. According to the villagers, Gorakhapur Industrial development Authority (GIDA) is acquiring the agricultural land of village in order to develop an industrial complex. So, the villagers are protesting against GIDA.

Observations along the left embankment were made from NH28 to Kathaur Village. This embankment is motorable. Guava orchards are still there and some new cement buildings are being constructed. Agricultural fields are also located in between embankment and riverbank. The left embankment is the dumping site for the garbage that will increase the pollution level in the river during monsoon season.

Observations along the right side of the embankment were also made. The density of the cement buildings is very high compared to the buildings along the left side of the embankment. This is due to the fact that the buildings along the right side are protected by the embankment. There was no water on the embankment during 1998 flood. The flood was 1.5 feet below from the embankment. However, there was seepage from the embankment during the high flood of 1998.Villagers of Kathaur village revealed the fact that bank erosion along the Rapti river is due to array flow of water in the river that is generated by the Habird bridge. Another new bridge is now under construction to minimize the heavy traffic. But this new bridge will increase bank erosion down stream in the monsoon period (Plate 10).

Nausar village is protected by the ring of embankments. The condition of the embankment is not good because there is rat hole and human induced cuttings. There is no restriction on land use in the flood plain of Rapti river. The scattered settlements mainly huts are located in the agricultural field. There was massive damage to crop during the 1998 flood due to sand casting in the agricultural fields. The cement buildings that are protected by the embankment have high foundation near about 4 feet form the ground. The Rapti river is shifting towards west and has engulfed many agricultural fields.

The area along the Ramgarh *Tal* has been developed for the construction of new buildings. A new road has been constructed along the western edge of *Tal*. The relative height of this road is 4 m. The winter rice fields are located nearby *Tal*. The area that is developing near Ramgarh *Tal* is highly flood prone. This is because of the backwater effect of Ramgarh *Tal* and the Gaura river in the monsoon period. Mohadipur area that is located nearby this *Tal* was severely affected during 1998 flood.

5.6 Conclusion

Structural measure i.e., embankments is practiced for the flood management in the lower Rapti river basin. Rat holes and human induced cuttings are responsible for breaches in the embankments during peak flow. Afforestation in mountain and *Tarai* region of Nepal and plain region of Eastern Uttar Pradesh is necessary to retard the over land flow and also to reduce the siltation in riverbeds. Construction of layered well, sediment detention basin, dams and reservoirs in *Tarai* regions of Nepal and Eastern Uttar Pradesh can be also very effective structural measures for flood control. There is no restriction on land use in flood prone area. Structural changes have incorporated in house design. The foundation of recently constructed houses has been raised by 2 to 3 feet above the 1998 flood level. Non-structural measures, if implemented efficiently, can be very effective for flood management. The dissemination of flood forecast from Nepal to India should be encouraged in order to make flood warning in proper time. Flood booth should be established for a group of six or seven flood prone villages in order to disseminate the flood forecast and warning during flood season. This can minimize the flood damage. The perception of the people on flood management is discussed in the following steps.

According to the villagers the causes of floods in the area are: 1. Natural water drainage routes blocking of embankments results in water logging, 2. The people are affected by water logging as well as by land acquisition by GIDA for industrial development, 3. The building of embankments is a recent idea, without taking into consideration the local geographic situations of lesser slope etc. At high floods embankments aggravate the flood problem. 4. Lower water holding capacity of mud embankments is not properly assessed, 5. Water from Nepal is also responsible for flood havoc.

Suggestions for the mitigation of floods as mentioned by villagers are: 1.Raising the height of embankments, 2. Making *'Pucca'* embankments only as a last option and where there is no other means to solve problem 3. Desiltation of riverbeds from time to time, 4. Planning for the new embankments only after proper site analysis, 5.Farmers need training in utilization of wasteland and new seed varieties appropriate for this new barren land, 6. It is important to conduct discussions on the catchment treatment with

Nepal as the Rapti originates in Nepal, 7. Flood forecast and the warning system are to be strengthened, 8. Long term planning keeping in mind the proper selection of crops and land use will also help, 9. Making of appropriate drainage schemes is absolutely essential, 10. Construction of a network of institutions such as schools, hospitals etc. at elevated places, which can be used for shelter during floods.

References

1. Sivasami, K.S., (2002), " Environmental Effect due to Floods and Reservoirs", in *Environmental Hazards in South Asia* edited by V. Subramanian, Capital Publishing Company, New Delhi, pp. 65-82.
2. Thapa, A.B., (2003), " West Rapti High Dam Project," *Spot Light,* Vol.22 No. 47, June 06, pp...
3. Shahi, Y.B., (2004), *A Study on Nepalese Territory,* A Master's Degree Dissertation submitted to the Department of Geography Education, Tribhuvan University, Kiritipur, Kathmandu, Nepal, pp.118-119.
4. Dogra, B., (1997), " More floods with Flood Control", *Economic and Political Weekly,* Vol. 32, No. 18, May 3, pp. 933-34.
5. *Flood Report of Gorakhpur District*, 2001, p.32.
6. *"Flood plain Zoning",* Pamphlet No. 1/96, December, 1996, CWC, New Delhi.
7. *Flood Report of Gorakhpur District, op., cit.,* p. 87.
8. Miller, John B., (1997), *Floods: People at Risk, Strategies for Prevention,* United Nations Publication, New York, pp. 78-80.
9. *Flood Report of Gorakhpur District, op., cit.,* pp. 50-90.

Chapter Six

Summary and Conclusion

Summary and Conclusion

Lower Rapti river basin is frequently affected by floods. The major rivers such as, the Rapti, the Burhi Rapti, the Rohini and the Ami that drain the basin, year after year bring untold miseries to the people. Most of flood waves occur in middle or end of August. They are characterized by large magnitude and extensive devastation. The susceptibility of flood in the basin varies from upstream to downstream. The susceptibility of flood at downstream site, Birdghat (Gorakhpur) is higher than the upstream site, Bhinga.

The following conclusions have drawn from the present study.

The Rapti river is the master stream of the basin. It is a foot hill fed river. The upper part of the basin lies in the Siwalik of Nepal and it receives heavy rainfall as compared to the lower part (Eastern Uttar Pradesh). Most of its annual discharge is found in the monsoon season (June to October).

The most prominent features of the lower Rapti flood plain are ox-bow lakes, alternative channel bars, swamps or marshes, natural levee and anabranching streams. The presence of ox-bow lakes (perennial and ephemeral) and the anabranching stream signify the low surface gradient. The Rapti river is a typical meandering stream. Low surface gradient and backwater effect of the Ghaghara river make the Rapti river more sinuous in lower reaches (from Gorakhpur to Barhaj) than the upper reaches (from Balauha to Gorakhpur). The Rapti riverbed has become shallow due to siltation. Therefore, it also causes backwater effect into its tributaries i.e., the Rohini, the Ami, the Gaura and the Taraina.

The land use presents a typical scenario of subsistence economy in the basin where agriculture is predominant activity. Deforestation in the mountain and *Tarai* region of Nepal is the main cause of landslide and soil erosion resulting in siltation of riverbeds. A significant increase in very coarse, coarse and medium sand has been observed in 2001-monsoon season as compared to 1998-monsoon season through sediment size analysis. This signifies deforestation in upper reaches of the Rapti river basin. As a result, deforestation not only increased the run off but also the sediment load in the rivers, which gets deposited in the riverbed making them shallow as well as in agriculture fields converting them into barren land.

The built-up area is increasing at an alarming rate, as a result more and more rainfall enters into the river as overland flow. In this way, discharge increases down stream and makes the channel unstable. For instance, the Rapti river is shifting towards west down stream of Gorakhpur city due to excessive discharge and array flow generated by Habird bridge.

Floods in the basin are mainly caused by intense rainfall and further accentuated by geomorphological factors and human activities.

The monsoon season starts with a low amount of rainfall in the month of June and attains its peak in the months of July and August. The intense rainfall in the months of July and August causes flooding in the basin. The empirical relationship between the amount of rainfall and the associated weather systems indicates that clustering of synoptic weather systems, which were near to the basin area or prevailed over the basin, produced intense rainfall during 1998 monsoon season. Major synoptic systems, responsible for the floods in the basin are break monsoon situation, passage of monsoon trough through the basin and low pressure, which prevailed over the basin during 1998. One catastrophic weather system (monsoon trough located near the foothills of Himalayas) amongst the clustered synoptic weather systems was solely responsible for the unprecedented floods at Bansi and Gorakhpur during 1998 monsoon season.

The geomorphological factors that cause floods in the basin are breaks of slope, high sinuosity and very low surface gradient in the lower reaches and the backwater effect. Flooding in *Tarai* region is mainly caused by the breaks of slope. High sinuosity aggravates the flood situation because water takes much longer time to flow downstream. Shallowness of the Ghaghara river bed causes back water effect in its tributary i.e., the Rapti river. On the other hand, the shallowness of the Rapti riverbed causes backwater effect and flooding in its tributaries i.e., the Rohini, the Gaura, the Ami and the Taraina.

The haphazard construction of road in the flood prone area creates water logging and aggravates flood situation.

The flood damages to total area and cropped area are showing an increasing trend in Gorakhpur district. This indicates that more and more area other than agricultural land is affected by the floods.

Structural measure i.e., embankments is practiced for the flood management in the lower Rapti river basin. Rat holes and human induced cuttings are responsible for breaches in the embankments during peak flow. Afforestation in mountain and *Tarai* region of Nepal and plain region of Eastern Uttar Pradesh is necessary to retard the over land flow and also to reduce the siltation in riverbeds. Construction of layered well, sediment detention basin, dams and reservoirs in *Tarai* region of Nepal and Eastern Uttar Pradesh can also be very effective structural measures for flood control.

Non-structural measures, if implemented efficiently, can be very effective for flood management. Since, the flood crest occured at Balrampur generally takes 2 to 5 days to reach Birdghat G/D sites therefore, dissemination of flood forecast from upstream to downstream can minimize the flood damages.

There is no restriction on land use in flood prone area. As the built-up area is increasing in the flood prone area, proper land use planning is necessary to minimize the flood damages. Structural changes have incorporated in house design after 1998 floods. The foundation of recently constructed houses has been raised by 2 to 3 feet above the 1998 flood level.

