Chapter IV: Characteristics of major Catchments

4.1 Introduction

Land use pattern of catchment has very important role in regulating the overall hydrological processes of the river. The six selected rivers namely, Tista, Torsa, Jaldhaka, Raidak, Sankosh and Mahananda have their watershed extended beyond the territorial boundary of India. Except the Mahananda and Tista all other rivers have their source along with considerable catchment area situated in Bhutan and in Tibet (China). It is also true that all the six rivers flow downstream to Bangladesh further south. The watershed characteristics has been assessed up to these points only as hydro-geomorphologically any change in watershed will have its implication at its outfall i.e., selected stations.

In view of non-availability and restricted nature of topographic maps (Survey of India) of the watersheds, the investigator used the US Army Topo Sheets (1:250000) No. NG 45-3, NG 45-4, NG 45-7, NG 45-8, NH 45-16, NH 46-13, NG 46-1, NG 46-5 for the delimitation of watersheds situated across the international boundary. An attempt has also been made to analyse the catchment characteristics along with land use pattern based on the maps. Satellite image available from NRSA and Google Earth has also been used to identify various features and updated land use data. The entire analysis has been carried out under GIS platform (ArcGIS and Global Mapper).

4.2 Hydro-geomorphic characteristics

Hydro-geomorphic characteristics of the drainage basins have considerable significance in analysing flood behavior in its down streams. The sub-Himalayan Jalpaiguri district is drains by major drainage systems like Tista, Jaldhaka, Torsa, Raidak, Sankosh and Mahananda. All these rivers are originating from beyond the geographical boundary of the state of West Bengal and some of them in fact originate from beyond the territory of India. Hydro-geomorphological characteristics of the concern drainage basins are discussed under two sub-headings i) Hydrological characteristics and ii) geomorphological characteristics.

4.2.1 Hydrological characteristics of drainage basins

When alluvial river has to be harnessed for irrigation, power, navigation, flood management etc., changes in the river regime take place in terms of channel widening, bank erosion, local scour aggradation & degradation leading to changes in slope etc. These changes in river regime take place because the equilibrium of the river is disturbed by human interferences (Jain V., Sinha R., 2003; Moriswa, M, 1968; Sen S., 1968). By studying the hydraulic characteristics of the river, likely changes in the river behaviour may be assessed through mathematical modeling or taking recourse to the physical methods. A few parameters such as peak discharge, channel slope variation, sediment load, aggradations & degradation of major rivers have been studied and are described below:

Peak discharge of the Tista, Torsa, Jaldhaka, Raidak, Sankosh and Mahananda rivers have been calculated at some strategic locations (WAPCOS, 2003) by various agencies (table 4.1).

Table No. 4.1
Calculated peak discharge of rivers under study

Name of river	Reach from origin up to	Catchment area (Sq. km.)	Length from origin (km)	Discharge (Peak) m^3/sec
Tista	(i) Snow line	2479	10	--
	(ii) Rango (Sikkim Border).	6220	132	12072
	(iii) AndersonBridge	7612	150	16309
	(iv) CoronationBridge	9359	173	17367
	(v) Domohani, Jalpaiguri	9568	234	20067
	(vi) Bangladesh Border	10205	276	21428
Torsa	(i) Up to Tibet-Bhutan boundary	1735	70.8	4283
	(ii) Phuntsholing	4045	132	12159
	(iii) NH 31, Hasimara	3872	147	12538
	(v) Koch Bihar	4533	258	13575
	(vi) After confluence with Kaljani	6045	287	16024
	(vii) Bangladesh Border	6407	296	16362
Jaldhaka	(i) SikkimBhutan Boundary	78	64	787
	(ii) Nagrakata	648	72	3716
	(iii) NH-31 Crossing	1626	96	8795
	(iv) Mathabhanga	4092	175	10067
	(v) Indo-Bangladesh boundary.	4766	218	10698
Sankosh	At Chepan/Barobhisa	10534	208	22297
Raidak	At Bhutanghat	4813	167.2	14530
Mahananda	NH 31, Champasari, Siliguri	175	26	995

Source: Master Plan for Flood Management &North Bengal Flood Control Commission, Jalpaiguri

The channel slope of the river in North Bengal varies depending upon the terrain characteristics. The aspects are discussed below according the physiographic set-up. The details of gradient of major rivers are given in table 4.2. Average gradient of the channel varies from 1:13 in the Mahananda to 1:29 in the Sankosh. The Torsa with a gradient of 1:21 (within the studied section) has four major tributaries with moderate gradient. The Tista, the largest river in the north of the Ganga-Padma system in West Bengal, although infested with innumerable island and shoals in its wide channel, is still flowing fairly fast within the studied section a gradient of 1:23.

Table No. 4.2
Gradient of the major rivers (physiographic region wise) in North Bengal

River	*Gradient*	*Hilly region*	*Piedmont zone*	*Active Plain*
Mahananda	1:13	1:7	1:185	-
Tista	1:23	1:32	1:215	1:342
Neora	1:196	1:17	1:307	-
Dharala (West)	1:3421	-	1:1561	1:4652
Jaldhaka	1:16	1:12	1:198	1:3129
Mujnai	1:2315	-	1:295	1:4000
Dharala (East)	1:7786	-	-	1:7786
Torsa	1:21	1:20	1:162	1:4611
Raidak	1:42	1:27	1:128	1:852
Kaljani	1:1056	-	1:154	1:2583
Jainti	1:1990	1:13	1:132	1:3656
Sankosh	1:29	1:38	1:112	1:1833

4.2.1.1 The river in hills and piedmont

Most of the rivers in this region are rather straight streams. The average slope ratio of the river channel in general cases is much lower indicating an obviously steeper gradient. The river Mahananda along its hilly course attains the highest gradient of 1:7 among the rivers under study, followed by the Jaldhaka (1:12), the Torsa (1:20) and the (Tista 1:32). Hydrological characteristics of the major identified watersheds have been depicted in table 4.3.

Pronounced development of conjugal alluvial fan, produced by diverging drainage system in the catchment area of the Mahananda and Jaldhaka is very much conspicuous in the western and central part of the piedmont zone. Series of contour lines arched down slope in a systematic pattern extending even below the 66 meter contour line, where the edges of the fans are loosing arched form. In the eastern section of the piedmont zone, particularly in the Tista and Sankosh catchments, the fan formation is of a subdued type. There are some streams diverging out locally, but the overall trend of run is that of earlier parallel or converging. From the Torsa to the Raidak, the tributaries like Alaikuri, Diana, Jainti, Dharsi, Dhaula etc. are running more or less parallel to each other and the contour lines maintained a general east-west direction without any significant arched form, either upward or downward. The river Sankosh along its piedmont course attains the highest gradient of 1:112 among the rivers under study, followed by the Torsa (1:162), the Mahananda (1:185), the Jaldhaka (1:198) and the (Tista 1:215).