Flood booth should be established for a group of six or seven flood prone villages in order to disseminate the flood forecast and warning during monsoon season. This measure can also minimize the flood damages at a great extent.

Some of the important remedial measures are suggested for the betterment of people living in the basin. They are as follows:

1. Since the basin area is very large, construction of embankments and their proper maintenance (before and after the flood) is necessary to combat the floods. Maintenance of embankment should be encouraged by people's participation. *Shramdan* camp may be arranged through National Service Scheme, roping in the school and college students during summer vacations. Construction of dams, reservoirs, sediment detention basin (in the *Tarai* region of Nepal and Eastern Uttar Pradesh) and soil conservation measures help in reducing the magnitude of floods and make the embankment durable for a long time by reducing sand and silt.

2. Bilateral talk on the catchment treatment and flood management between India and Nepal will also help in reducing the adverse consequences of floods in both countries since the Rapti river originates in Nepal.
3. Flood plain zone mapping through multi-dated satellite imageries, topographical sheets (1:15000, with 0.3 to 0.5 m contour interval) and GPS should be taken into the consideration in order to regulate the land use in flood prone area.
4. Dissemination of flood forecast in flood prone villages at real time should be encouraged in order to evacuate the villages before the advent of flood.
5. Afforestation in mountain, *Tarai* and *Usar* zones of the plain region is necessary to reduce the soil erosion and siltation in the riverbed.
6. Desiltation of riverbed from time to time is necessary for easy flow during monsoon season.
7. Research on the seed varieties, which can be suitable for the sand filled agricultural lands.
8. Selection of paddy varieties on the basis of water depth is necessary for agricultural adjustments in the flood prone areas.
9. Proper maintenance of drains in urban areas should be taken into the consideration before monsoon season.

BIBLIOGRAPHY

Bibliography

1. Abdul Kalam, A.P.J., (2005), "Integrated Water Mission", *Yojana,* Vol.49, June, pp.2-5.
2. Ahrens, C. D., (2003), *Meteorology Today: An Introduction to Weather, Climate and the Environment,* Thomson Brooks/Cole, Australia.
3. Anbazhagan, S., and Dash, P., (2003), "Environmental Case Study of Cauvery river flood plain", *GIS Development,* December, pp. 1-9.
4. Ansari, J.H., (2001), "Land use Planning for Disaster mitigation in Flood prone areas", *Spatio-Economic Development Record,* Vol.8, No.1, January- February, pp.32-37.
5. Apte, N.Y., Das, A.K., and Ram, L.C., (1993), "Study of Temporal Distribution of Rainstorms for Flood Forecasting, *Mausam*, Vol.44, No.1, January, pp.104-107.
6. Beven, K. and Carling, P., (ed.), (1989), *Floods: Hydrological, Sedimentological and Geomorphological Implications,* John Wiley and Sons, New York.
7. Bose, S.C., (1972), *Geography of Himalaya,* Thomson Press Limited, New Delhi-21, p.159.
8. Chorley, R.J., (ed.), (1969), *Water, Earth and Man: A Synthesis of Hydrology, Geomorphology and Socio-economic Geography,* Methuen & co. Ltd., London.
9. Chow, V.T., (1956), " Hydrological studies of floods in the United State" *International Association of Scientific Hydrology*, Vol 42, No...pp. 134-170.
10. Das, A.K., (2000), *Fluvial Processes in the Flood Plains of Subansiri river and their impact on Arable Land,* Unpublished Ph.D. Thesis, CSRD, JNU, New Delhi.
11. Das, P.K., (1968), *The Monsoon,* National Book Trust of India, New Delhi, pp. 53-55.
12. Davies, H.R.J., (1992), "The Khartoum Floods of 1988", *XII INCA Conference,* Nov. 4 - 8, Dept. of Geography, Jamia Millia Islamia, New Delhi, pp. 40-48.
13. De. Wiest, R.J.M., (1965), *Geohydrology*, John Wiley & Sons, New York, pp. 99-106.
14. Dhar, O.N., and Nandargi, S., (2003), "Flood Study of the Himalayan tributaries of the Ganga river", *Natural Hazards,* January, Vol.28, No.1, pp. 1-33.

15. Dhar, O.N., and Nandargi, S., (2003), "Hydrological Aspects of Floods in India", *Natural Hazards,* Vol. 28, No... pp. 7-9.

16. Dogra, B., (1997), " More flood with Flood Control", *Economic and Political Weekly,* Vol.32, No.18, May 3, pp.33-34.

17. *Draft Proposal of Task Force on Land use and Erosion Control,* National Planning Commission, Secretarial, Government of Nepal, August 1974.

18. *Flood forecasting and Warning network Performance Appraisal,* Central Water Commission, April 2000, New Delhi, pp. 36-37.

19. *Flood Plain Management in Australia: Best Practices and Guidelines,* Scram Report-73, CSIRO Publishing, Australia, pp. 13-23.

20. *"Floodplain Zoning",* Pamphlet No. 1/96, December, 1996, CWC, New Delhi.

21. *Flood Report of Gorakhpur district,* 2001, pp. 101-103.

22. *Floods Related Preparations in the Year 2004, What? And How?,* Irrigation Department, Uttar Pradesh, 2004, p.2.

23. Gardon, N.D., Mcmahon, T.A., & Finlayson, B. L., (1993), *River Hydrology,* John Wiley & Sons Ltd., U.K., pp.316-317.

24. Gregory, K.J., and Walling, D.E., (1973), *Drainage Basin Form and Processes: A Geomorphological Approach,* Edward Arnold, London.

25. Haq, K.M.F., and Bhuiyan, R.H., (2004), "Delineation and Zonation of Flood Prone Area: A Case Study of Tangail District, Bangladesh, *Indian Journal of Regional Science,* Vol. 36, No.1, pp.21-29.

26. Harsh, K., (2005), "Intzar Videshi Mehmano Ka", *India today,* February 14, pp. 52-53.

27. Jain, V., and Sinha, R., (2003), "River System in the Gangetic Plains and their Comparison with the Siwaliks", *Current Science,* Vol.84, No.825, April, pp.1025-33.

28. John, M., (1988), "Grain size determination and interpretation" in *Techniques in Sedimentology,* edited by Maurice Tucker, Blackwell Scientific Publication, London, pp. 67-68.

29. Jones, J.A.A., (1997), *Global Hydrology: Processes, Resources and Environment Management*, Addison Wesley Longman Limited, England, p.106.

30. Kale, V.S., (1999), "Long-period Fluctuation in Monsoon Floods in the Deccan Peninsula, India", *Journal Geological Society of India,* Vol. 53, January, pp. 5-15.

31. Kayastha, S.L. and Yadav, R.P., (1980), "Flood Hazard in Lower Ganga-Ghaghara Plain (U.P., India): A Study in Perception and Impact on Socio-economic Development", *National Geographical Journal of India,* Vol.26, Parts II & I, pp.19-28.

32. Kayastha, S.L., (1983), "Floods in India: A Study of their Occurrence, Causes, Forecasting and Control," *National Geographical Journal of India,* Vol. 29, Part 3 and 4, p.121.

33. Khan, I.A., Bridge, J.S., Kappelman, J and Wilson, R., (1997), *Sedimentology,* ....pp.221-251.

34. Knighton, D., (1998), *Fluvial From and Processes: A New Perspective,* Arnold, London, p. 236.

35. Kulshrestha, S.M., (2000), *Flood Management in India*, Joint COLA/CARE Technical Report No. 3, Centre for Ocean-Land-Atmosphere studies/ Centre for the Application of Research on the Environment, Maryland, pp....

36.Kumar, A., (1995), *Flood Control and Settlement Planning,* Mohit Publications, New Delhi, pp.78-84.

37. Kumar, A., and Ram, L.C., (1995), " Semi-Quantitative Precipitation Forecast for Rapti Catchment by Synoptic Analogue Method", *Mausam,* Vol. 46, No. 1, January, pp. 97-99.

38. Leopold, L. B., Wolman, M. G., and Miller, (1963), *Fluvial Geomorphology* .... p.281.

39. Leopold, L.B. and Wolman, M.G., (1957), " *River Channel Pattern: Braided, Meandering and Straight,* U.S. Geological Survey, Professional Paper, pp. 282-B.

40.Linsley, R. K., Kohler, M.A., and Paulhus, J.L.H., (.....), *Applied Hydrology,* McGraw-Hill Book Company, INC., New York, pp.630-655.

41. *Manual on Flood Forecasting, CWC, River Management Wing,* March 1989, New Delhi, p. 4.

42. Menon, P.A., (1989), *Our Weather*, National Book Trust of India, New Delhi, pp. 270-338.

43. Miller, John B., (1997), *Floods: People at Risk, Strategies for Prevention,* United Nations Publication, New York.

44. Mirza, M.M.Q., Warrick, R.A., and Ericksen, N.J., (2003), "The implication of Climate Change on Floods of the Ganges, Brahmaputra and Meghna rivers in Bangladesh, *Climate Change,* Vol.57, No.3, pp.287-318.

45. Mishra, D.K., (2001), "Living with Floods: People's Perspective", *Economic and Political Weekly,* Vol.36, No.29, July 21, pp.2756-2761.

46. Mishra, D.K., *Floods Despite Dams,* Barh Mukti Abhiyan, Bihar, pp.1-31.

47. Newson, M., (1992), *Land, Water and Development: River Basin System and their Sustainable management,* Routledge, London.

48. Niyogi, M., (1988), "Spatio-Temporal Analysis of Runoff in the Ajay Basin", *Geographical Review of India,* Vol.50, No.2, June, pp.58-66.

49. Parker, D.J., (ed.), (2000), *Floods*, Vol. I & II, Routledge, London.

50. Paul S.K., Bartarya, S.K., Rautela, P. and Mahajan, A.K., (2000): " Catastrophic mass movement of 1998 monsoons at Malpa in Kali Valley, Kumaun Himalaya, India, *Geomorphology*, Vol. 35 No...pp. 169-180.

51. Raman, V.A.V., (2003), *PhotoGeomorphological analysis of Fluviatile Depositional Surface: A study in Ganga and Brahmaputra Alluvial Plains,* Unpublished Ph.D. Thesis, submitted to the University of Delhi, p.66.

52. Rao, K.L., (1979), *India's Water Wealth, Orient* Longman Ltd., New Delhi.

53. Schumm, S.A., (1977), *The Fliuvial System,* John Wiley and Sons, Inc, New York.

54. Schumm, S.A., (1980), " Planform of Alluvial Rivers", *Proceeding of the International Workshop on Alluvial River Problems* held at Roorkee, India, p.4 -22.

55. Shahi, Y.B., (2004), *A Study on Nepalese Territory,* A Master's Degree Dissertation submitted to the Department of Geography Education, Tribhuvan University, Kiritipur, Kathmandu, Nepal, pp.118-119.

56. Sharma, K.D., Vangani, N.S., Chatterji, P.C. and Singh, G., (1982): " A severe flood in Luni Basin, western Rajasthan during July 1979- A case study, *Mausum,* Vol. 33, No... pp. 377-384.

57. Sharma, M.K., (2003), "Overview of Flood Management in India", *Indian Journal of Public Administration,* Vol. 59, No. 3, July-September, p.520.

58.Sharma, R.P., (1974), *Nepal: A Detailed Geographical Account*, Pustak Sagar, Bhotahity, Kathmandu, Nepal p.10.

59. Sharma, V.K., (1976), "Some Hydrological Characteristics of the Damodar river", *Geographical Review of India,* Vol. 38, No. 4, December, pp. 331-343.

60. Singh, L.R. and Singh, R., (1995), *Mapwork and Practical Geography,* Central Book Depot, Allahabad, pp.

61. Singh, R.L, (ed.), (1971), *India: A Regional Geography,* NGSI, 1971, Varanasi, p. 191.

62.Sinha, R. and Roy, N.G., (2005), "Alluvial Geomorphology and Confluence Dymnamics in the Gangetic Plains, Farrukhabad-Kannauj area, Uttar Pradesh, India", *Current Science*, Vol.88, No.12, 25 June, pp.2000-2006.

63. Sivasami, K.S., (2002), " Environmental effect due to Floods and Reservoirs" in *Environmental hazard in South Asia* edited by V. Subramanian, Capital Publishing Company, New Delhi, pp.65-82.

64. Statistical Year Book of Nepal, Central Bureau of Statistics, Kathmandu, Nepal, 2001-02.

65. Strahler, A., and Strahler, A., (2002), *Physical Geography,* John Willey & Sons (Asia), p. 711.

66. Sullivan, A., Ternan, J.L., and Williams, A.G., (2004), " Land use Change and Hydrological response in the Camel Catchment, Cornwall", *Applied Geography,* Vol. 24, No. 2, pp.119-136.

67. Thapa, AB, (2003), "West Rapti high Dam Project", *Spotlight,* Vol.22, No.47, June 06, pp……

68.Thapa, N.B., and Thapa, D.P., (1969), *Geography of Nepal,* Orient Longman, 1969, Calcutta, pp.13.

69.Thornbury, W.D., (1954), *Principles of Geomorphology,* Wiley Eastern Limited, New Delhi, pp.162-175.

70. Tiwari, K.M., (1984), "Measures to Control Floods in the Ganga Basin", *Indian Forest Records,* Vol.3, No.1, pp.1-12.

71. U.P. District Gazetteers, *Bahraich,* Govt. of U.P., 1988, p. 5.

72. U.P. District Gazetteers, *Basti,* Govt. of U.P., 1988, p. 9.

73. U.P. District Gazetteers, *Gonda,* Govt. of U.P., 1989, pp. 5-6.

74. U.P. District Gazetteers, *Gorakhpur,* Govt. of U.P., 1987, p. 4.

75. Urban, M.A., (2002), "Conceptualizing Anthropogenic Change in Fluvial System: Drainage Development on the Upper Embarras river, Illinois", *The Professional Geographer,* Vol.54, No.2, pp.204-217.

76. Verma, R., and Ram, L.C., (2001), " A Case study of Heavy Flood in River Ken during September 1992, *Mausam, Vol. 52, No. 3*, July, pp. 597-601.

77. Vijayasankar, P.S., and Shah, M., (1997), "Water Crisis in Dewas: Is Rainfall the Culprit?", *Economic and Political Weekly,* Vol. 32, No. 24, June14-20, pp.1416-1425.

78. Ward, R.C., (1978), *Floods: A Geographical Perspective*, Mcmillon, London, pp.324 - 325.

79. Willis, B.J., and Behrensmeyer, A.K., (1994), " ....", *Journal of Sediment Research*, B64, pp.60-67.

80. World Meteorological Organization (WMO), (1974), *WMO/UNENSO International Glossary of Hydrology*, WMO Publication No. 385, Geneva.

81. Yadav, H.R., and Yadav, H.L., (1998), "Hierarchy of Commercial Centres in Gorakhpur City", *National Geographical Journal of India*, Vol.44, No.1-4, p.19.

82. Yadav, R.P., (1999), *Floods in Eastern Uttar Pradesh*, Radha Publication, New Delhi, p.1.

83. Yevyevich, V., (1992), "Floods and Society", in *Coping with Floods*, edited by G. Ross, N. Harmancioglu and V. Yevyevich, NATOASI Series, Dordreecht, Kluwer, pp.3-9.

PLATES

Plate 1: Nausar village is protected by the embankment-1. Agricultural fields are visible in the foreground.

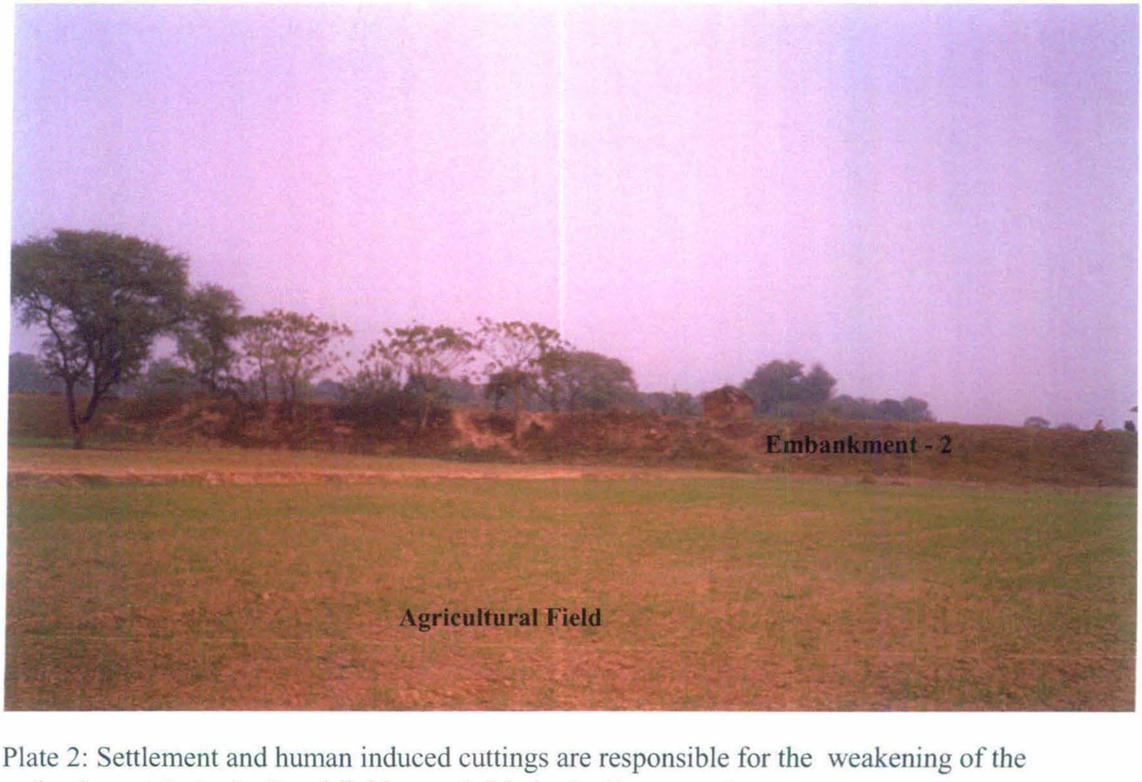


Plate 2: Settlement and human induced cuttings are responsible for the weakening of the embankment-2. Agricultural fields are visible in the foreground.

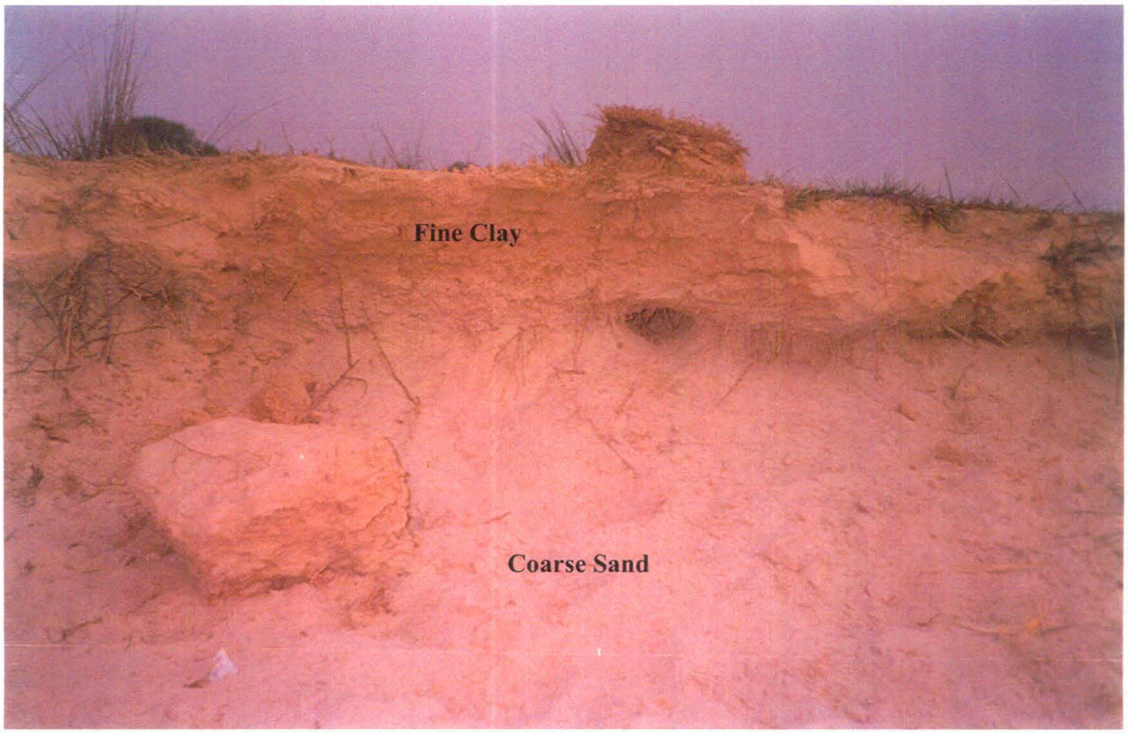


Plate 3: Sediment deposited in agricultural fields follow the Stoke's Law of sediment settling. Fine clay is visible on the top horizon while the coarse sand on the bottom.