Table No 4.3 Watershed Characteristics

Name of Watershed	Highest elevation (m)	Lowest elevation (m)	Max. length of watershed (km)	Max width in km	L/B ratio	Watershed gradient
Mahananda	2040	50	105	46	2.28	1:18.95
Tista	8585	41	211	83	2.54	1:40.49
Jaldhaka	5964	40	155.5	52	2.99	1:38.09
Torsa	7313	30	230	46	5.00	1:31.67
Raidak	7270	30	193	62	3.11	1:37.52
Sankosh	7516	30	220	122	1.80	1:34.03

4.2.1.1 The rivers in active plains

The streams, which are coming out from the Lesser Himalayas are entirely rain-fed and are generally non-perennial. The Mahananda and Jaldhaka systems are entirely rain-fed. Excepting the main Tista and its tributaries the great Rangit, all other channels within this system are rain-fed. The Torsa and the Sankosh have their origins in the glaciers in the Himalayas. The drainage pattern in this area is still divergent. Wide rivers frequently overflow its shallow bank during torrent but water clears out speedily without causing water logging while leaving behind fresh silt (Mukhopadhyay, SC; 1982).

Average gradient of the channel varies from 1:342 in the Tista to 1:4611 in the Torsa. The river Sankosh with a gradient of 1:1833 followed by the river Jaldhaka with a gradient of 1:3129 within the active plain is rather swift river. The Tista, the largest river in the north of the Ganga-Padma system in West Bengal, although infested with innumerable island and shoals in its wide channel, is still flowing fairly fast within the section a gradient of 1:342.

4.2.2 Sediment load

When the raindrops fall on the soil devoid of vegetation, each raindrop explodes on contact with the ground. By this, the soil particles are dislodged from their position and are drifted along with the flowing sheet of water. The runoff i.e. the excess of rain water which has not infiltrated into the ground washed the soil and erodes the surface. The basic source of sediment in rivers is the erosion of land surface and to some extent erosion ofbeds. The ratio of total sediment charge at any given point in a river varies as 0.8 powers on the drainage area on an average. The sediment load due to the flat slopes of a river gets deposited in the bed and the causes the river channel to meander to find equilibrium condition of discharge, velocity, silt load, slope and flow section.

The rivers in North Bengal are not stable and process of erosion in the steep hilly catchment, transportation of sediment in the river and its subsequent progressive deposition lower down in the river with flatter slope is a continuous phenomenon. In the upper reaches in the plains, the river and their tributaries have got steeper slopes as compared to the lower reaches, thus, the carrying capacity for the silt load in the upper reaches in the Plains is comparatively more than in the lower reaches. The river bed, just after it debauches into the plains, consists of shingle and sand, whereas further down in the flatter plains, the alluvial channels mostly consist of coarse and medium silt. The hydrological characteristics of major watersheds in sub-Himalayan North Bengal is shown in the following table.

Table 4.4Hydrological characteristics of major watersheds

Watershed	Area in km^2	Discharge		Mean discharge		Mean annual runoff m.m^3	Mean annual suspended load (m.m.ton)
		Base flow	Mean maxima	Non-monsoon	Monsoon		
Sankosh	8521	85.0	3000	125.0	1500	16262	3.62
Tista	7900	30.0	5000	40.0	2000	21510	15.89
Raidak	4570	20.0	3000	30.0	700	6195	4.26
Torsa	3920	20.0	1000	40.0	400	7657	2.73
Jaldhaka	1590	13.0	2500	25.0	600	6628	4.03
Mahananda	250	1.0	300	1.2	60	2411	0.85
Balason	350	1.8	400	4.2	70	1264	1.47

It is evident that sub-Himalayan rivers in North Bengal are producing largest amount of sediment (per unit area) at global scale. The mean annual sediment yield from these rivers would be estimated about 30 million metric ton or 15.76 million cubic meter suspended load. The magnitude of such a huge load may be visualized when the materials if spread uniformly will create a hill with dimension of 250x250x250 meter. The frequency and magnitude of sediment load depends on the magnitude of extreme event i.e., in 1968 flood estimated 3.5 million ton sediment transported in 3 days (3-5th October).

Suspended load concentration is also found very high and a maximum of 1.5gm/litre has been recorded in the river Jaldhaka during 2002 flood. The Jainti watershed in western Duars recorded the highest amount of suspended load of 7570 metric tons per sq. km. per year which is nearly 3 times more than that of Yellow river the highest at global scale. The Torsa watershed is producing the least amount of suspended load among the major watersheds in North Bengal which is only 520 metric tons per sq. km. per year i.e., about 14 times less than that of the Jainti watershed. Another worst degraded watershed is the Mahananda that yielded about 3265 metric tons/year/sq.km (Sarkar, 2008).

4.2.2.1 Aggradation and degradation

In an alluvial river, the state of equilibrium is achieved, if the discharge, sediment load, sediment size and slope are balanced. A change in any of these parameters will disturb the equilibrium and the river starts to change its course resulting in aggradation and degradation (Moriswa, M. 1968; Starkel, L & Sarkar, S. 2002). During the process of meandering in the alluvial plains, the river course goes on shifting with the change of meandering pattern, with consequent bank erosion at different places. For the purpose of assessing the extent of aggradation / degradation, the cross-section of various rivers studied by the NBFCC for different years has been analysed (NBFCC, 1965).

It was that the length of cross-sections varies considerably from one cross section to another at different locations. There is significant variation in the area of flow from one year to another indicating deposition or erosion at each of the cross sections. Smaller area of section occurs where velocity is higher (WAPCOS, 2003).

It was also observed that the average depth of deposition or scour varies from 1 cm to 18cm in Tista river, while the same is substantial in case of Jaldhaka and Torsa, varying from 6 cm to 72 cm and 17 cm to 72 cm respectively. There is, however, very high scouring observed in Sankosh river of the order of 165 cm over a period of 14 years from 1986 to 2000. The above studies are only indicative in nature and in no way, can form a basis for planning of any remedial measures (WAPCOS, 2003).