Plate 4: Rat holes are responsible for the seepage and weakening of the embankment-2 during monsoon season.

Plate 5: Guava orchard located along the right bank of the Rapti river is visible in the background

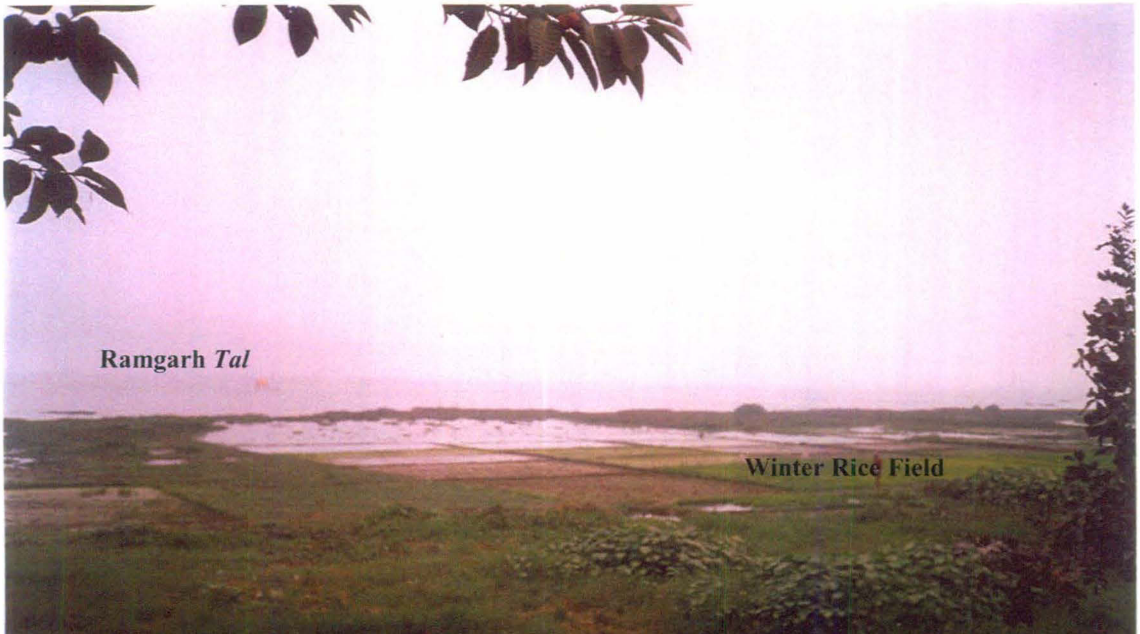


Plate 6: Winter rice fields are visible along the Ramgarh *Tal*.

Plate 7: Road along the Ramgarh *Tal* and open space with scrub are visible in the foreground while built-up area in the background.

Plate 8: Lifted petrol tanks show the severity of 1998 floods along NH 29. Natural *Tal* created due to flood is visible on the left.

Plate 9: Presence of *Gumati* (small shop) and households attract more rodent population, which burrow and weaken the embankment along the NH-28.

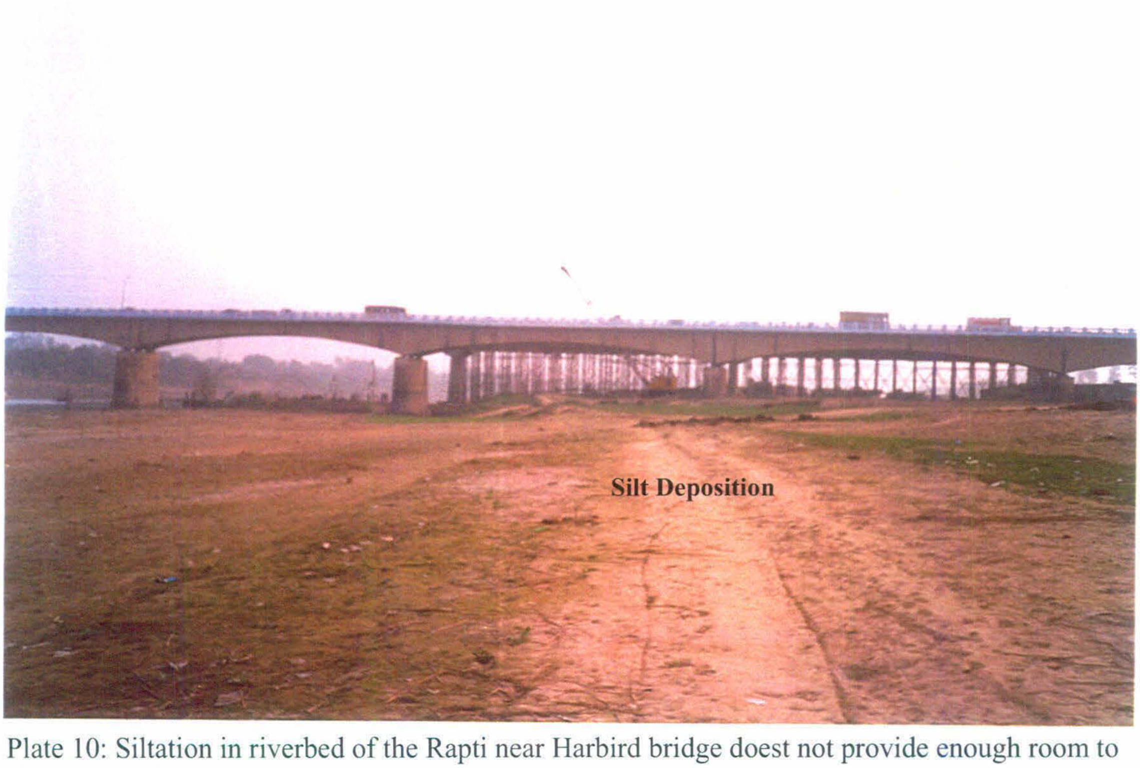


Plate 10: Siltation in riverbed of the Rapti near Harbird bridge doest not provide enough room to flood water during monsoon season.

APPENDICES

Appendix 1: K value for Log Pearson Type III Distribution

Recurrence Interval In Years								
1.0101	2	5	10	25	50	100	200	
SKEW COEFFICIENT Cs	Percent Chance (>=) = 1-F							
	99	50	20	10	4	2	1	0.5
3	-0.667	-0.396	0.42	1.18	2.278	3.152	4.051	4.97
2.9	-0.69	-0.39	0.44	1.195	2.277	3.134	4.013	4.904
2.8	-0.714	-0.384	0.46	1.21	2.275	3.114	3.973	4.847
2.7	-0.74	-0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	-0.769	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	-0.799	-0.36	0.518	1.25	2.262	3.048	3.845	4.652
2.4	-0.832	-0.351	0.537	1.262	2.256	3.023	3.8	4.584
2.3	-0.867	-0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	-0.905	-0.33	0.574	1.284	2.24	2.97	3.705	4.444
2.1	-0.946	-0.319	0.592	1.294	2.23	2.942	3.656	4.372
2	-0.99	-0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	-1.037	-0.294	0.627	1.31	2.207	2.881	3.553	4.223
1.8	-1.087	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	-1.14	-0.268	0.66	1.324	2.179	2.815	3.444	4.069
1.6	-1.197	-0.254	0.675	1.329	2.163	2.78	3.388	3.99
1.5	-1.256	-0.24	0.69	1.333	2.146	2.743	3.33	3.91
1.4	-1.318	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	-1.383	-0.21	0.719	1.339	2.108	2.666	3.211	3.745
1.2	-1.449	-0.195	0.732	1.34	2.087	2.626	3.149	3.661
1.1	-1.518	-0.18	0.745	1.341	2.066	2.585	3.087	3.575
1	-1.588	-0.164	0.758	1.34	2.043	2.542	3.022	3.489
0.9	-1.66	-0.148	0.769	1.339	2.018	2.498	2.957	3.401
0.8	-1.733	-0.132	0.78	1.336	1.993	2.453	2.891	3.312
0.7	-1.806	-0.116	0.79	1.333	1.967	2.407	2.824	3.223
0.6	-1.88	-0.099	0.8	1.328	1.939	2.359	2.755	3.132
0.5	-1.955	-0.083	0.808	1.323	1.91	2.311	2.686	3.041
0.4	-2.029	-0.066	0.816	1.317	1.88	2.261	2.615	2.949
0.3	-2.104	-0.05	0.824	1.309	1.849	2.211	2.544	2.856
0.2	-2.178	-0.033	0.83	1.301	1.818	2.159	2.472	2.763
0.1	-2.252	-0.017	0.836	1.292	1.785	2.107	2.4	2.67
0	-2.326	0	0.842	1.282	1.751	2.054	2.326	2.576
-0.1	-2.4	0.017	0.846	1.27	1.716	2	2.252	2.482
-0.2	-2.472	0.033	0.85	1.258	1.68	1.945	2.178	2.388
-0.3	-2.544	0.05	0.853	1.245	1.643	1.89	2.104	2.294
-0.4	-2.615	0.066	0.855	1.231	1.606	1.834	2.029	2.201
-0.5	-2.686	0.083	0.856	1.216	1.567	1.777	1.955	2.108
-0.6	-2.755	0.099	0.857	1.2	1.528	1.72	1.88	2.016
-0.7	-2.824	0.116	0.857	1.183	1.488	1.663	1.806	1.926
-0.8	-2.891	0.132	0.856	1.166	1.448	1.606	1.733	1.837
-0.9	-2.957	0.148	0.854	1.147	1.407	1.549	1.66	1.749
-1	-3.022	0.164	0.852	1.128	1.366	1.492	1.588	1.664
-1.1	-3.087	0.18	0.848	1.107	1.324	1.435	1.518	1.581
-1.2	-3.149	0.195	0.844	1.086	1.282	1.379	1.449	1.501
-1.3	-3.211	0.21	0.838	1.064	1.24	1.324	1.383	1.424
-1.4	-3.271	0.225	0.832	1.041	1.198	1.27	1.318	1.351
-1.5	-3.33	0.24	0.825	1.018	1.157	1.217	1.256	1.282
-1.6	-3.88	0.254	0.817	0.994	1.116	1.166	1.197	1.216
-1.7	-3.444	0.268	0.808	0.97	1.075	1.116	1.14	1.155
-1.8	-3.499	0.282	0.799	0.945	1.035	1.069	1.087	1.097
-1.9	-3.553	0.294	0.788	0.92	0.996	1.023	1.037	1.044
-2	-3.605	0.307	0.777	0.895	0.959	0.98	0.99	0.995
-2.1	-3.656	0.319	0.765	0.869	0.923	0.939	0.946	0.949
-2.2	-3.705	0.33	0.752	0.844	0.888	0.9	0.905	0.907
-2.3	-3.753	0.341	0.739	0.819	0.855	0.864	0.867	0.869
-2.4	-3.8	0.351	0.725	0.795	0.823	0.83	0.832	0.833
-2.5	-3.845	0.36	0.711	0.711	0.793	0.798	0.799	0.8
-2.6	-3.899	0.368	0.696	0.747	0.764	0.768	0.769	0.769
-2.7	-3.932	0.376	0.681	0.724	0.738	0.74	0.74	0.741
-2.8	-3.973	0.384	0.666	0.702	0.712	0.714	0.714	0.714
-2.9	-4.013	0.39	0.651	0.681	0.683	0.689	0.69	0.69
-3	-4.051	0.396	0.636	0.66	0.666	0.666	0.667	0.667

Appendix 2: Absolute Area under various land use categories (in hectare)

Bahraich	1970-71	1980-81	1990-91	1999-00
Forest	101219	101789	102679	102077
Barren & Unculturable land	9208	8135	7984	6663
Area under non Agricultural uses	56778	64221	71279	70472*
Culturable Waste land	23926	10888	7685	6758
Land under grazing, Misc. tree crops & groves	21863	14908	10799	25827*
Current fallow and other fallow lands	29583	31108	29689	20401
Net area sown	448819	455623	457585	456244
Reported area	**691396**	**686672**	**687700**	**592143**
Gonda				
Forest	72380	71824	73341	71973
Barren & Unculturable land	4952	9266	8334	8305
Area under non Agricultural uses	65976	68963	74135	82095
Culturable Waste land	30284	16233	11582	12012
Land under grazing, Misc. tree crops & groves	21555	16295	15834	36096*
Current fallow and other fallow lands	28757	47509	50556	57448
Net area sown	521911	504290	502282	486294
Reported area	**745815**	**734380**	**736064**	**718127**
Basti				
Forest	5584	8234	7209	12016
Barren & Unculturable land	5976	7641	7666	9400
Area under non Agricultural uses	75881	79250	80075	89759
Culturable Waste land	27453	15152	11929	10404
Land under grazing, Misc. tree crops & groves	23105	24977*	15314	14179
Current fallow and other fallow lands	32951	30040	30416	24689
Net area sown	560449	563714	576102	590486
Reported area	**731399**	**704031**	**728711**	**750933**
Gorakhpur				
Forest	55628	55630	55794	50871
Barren & Unculturable land	4462	5462	6234	6559
Area under non Agricultural uses	52058	57641	65804	69419
Culturable Waste land	11334	7746	5626	5871
Land under grazing, Misc. tree crops & groves	17155	10668	16525	4270*
Current fallow and other fallow lands	16604	22033	25934	25585
Net area sown	475839	475957	468179	465435
Reported area	**633080**	**635137**	**644096**	**623740**
Deoria				
Forest	1099	1142	422*	1224
Barren & Unculturable land	9652	8396	12271*	9467
Area under non Agricultural uses	40248	51136	64678	72121
Culturable Waste land	9866	8033	6230	4178
Land under grazing, Misc. tree crops & groves	17011	17354	7519	6401
Current fallow and other fallow lands	19687	7462*	19071	17834
Net area sown	438427	444194	426527	426051
Reported area	**535990**	**537717**	**536718**	**537276**

Source: 1.Indian Agricultural Statistics, Vol. II, 1970-71, 1980-81 and 1990-91, Directorate of Economics and Statistics, Ministry of Agriculture, Govt. of India, New Delhi.
2.Statistical Diary of Uttar Pradesh, 2001, Economics and Statistics Division, State Planning Institute, Uttar Pradesh.

Appendix 3: Percentage variation in urban area

Town	District as per 2001	Urban area (in sq.km)			% change in urban area		
		1971	1981	1991	1971-81	1981-91	1971-91
Bhinga	Sharawasti	1.71	1.71	1.71	0.00	0.00	0.00
Balrampur	**Balrampur**	**8.52**	**14.25**	**14.25**	**67.25**	**0.00**	**67.25**
Utraula	Balrampur	2.59	2.65	2.65	2.32	0.00	2.32
Tulsipur	Balrampur	2.06	2.06	2.06	0.00	0.00	0.00
Pachperwa	Balrampur	NC	3	3		0.00	
Intai Rampur	Balrampur	NC	18	18		0.00	
Bansi	**Siddharthanagar**	**7.69**	**7.69**	**12**	**0.00**	**56.05**	**56.05**
TetriBazar	Siddharthanagar	NC	4	9		125.00	
Barhni Bazar	Siddharthanagar	NC	1.7	6		252.94	
Shohratgarh	Siddharthanagar	NC	2.75	2.75		0.00	
Khalilabad	**Santkabirnagar**	**6.06**	**6.06**	**7.04**	**0.00**	**16.17**	**16.17**
Mehdawal	Santkabirnagar	NC	3	3		0.00	
Maghar	Santkabirnagar	NC	3.02	3.02		0.00	
Ledwa Mahuwa	Santkabirnagar	NC	1.18	2		69.49	
Nautanwa	Maharajganj	NC	8.51	8.51		0.00	
Maharajganj	Maharajganj	NC	NC	10			
Anandnagar	Maharajganj	NC	1.19	4		236.13	
Siswa Bazar	Maharajganj	NC	5	5		0.00	
Nichlaul	Maharajganj	NC	6.57	6.57		0.00	
Gorakhpur	**Gorakhpur**	**38.85**	**45.6**	**136.58**	**17.37**	**199.52**	**251.56**
Barhalganj	Gorakhpur	3.63	3.63	3.63	0.00	0.00	0.00
Pipiganj	Gorakhpur	NC	0.31	4		1190.32	
Pipraich	Gorakhpur	NC	2	2		0.00	
MunderaBazar	Gorakhpur	NC	6	6		0.00	
Bansgaon	Gorakhpur	NC	NC	0.75			
Rudrapur	Deoria	NC	5.43	5.43		0.00	
Gaura Barhaj	**Deoria**	**5.1**	**5.1**	**9**	**0.00**	**76.47**	**76.47**
Total		**76.21**	**160.41**	**287.95**	**110.48**	**79.51**	**277.84**

Source: 1. General Population Tables, Uttar Pradesh, Census of India 1991, Series- 25, Part- IIA, pp. 121-127.

2. General Population Tables, Uttar Pradesh, Census of India 1981, Series- 22, Part- IIA, pp. 65-70.

3. General Population Tables, Uttar Pradesh, Census of India 1971, Series- 21, Part- IIA, .pp.52-57

Appendix 4: Percentage Variation in Urban Population

Town	District as per 2001	Urban Population			% Change in urban Population		
		1971	1981	1991	1971-81	1981-91	1971-91
Bhinga	Sharawasti	9819	13307	16528	35.52	24.21	68.33
Balrampur	Balrampur	36191	46058	59619	27.26	29.44	64.73
Utraula	Balrampur	12637	17597	24950	39.25	41.79	97.44
Tulsipur	Balrampur	9599	12479	18098	30.00	45.03	88.54
Pachperwa	Balrampur	NC	9335	12472		33.60	
Intai Rampur	Balrampur	NC	11283	14481		28.34	
Bansi	Siddharthanagar	12125	15573	26095	28.44	67.57	115.22
TetriBazar	Siddharthanagar	NC	12767	17596		37.82	
Barhni Bazar	Siddharthanagar	NC	6668	8509		27.61	
Shohratgarh	Siddharthanagar	NC	5756	7308		26.96	
Khalilabad	Santkabirnagar	13539	19399	27965	43.28	44.16	106.55
Mehdawal	Santkabirnagar	NC	18839	22490		19.38	
Maghar	Santkabirnagar	NC	10489	12985		23.80	
Ledwa Mahuwa	Santkabirnagar	NC	6813	10002		46.81	
Nautanwa	Maharajganj	NC	16484	21787		32.17	
Maharajganj	Maharajganj	NC	NC	17430			
Anandnagar	Maharajganj	NC	5951	7798		31.04	
Siswa Bazar	Maharajganj	NC	13347	16222		21.54	
Nichlaul	Maharajganj	NC	8382	11017		31.44	
Gorakhpur	Gorakhpur	230911	290814	505566	25.94	73.85	118.94
Barhalganj	Gorakhpur	9247	12808	15881	38.51	23.99	71.74
Pipiganj	Gorakhpur	NC	6160	8341		35.41	
Pipraich	Gorakhpur	NC	10019	12315		22.92	
MunderaBazar	Gorakhpur	NC	8044	9951		23.71	
Bansgaon	Gorakhpur	NC	NC	13489			
Rudrapur	Deoria	NC	17566	22344		27.20	
Gaura Barhaj	Deoria	17943	21689	29793	20.88	37.36	66.04
Total		**352011**	**617627**	**971032**	**75.46**	**57.22**	**175.85**

Source: 1. General Population Tables, Uttar Pradesh, Census of India 1991, Series- 25, Part- IIA, pp. 121-127.