4.2.3 Geomorphic characteristics

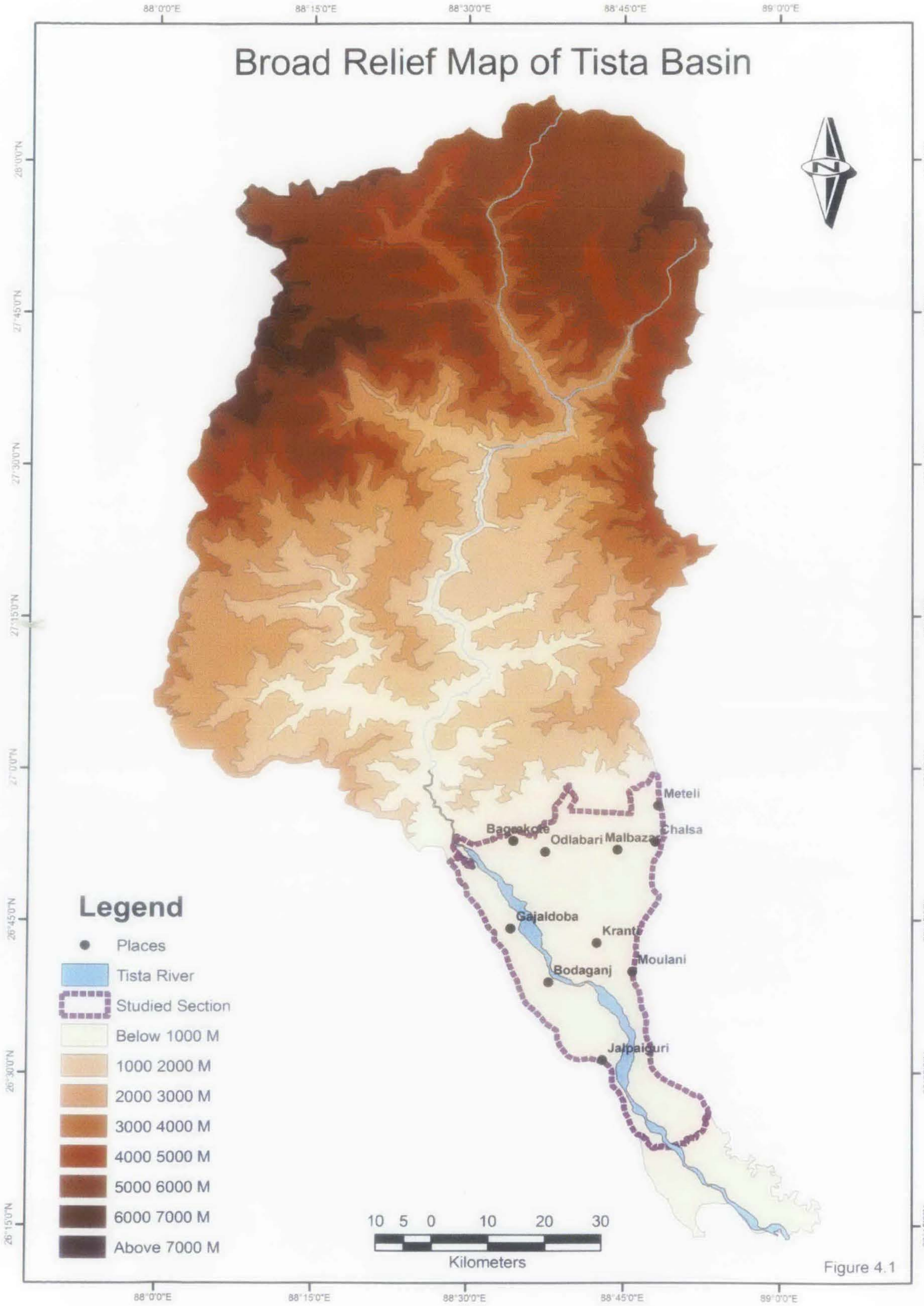
The watersheds under consideration include trans-Himalayan Rivers like the Tista, Torsa, Raidak and Sankosh. While, watersheds like Mahananda and Jaldhaka belongs to lower Himalayan system. The rivers are fed by glacier or ice fields and are supplemented by high intensity rainstorms occurred in sub-Himalayan North Bengal. Each of the watersheds displays unique and fascinating geomorphic characteristics of its own (table 4.5). An attempt has been made to assess geomorphic characteristics of the watersheds in the following sections.

Table No 4.5
Area under different elevation zones for the studied watersheds

Watersheds	Area in sq.km under different altitude zones (meter).							
	< 1000	1 - 2000	2 - 3000	3 - 4000	4 - 5000	5- 6000	6 - 7000	> 7000
Mahananda	141	34	0	0	0	0	0	0
Tista	1834	1946	1647	972	807	2061	247	34
Jaldhaka	857	368	301	76	24	0	0	0
Torsa	288	627	770	801	969	388	29	0
Raidak	809	556	1385	1783	622	106	32	2
Sankosh	542	2501	2458	1690	1178	1308	855	2