2. General Population Tables, Uttar Pradesh, Census of India 1981, Series- 22, Part- IIA, pp. 65-70.

3. General Population Tables, Uttar Pradesh, Census of India 1971, Series- 21, Part- IIA, .pp................

Appendix 5 : Daily rainfall and water level at Bansi and average areal rainfall under various Synoptic Systems during 1998 monsoon season

1	2	3	4	5	6	7
20July.	84.62	17.80	24.5	-0.28	-0.95	s7
21 July.	84.79	1.60	6.0	-0.11	-0.78	s6
22 July.	84.87	0.00	2.0	-0.03	-0.70	s6
23 July.	84.85	0.60	2.1	-0.05	-0.72	s6
24 July.	84.88	0.00	2.1	-0.03	-0.69	s6
25 July.	84.88	12.00	5.3	-0.03	-0.69	s8
26 July.	85.00	50.60	41.7	0.09	-0.57	s8
27 July.	85.12	15.00	7.3	0.22	-0.45	s6
28 July.	85.17	21.20	23.6	0.27	-0.40	s6
29 July.	85.16	0.00	3.4	0.26	-0.41	s6
30 July.	85.12	0.00	2.1	0.22	-0.45	s9
31 July.	85.04	0.00	3.1	0.14	-0.53	s6
1 Aug.	84.92	0.00	0.0	0.02	-0.65	s3
2 Aug.	84.54	0.00	0.1	-0.36	-1.03	s6
3 Aug.	84.02	2.20	42.4	-0.88	-1.55	s7
4 Aug.	84.00	24.60	39.6	-0.90	-1.57	s7
5 Aug.	84.00	0.00	3.9	-0.90	-1.57	s6
6 Aug.	84.02	8.00	18.5	-0.88	-1.55	s1
7 Aug.	84.08	2.20	13.9	-0.82	-1.49	s2
8 Aug.	84.04	0.00	1.6	-0.86	-1.53	s3
9 Aug.	83.92	0.00	6.9	-0.98	-1.65	s3
10 Aug.	83.71	0.00	1.7	-1.19	-1.86	s3
11 Aug.	83.42	0.40	14.6	-1.48	-2.15	s3
12Aug.	83.40	9.60	16.3	-1.51	-2.18	s2
13 Aug.	83.83	4.20	58.5	-1.07	-1.74	s7
14Aug.	84.04	39.60	22.7	-0.86	-1.53	s5
15Aug.	84.21	13.80	12.0	-0.69	-1.36	s5
16 Aug.	84.37	32.80	42.2	-0.53	-1.20	s6
17 Aug.	84.58	3.20	5.2	-0.32	-0.99	s8
18 Aug.	84.79	163.00	88.7	-0.11	-0.78	s8
19 Aug.	85.25	180.40	81.5	0.35	-0.32	s7
20 Aug.	85.50	3.40	3.4	0.59	-0.07	s6
21Aug.	85.82	54.20	18.8	0.92	0.25	s6
22 Aug.	85.67	52.20	15.5	0.77	0.10	s6
23 Aug.	85.54	1.40	17.3	0.64	-0.03	s5
24 Aug.	85.41	0.00	3.0	0.51	-0.16	s9
25 Aug.	85.33	32.20	24.6	0.43	-0.24	s3
26 Aug.	85.29	9.80	6.2	0.39	-0.28	s3
27 Aug.	85.33	45.80	34.1	0.43	-0.24	s6
28 Aug.	85.21	5.60	6.3	0.31	-0.36	s9
29 Aug.	85.08	0.00	0.0	0.18	-0.49	s9
30 Aug.	85.00	10.40	2.6	0.10	-0.57	s6
31 Aug.	84.96	0.80	5.0	0.06	-0.61	s9

1Sept.	85.21	0.00	18.9	0.31	-0.36	s6
2 Sept.	85.08	1.80	0.6	0.18	-0.49	s9
3 Sept.	85.00	7.40	6.1	0.10	-0.57	s9
4 Sept.	84.96	0.00	0.5	0.06	-0.61	s9
5 Sept.	84.91	0.00	0.0	0.01	-0.66	s10
6 Sept.	84.80	68.80	17.7	-0.11	-0.77	s5
7 Sept.	84.71	0	1.7	-0.19	-0.86	s9
8 Sept.	84.62	0	0.0	-0.28	-0.95	s10
9 Sept.	84.54	0	0.0	-0.36	-1.03	s10
10 Sept.	84.50	0	0.0	-0.40	-1.07	s10
11 Sept.	84.46	1.6	3.7	-0.44	-1.11	s9
12 Sept.	84.30	0	4.3	-0.61	-1.27	s9
13 Sept.	84.25	0	0.0	-0.66	-1.32	s10
14 Sept.	83.83	0	0.0	-1.07	-1.74	s10
15 Sept.	83.71	0	0.0	-1.19	-1.86	s10
16 Sept.	83.45	0	0.0	-1.45	-2.12	s10
17 Sept.	83.25	0	0.0	-1.66	-2.32	s10
18 Sept.	83.04	0	0.0	-1.86	-2.53	s10

1.Date (1998) 2. Water level (m) 3. Rainfall (mm) 4. Average areal rainfall (mm) 5. Difference between water level and danger level (84.90m) 6. Difference between water level and highest flood level (85.57m) 7. Synoptic System.

Source: 1.Flood Forecasting and Warning network Performance Appraisal, April 2000, Central Water Commission, New Delhi. 2. IMD, Pune-5 and 3. Indian Daily Weather Report (June to September, 1998), IMD, Pune-5

Appendix 6: Daily rainfall and water level at Birdghat and average areal rainfall under various Synoptic Systems during 1998 monsoon season

1	2	3	4	5	6	7
9 July.	74.00	224.7	67.8	-0.98	-2.84	s5
10 July.	74.85	0.7	0.8	-0.13	-1.99	s2
11 July.	75.51	0	0.0	0.53	-1.33	s2
12 July.	75.85	41.2	14.1	0.87	-0.99	s3
13 July.	76.20	18.5	27.3	1.22	-0.64	s3
14 July.	76.28	13	16.2	1.30	-0.56	s3
15 July.	76.26	10.4	16.3	1.28	-0.58	s3
16 July.	76.28	69.6	77.1	1.30	-0.56	s8
17 July.	76.25	105.6	52.7	1.27	-0.59	s8
18 July.	76.30	3.6	26.9	1.32	-0.54	s8
19 July.	76.51	24.7	35.5	1.53	-0.33	s7
20 July.	76.73	11	24.5	1.75	-0.11	s7
21 July.	76.79	3.8	6.0	1.81	-0.05	s6
22 July.	76.79	0	2.0	1.81	-0.05	s6
23 July.	76.65	1	2.1	1.67	-0.19	s6
24 July.	76.65	0	2.1	1.67	-0.19	s6
25 July.	76.65	0	5.3	1.67	-0.19	s8
26 July.	76.65	55.2	41.7	1.67	-0.19	s8
27 July.	76.65	13.8	7.3	1.67	-0.19	s6
28 July.	76.70	22.8	23.6	1.72	-0.14	s6
29 July.	76.78	0	3.4	1.80	-0.06	s6
30 July.	76.79	8.5	2.1	1.81	-0.05	s9
31 July.	76.79	12.4	3.1	1.81	-0.05	s6
1 Aug.	76.71	0	0.0	1.73	-0.13	s3
2 Aug.	76.65	0.3	0.1	1.67	-0.19	s6
3 Aug.	76.50	71.4	42.4	1.52	-0.34	s7
4 Aug.	76.44	61.2	39.6	1.46	-0.40	s7
5 Aug.	76.45	0.7	3.9	1.47	-0.39	s6
6 Aug.	76.35	20.5	18.5	1.37	-0.49	s1
7 Aug.	76.41	13	13.9	1.43	-0.43	s2
8 Aug.	76.30	6.3	1.6	1.32	-0.54	s3
9 Aug.	76.15	19.1	6.9	1.16	-0.70	s3
10 Aug.	75.93	0	1.7	0.95	-0.91	s3
11 Aug.	75.71	36.3	14.6	0.73	-1.13	s3
12 Aug.	75.60	20	16.3	0.62	-1.24	s2
13 Aug.	75.63	60.3	58.5	0.65	-1.21	s7
14 Aug.	75.61	24.5	22.7	0.63	-1.23	s7
15 Aug.	75.70	19.6	12.0	0.72	-1.14	s5
16 Aug.	75.80	49.6	42.2	0.82	-1.04	s5
17 Aug.	75.85	0.6	5.2	0.87	-0.99	s6
18 Aug.	75.90	99.4	88.7	0.92	-0.94	s8

19 Aug.	76.15	27.6	81.5	1.17	-0.69	s8
20 Aug.	76.50	1.5	3.4	1.52	-0.34	s6
21 Aug.	76.85	0	18.8	1.87	0.01	s6
22 Aug.	77.13	8.1	15.5	2.15	0.29	s6
23 Aug.	77.54	68.6	17.3	2.56	0.70	s5
24 Aug.	77.40	11.7	3.0	2.42	0.56	s9
25 Aug.	77.15	0	24.6	2.17	0.31	s3
26 Aug.	76.85	9.6	6.2	1.87	0.01	s3
27 Aug.	76.69	69.8	34.1	1.71	-0.15	s6
28 Aug.	76.50	11.6	6.3	1.52	-0.34	s9
29 Aug.	76.36	0	0.0	1.38	-0.48	s9
30 Aug.	76.30	0	2.6	1.32	-0.54	s6
31 Aug.	76.23	19.1	5.0	1.25	-0.61	s9
1 Sept.	76.15	1.6	18.9	1.17	-0.69	s6
2 Sept.	76.00	0.4	0.6	1.02	-0.84	s9
3 Sept.	75.90	1.9	6.1	0.92	-0.94	s9
4 Sept.	75.80	1.4	0.5	0.82	-1.04	s9
5 Sept.	75.70	0	0.0	0.72	-1.14	s10
6 Sept.	75.55	1.8	17.7	0.57	-1.29	s5
7 Sept.	75.45	4.4	1.7	0.47	-1.39	s9
8 Sept.	75.35	0	0.0	0.37	-1.49	s10
9 Sept.	75.25	0	0.0	0.27	-1.59	s10
10 Sept.	74.90	0	0.0	-0.08	-1.94	s10
11 Sept.	74.86	0.4	3.7	-0.12	-1.98	s9
12 Sept.	74.60	7	4.3	-0.38	-2.24	s9
13 Sept.	74.35	0	0.0	-0.63	-2.49	s10
14 Sept.	74.10	0	0.0	-0.88	-2.74	s10