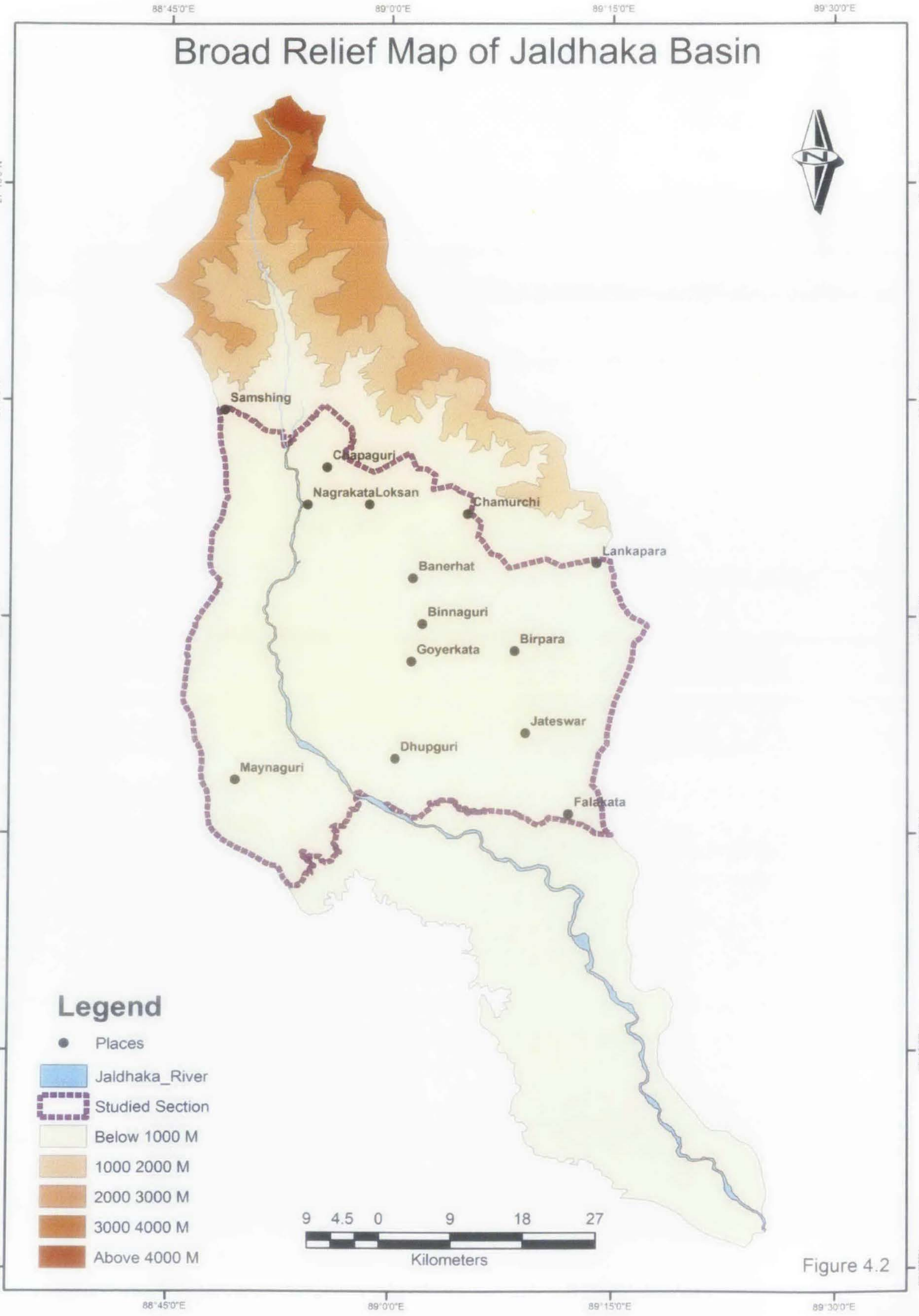
4.2.3.1 The Tista Watershed

The river Tista originates from a cluster of glaciers at the southeastern base of the Kanchenjangha Massif (mean altitude >7000 meter) the second loftiest peak in the World. The Tista watershed under study thus extends from the Kanchenjangha peak (8585 meter) to the gauging station at Domohani (80 meter) thus exhibits fascinating topographic diversities. The total amplitude has been estimated to be 8000 meter within an aerial distance of 178 km.



Broad Relief Map of Tista Basin
88°0'0"E
88°15'0"E
88°30'0"E
88°45'0"E
89°0'0"E
28°0'0"N
27°45'0"N
27°30'0"N
27°15'0"N
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N
N
Meteli
Bagrakote
Odlabari
Malbazar
Chalsa
Gajaldoba
Kranti
Moulani
Bodaganj
Jalpaiguri
Legend
Places
Tista River
Studied Section
Below 1000 M
1000 2000 M
2000 3000 M
3000 4000 M
4000 5000 M
5000 6000 M
6000 7000 M
Above 7000 M
10 5 0 10 20 30
Kilometers

Figure 4.1



Broad Relief Map of Jaldhaka Basin
88°45'0"E
89°0'0"E
89°15'0"E
89°30'0"E
27°15'0"N
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N
26°0'0"N
N
Samshing
Chapaguri
NagrakataLoksan
Chamurchi
Lankapara
Banerhat
Binnaguri
Birpara
Goyerkata
Jateswar
Dhupguri
Maynaguri
Falakata
Legend
Places
Jaldhaka_River
Studied Section
Below 1000 M
1000 2000 M
2000 3000 M
3000 4000 M
Above 4000 M
9 4.5 0 9 18 27
Kilometers

Figure 4.2

The mean gradient of Tista watershed under studied section has been estimated to a staggering figure of 1:21 one of the steepest at global scale for a comparable size watershed. Topographic parameters of the studied watersheds have been assessed from the US Army Topographic Sheets and tabulated in table 4.5 and diagrammatically represented in figure 4.1.

4.2.3.2 The Jaldhaka Watershed

The river Jaldhaka originates from Bidan Lake in Sikkim near the famous Kalimpong-Lhasa Trade Route (*Silk Route*) along Indo-China border in Sikkim (mean altitude >5000 meter). The Jaldakha watershed under study thus extends from Nangpo (5964 meter) at tri-junction point (boundary among India, China (Tibet) and Bhutan) to the gauging station at Dhupguri (88 meter) thus exhibits fascinating topographic diversities. The total amplitude has been estimated to be 5876 meter within an aerial distance of 86 km. The mean gradient of Jaldhaka watershed under studied section has been estimated to a staggering figure of 1:15 one of the steepest at global scale for a comparable size watershed. Topographic parameters of the studied watersheds have been assessed from the US Army Topographic Sheets and tabulated in table 4.5 and diagrammatically represented in figure 4.2.

4.2.3.3 The Torsa Watershed

The river Torsa originates from Chumuk glacier of Great Himalaya in Chumbi valley in Tibet (China) (mean altitude >6000 meter). The Torsa watershed under study thus extends from the Chumbi valley (China) to the gauging station at Hasimara thus exhibits fascinating topographic diversities. The total amplitude has been estimated to be 7197 meter within an aerial distance of 147 km. The mean gradient of Torsa watershed under studied section has been estimated to a staggering figure of 1:20 one of the steepest at global scale for a comparable size watershed. Topographic parameters of the studied watersheds have been assessed from the US Army Topographic Sheets and tabulated in table 4.5 and diagrammatically represented in figure 4.3.

4.2.3.4 The Raidak Watershed

In the hilly tract of Bhutan, the river receives a large number of tributaries and the river is locally known as the Wong Chu, Paro Chu and Ha Chu. It passes through steep, narrow gorges and consequently it has no scope to change its course. In this tract the bed

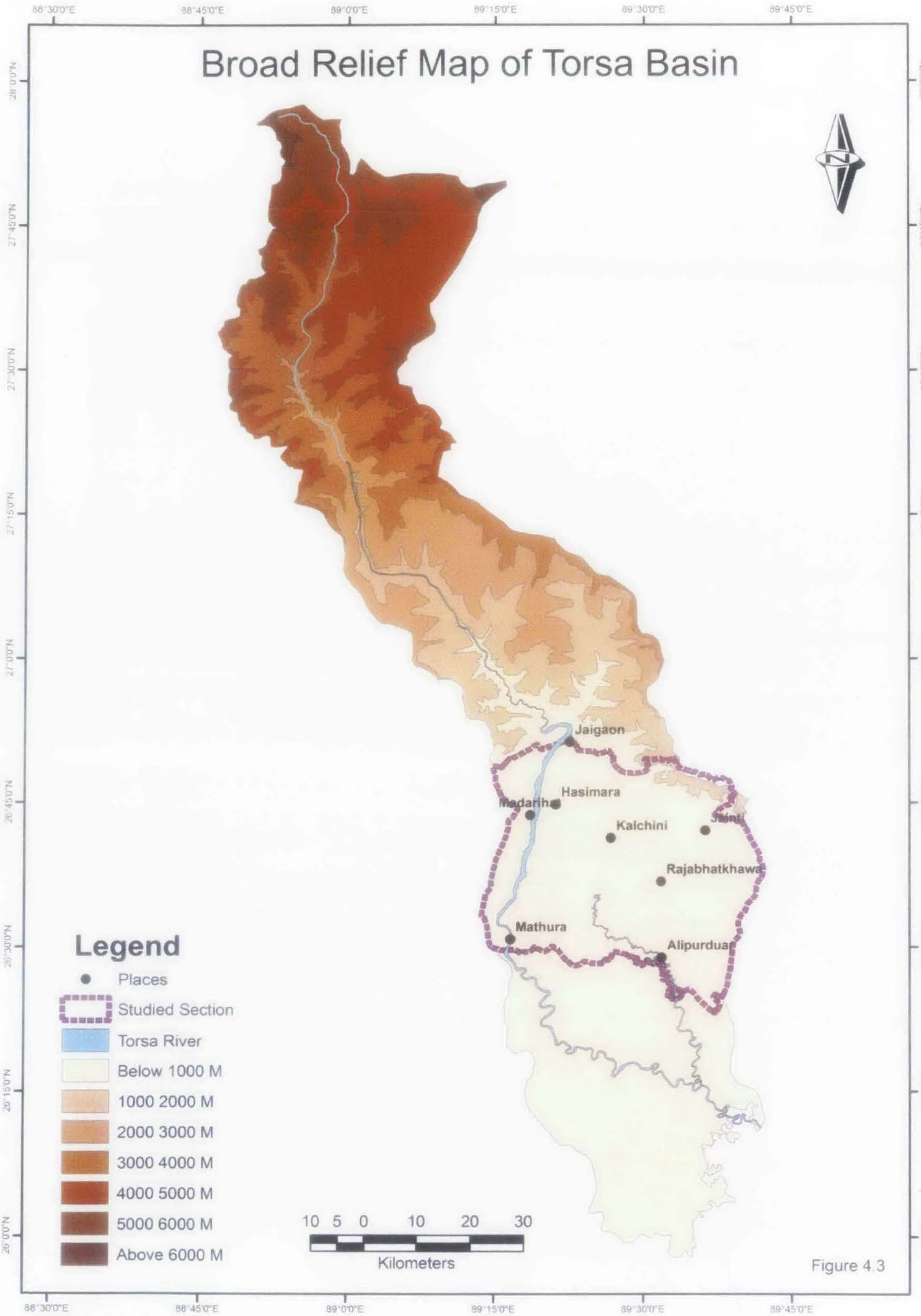
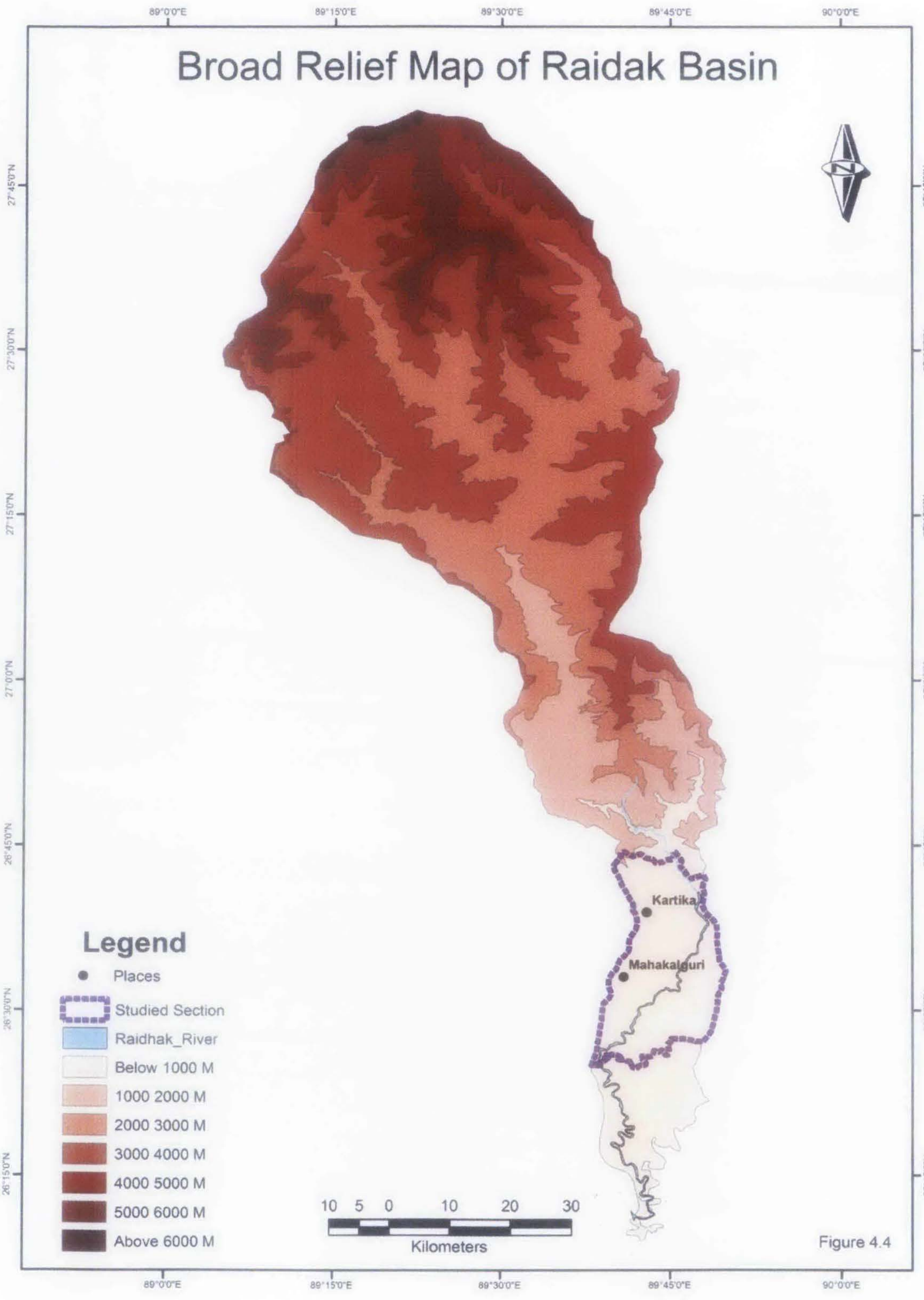