1.Date (1998) 2. Water level (m) 3. Rainfall (mm) 4. Average areal rainfall (mm) 5. Difference between water level and danger level (74.98m) 6. Difference between water level and highest flood level (76.84m) 7. Synoptic System

Source: 1.Flood Forecasting and Warning network Performance Appraisal, April 2000, Central Water Commission, New Delhi. 2. IMD, Pune-5 and 3. Indian Daily Weather Report (June to September, 1998), IMD, Pune-5

Appendix 7: Flood Damages to Area and Cropped Area (in hectare)

1	2	3	4
1981	307.231	106.773	35
1982	212.479	136.386	64
1983	150.724	70.767	47
1984	136.828	78.17	57
1985	17.73	9.383	53
1986	90.184	73.706	82
1987	11.355	6.819	60
1988	89.785	53.903	60
1989	192.905	117.604	61
1990	31.242	6.885	22
1991	0.392	0.241	61
1992	0.789	0.607	77
1993	102.525	67.488	66
1994	18.789	12.537	67
1995	14.594	7.56	52
1996	92.006	35.985	39
1997	24.644	12.525	51
1998	267.416	92.804	35
1999	32.448	13.67	42
2000	50.032	38.085	76

1. Year 2. Area affected 3. Cropped area affected 4. Percentage of Cropped area to the Total area affected by floods.
Source: Floods Report of Gorakhpur district- 2001, p.180

Appendix 8: Density of population.

District	1991	2001
Bahraich	320	415
Shrawasti	820	1044
Balrampur	468	576
Siddharthnagar	584	741
Basti	556	682
Santkabirnagar	799	988
Maharajganj	568	734
Gorakhpur	923	1140
Kushinagar	775	994
Deoria	861	1077

Source: Provisional Population Total, Uttar Pradesh, 2001, p.21.

Appendix-9

General

1. Location:
2. Name of the Person interviewed:
3. Age 4. Sex 5. Education 6. Caste/ Religion
7. Type of House: (a) Mud Thatch (b) Brick Tile (c) Cement
8. Total Family Members:
9. Size of House
   Rooms 1 2 3 4 5
10. Main source of Income (amount in Rs):
% of Cash Income: (a). Agri. (b). Labor (c). Milk (d). Employ. (Pvt./Govt.)

Assessment of Flood

1. Land Information:

SL.	Holding Size	Location	Quality of Land	Frequency of Flood			Nature of Damage			CP at the time of Flood
				F	OT	OF	CP	SD	ER	
1										
2										
3										

Crop after Flood	Period	Irrigation	Fertilizer use	Period of Standing Water/ Depth of Water

2. What is the cause of inundation of Fields: (a). Heavy Rainfall (b). Back Water (c). Bank Erosion (d) Other
3. Fertility of Field after Flood: (a). Increased (b). Decreased. Why it is so?

4. Do you get the bumper Rabi crops after the flood and whether it compensates the loss of Kharif crops? Yes/ No
5. What do you think are the causes of floods?

6. Height (up to which place on flood plain does flooding take place every year)
(a). Up to Levy (b). Bank (c). Embankment (d). Beyond the embankment
7. Loss/damage: (a). Crops (b). Shelter (c).Cattles (d). Public utilities (Elect.,Telephone etc)
8. What type of structural changes takes place in houses due to flood?

9. What do you think are the causes of Bank erosion?

10. What do you think are the causes of Breaches in the embankment?
(a). Overflow (b). Seepage (c). Slumping of top portion
11. Do the villagers cut the embankment to protect the village from submergence? Yes/ No.
12. What are the measures do you suggest for the protection of the embankment?

13. Community participation in flood control measures
(a). Kind of efforts
(b). Material use
(c). Cost and results
14. Does the embankment cause waterlogging nearby field?
(a). Frequently (b). Three months and above
15. Are you aware of Flood warning system? Yes/No.
16. From where do you manage drinking water during flood?

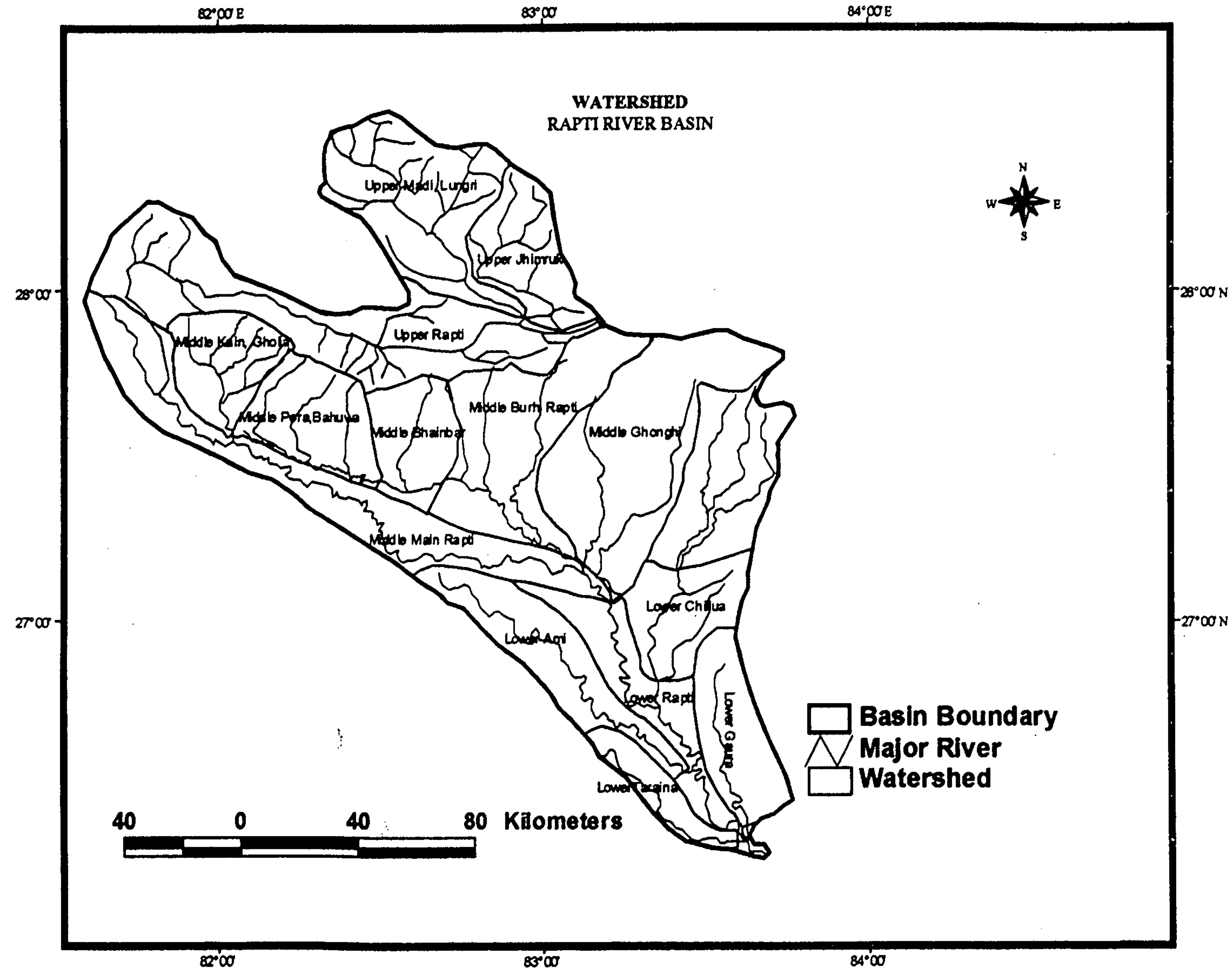
17. Damage reporting and relief seeking system:
(a). Relief materials
(b). Duration
18. Govt. Support: (a). Payment of crop insurance (b). Providing medicine and food
(c) Drinking water (d) Shelter.
19. Where do you shift during flood: (a). Elevated place (b). School or Highway
(c). Relative's home
20. Where do you want to go during next flood?

21. Who helps you to evacuate the flooded village: (a). Self (b). Panchayat (c). Rescue party
22. Mode of transportation during flood for evacuation