Broad Relief Map of Torsa Basin
Jaigaon
Hasimara
Madariha
Kalchini
Rajabhatkhawa
Mathura
Alipurduar
Legend
Places
Studied Section
Torsa River
Below 1000 M
1000 2000 M
2000 3000 M
3000 4000 M
4000 5000 M
5000 6000 M
Above 6000 M
10 5 0 10 20 30
Kilometers

Figure 4.3



Broad Relief Map of Raidak Basin
89°0'0"E
89°15'0"E
89°30'0"E
89°45'0"E
90°0'0"E
27°45'0"N
27°30'0"N
27°15'0"N
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N
Kartika
Mahakalguri
Legend
Places
Studied Section
Raidhak_River
Below 1000 M
1000 2000 M
2000 3000 M
3000 4000 M
4000 5000 M
5000 6000 M
Above 6000 M
10 5 0 10 20 30
Kilometers

Figure 4.4

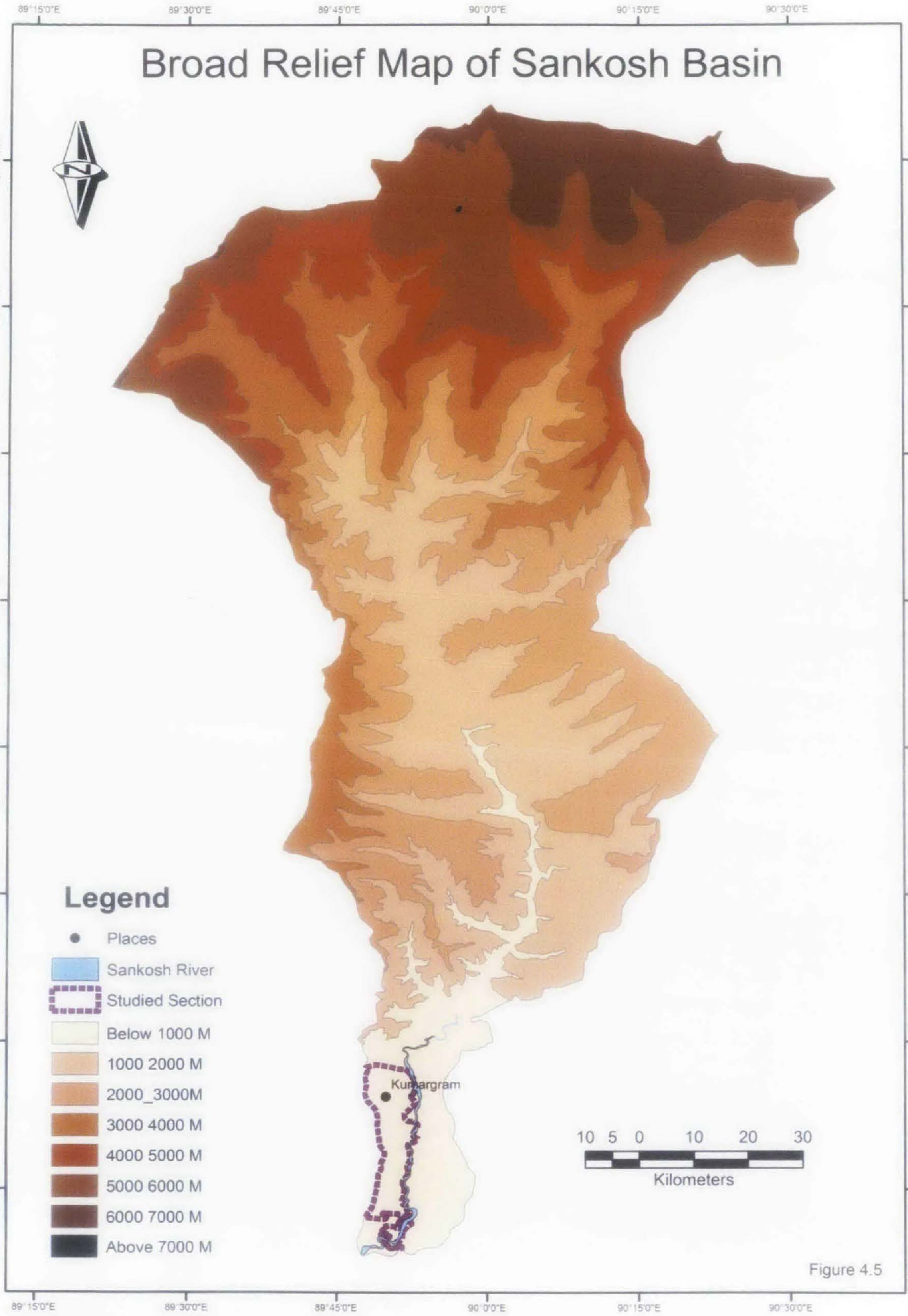
slope is very steep. The slope exceeds at some places causing great velocity of flow particularly during high floods. Though the gorges are very deep and narrow, these consist of rock, which are soft and denuded and cannot withstand the high velocity during floods. Consequently, land slips occur rather frequently. Large quantities of detritus came down into the river and are carried down into the lower regions. The silt charge of the river increases many times during flood. The behaviour of the river in the lower reach is a history of the frequent changes of its course. The river is bifurcated into Raidak I and Raidak II in Jalpaiguri district. It had changed it course frequently during the last century.Topographic parameters of the studied watersheds have been assessed from the US Army Topographic Sheets and tabulated in table 4.5 and diagrammatically represented in figure 4.4.

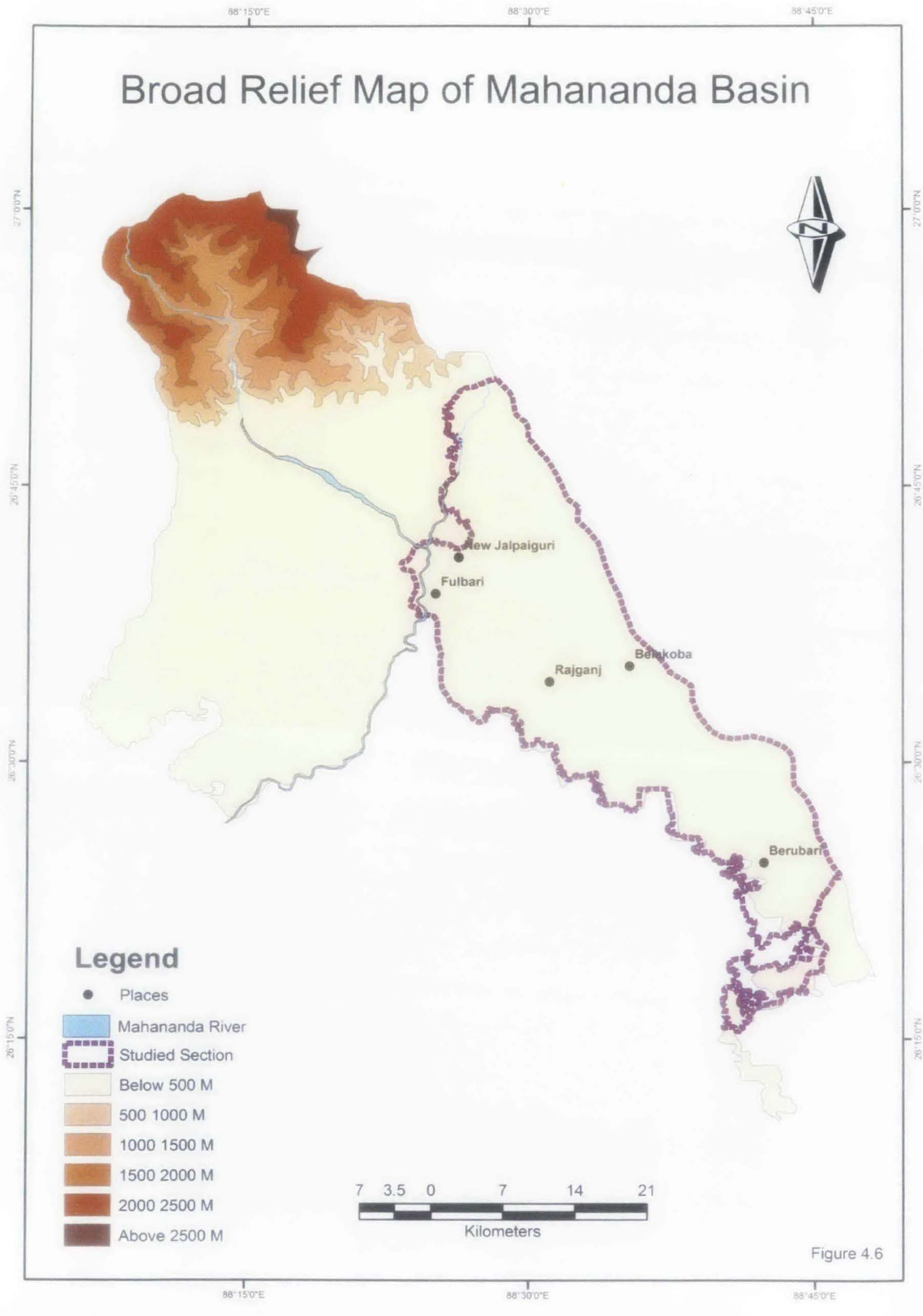
4.2.3.5 The Sankosh Watershed

The river Sankosh originates from a cluster of ice fields from the Bhutan-Tibet (China) border (mean altitude >6500 meter). The Sankosh watershed under study thus extends from Tibet-Bhutan border Tamrei Gangri (7516 meter) to the gauging station at Domohani (48 meter) thus exhibits fascinating topographic diversities. The total amplitude has been estimated to be 7468 meter within an aerial distance of 208 km. The mean gradient of Sankosh watershed under studied section has been estimated to a staggering figure of 1:28 one of the steepest at global scale for a comparable size watershed. Topographic parameters of the studied watersheds have been assessed from the US Army Topographic Sheets and tabulated in table 4.5 and diagrammatically represented in figure 4.5.

4.2.3.6 The Mahananda Watershed

The river Mahananda originates from Chimli in Dow Hills, Kurseong at an altitude of 2040 meter. The Mahananda watershed under study thus the smallest one extends from the Dow Hills to the gauging station at Champasari (125 meter) thus exhibits fascinating topographic diversities. The total amplitude has been estimated to be 2070 meter within an aerial distance of 26 kms. The mean gradient of Mahananda watershed under studied section has been estimated to be of 1:14. Topographic parameters of the studied watersheds have been assessed from the US Army Topographic Sheets and tabulated in table 4.5 and diagrammatically represented in figure 4.6.


Broad Relief Map of Sankosh Basin
Legend
Places
Sankosh River
Studied Section
Below 1000 M
1000 2000 M
2000_3000M
3000 4000 M
4000 5000 M
5000 6000 M
6000 7000 M
Above 7000 M
Kumargram
10 5 0 10 20 30
Kilometers
N
Figure 4.5



Broad Relief Map of Mahananda Basin
88°15'0"E
88°30'0"E
88°45'0"E
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N
N
New Jalpaiguri
Fulbari
Belakoba
Rajganj
Berubari
Legend
Places
Mahananda River
Studied Section
Below 500 M
500 1000 M
1000 1500 M
1500 2000 M
2000 2500 M
Above 2500 M
7 3.5 0 7 14 21
Kilometers

Figure 4.6

4.3 Land use characteristics

Watershed land use constitutes an important controlling parameter in the overall process-response mechanism of respective fluvial system. Land use transformations have had cascading effects in fluvial dynamics of each of the studied catchments. Land use/cover data were derived from the Satellite images (Google Earth 2008) and US topographic maps at scale of 1:250000.