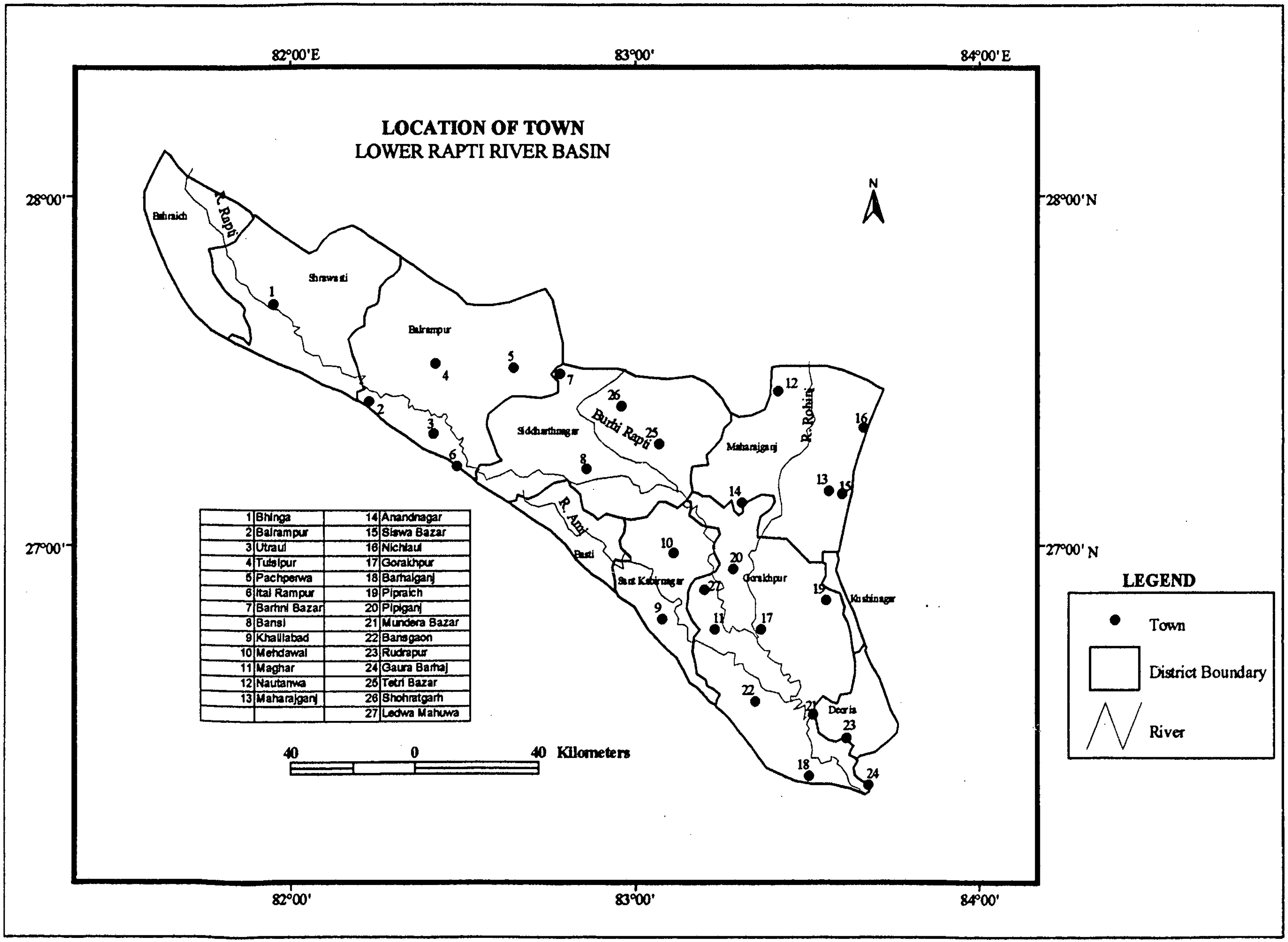
23. Do you pose country boat? Yes/No.

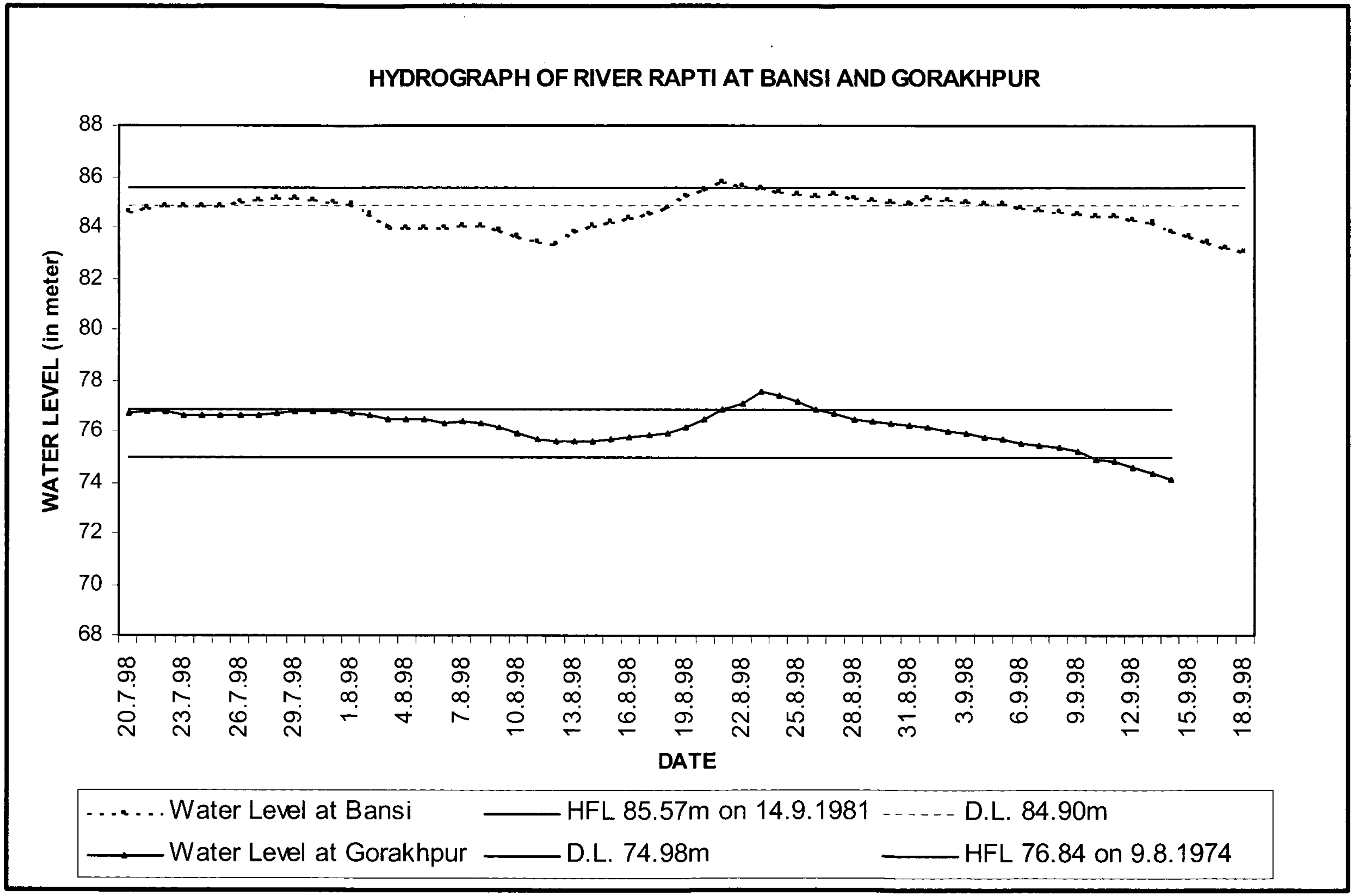
Memory of 1998 Floods

F- Frequent, OT- Once in Two years, OF- Once in Five years, CP-Crop,
SD-Sand deposition, ER- Erosion.



Source: National Atlas of India, Vol. II, 1981 and Watershed Atlas of India.1990


LOCATION OF TOWN
LOWER RAPTI RIVER BASIN
82°00'E
83°00'
84°00'E
28°00'
28°00'N
27°00'
27°00'N
82°00'
83°00'
84°00'
N
Bahraich
R. Rapti
Shrawasti
Balrampur
Siddharthnagar
Burhi Rapti
Maharajganj
R. Rohini
R. Ami
Basti
Sant Kabirnagar
Gorakhpur
Kushinagar
Deoria
1 Bhinga
2 Balrampur
3 Utraul
4 Tulsipur
5 Pachperwa
6 Itai Rampur
7 Barhni Bazar
8 Bansi
9 Khalilabad
10 Mehdawal
11 Maghar
12 Nautanwa
13 Maharajganj
14 Anandnagar
15 Siswa Bazar
16 Nichlaul
17 Gorakhpur
18 Barhalganj
19 Pipraich
20 Pipiganj
21 Mundera Bazar
22 Bansgaon
23 Rudrapur
24 Gaura Barhaj
25 Tetri Bazar
26 Shohratgarh
27 Ledwa Mahuwa
40 0 40 Kilometers
LEGEND
Town
District Boundary
River


HYDROGRAPH OF RIVER RAPTI AT BANSI AND GORAKHPUR
WATER LEVEL (in meter)
88
86
84
82
80
78
76
74
72
70
68
20.7.98
23.7.98
26.7.98
29.7.98
1.8.98
4.8.98
7.8.98
10.8.98
13.8.98
16.8.98
19.8.98
22.8.98
25.8.98
28.8.98
31.8.98
3.9.98
6.9.98
9.9.98
12.9.98
15.9.98
18.9.98
DATE
Water Level at Bansi
HFL 85.57m on 14.9.1981
D.L. 84.90m
Water Level at Gorakhpur
D.L. 74.98m
HFL 76.84 on 9.8.1974

GLOSSARY

Local Term	*English Synonym*

1. ***Bandh:*** (Embankment). It is generally made-up of earth.
2. ***Chaur:*** (Ephemeral *Tal*). It is a depression in flood plain and generally flooded in monsoon season.
3. ***Diara:*** (River Island). Flood plain liable to frequent erosion and inundation situation on either sides of the rivers or between the river channels.
4. ***Doab:*** (Inter-fluive), Do- means two and Ab- means water or river, thus a land between the two rivers or river channels.
5. ***Domat:*** (Loamy Soil). A type of friable soil containing mainly sand and silt with a small proportion of clay.
6. ***Jalmagna:*** A variety of paddy, which survives in deep water, and hence grown in flood plain.
7. ***Kacchar:*** (Flood plain). The term is locally used in *Saryupar* Plain (Flood Plain of R. Rapti) to denote area liable to flood every year.
8. ***Kharif:*** the Crops grown during the S. W. Monsoon period (June to September), viz. Rice, Maize, Millets etc.
9. ***Loo:*** (Hot dry wind). It blows in North India Plain during summer (May-June) causing death of life and cattle.
10. ***Munj:*** A tall grass usually in low-lying tracts.
11. ***Rabi:*** The crops sown in autumn season and harvested in spring season, viz. wheat, barley, gram, etc.
12. ***Tal:*** (Shallow depression). Remnants of old riverbeds, generally found in the flood plain.
13. ***Tarai:*** (Humid). The zone below the foothills of Himalaya, receiving high rainfall, having dense forest, swampy land, malarial climate is locally called *Tarai*.
14. ***Usar:*** (Barren land). The land, which has turned into barren land due to formation and accumulation of calcium carbonate.
15. ***Zaid:*** (Extra). The additional crops sown between *Rabi* and *Kharif* seasons i.e., Mid-March to Mid-June, viz. Cucumber, watermelon, vegetables etc.