Six land use/cover classes were delimited: forests, cultivated & settlement, tea plantation, rocky wastes, ice field and glaciers. The boundaries between them were manually digitized on screen using visual interpretation technique under GIS platform. The analytical findings have been tabulated in table 4.6 and 4.7.

Table No 4.6

Land use pattern of selected watersheds from source up to Indian territory

Watershed	Area in sq. km under different land use category					
	Forest	Cultivated & Settlement	Tea Plantation	Rocky wastes	Ice field	Glaciers	Watershed Area
Mahananda	587	1328	237	0	0	0	2144
Tista	4339	2641	307	1749	1100	105	10189
Jaldhaka	1376	2694	211	79	0	0	4370
Torsa	3321	2350	163	920	48	8	7129
Raidak	3704	804	67	914	45	0	5472
Sankosh	6995	618	15	2019	1294	12	10879

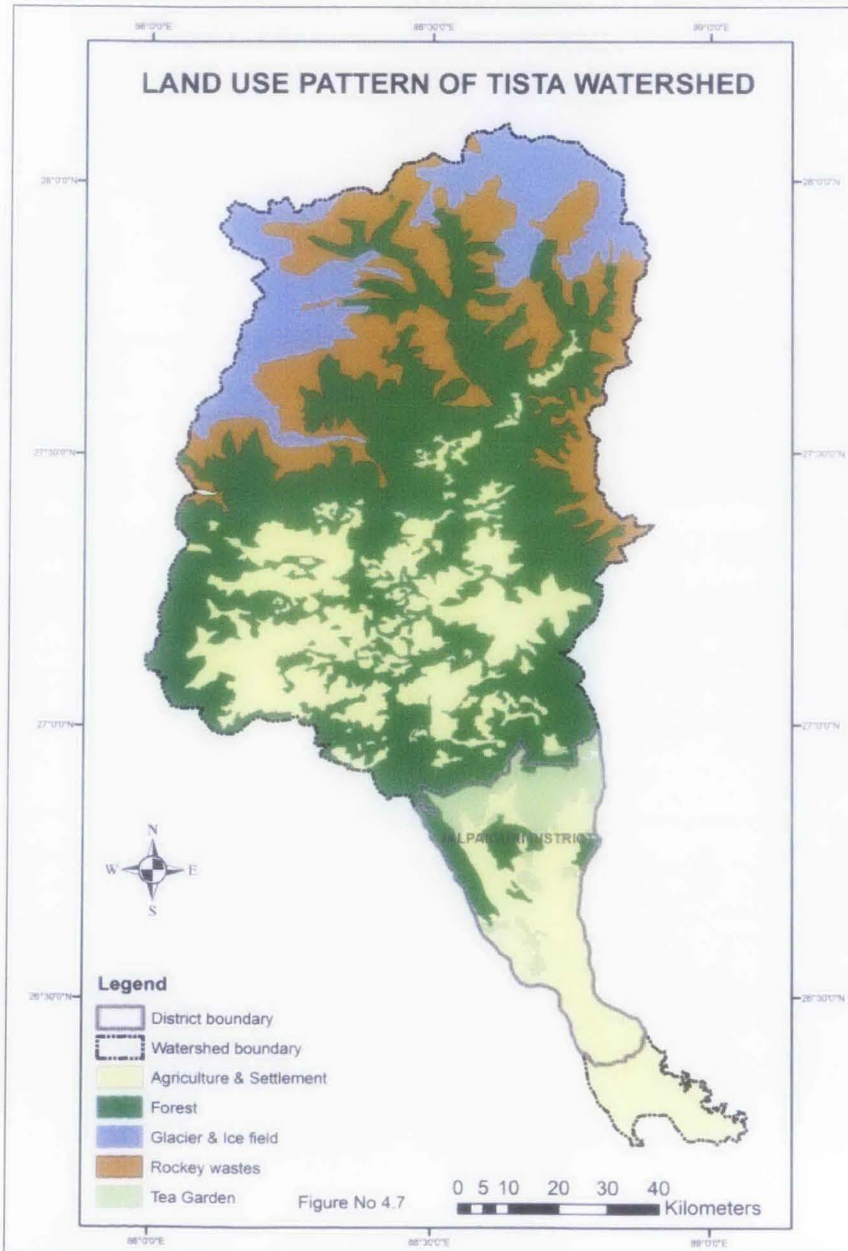
Table No. 4.7

Land use Pattern of the Watersheds situated within Jalpaiguri district

Watersheds	Area	Forest	Agriculture & Settlement	Tea Garden	Rocky Land	Ice Field & Glacier
Tista	1204	194	705	307	0	0
Torsa	1645	896	619	163.2	0	0
Jaldhaka	2033	474	1409	211	0	0
Mahananda	771	114	652	5	0	0
Raidak	451	158	264	32.7	0	0
Sankosh	176	73	87	15	0	0

4.3.1 Land use in Tista watershed

The spatial distribution of major land use/cover zone of the Tista catchment has been shown in figure 4.7 and tabulated in table4.6 and that of situated within Jalpaiguri district has been diagrammatically represented in figure 4.8B. The 42% of the total catchment area is still under forest cover in the Tista basin located in Sikkim and West Bengal. Arable use and settlement occupy about 26% and another 3% occupied by tea garden. Nearly one third of the catchment area remains beyond limit of possible human interferences includes rocky wastes (17%), ice field (11%) and glacier (1%).



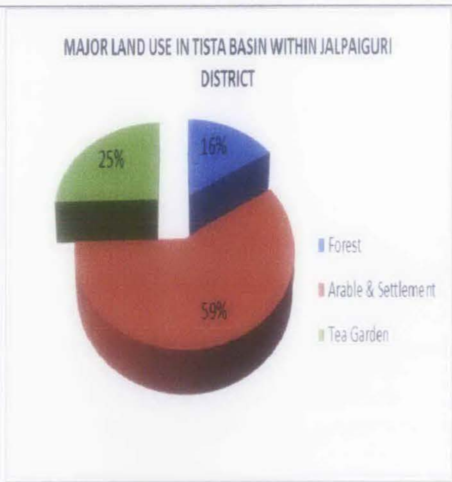


Figure 4.8A Land use of Tista Watershed in Jalpaiguri District

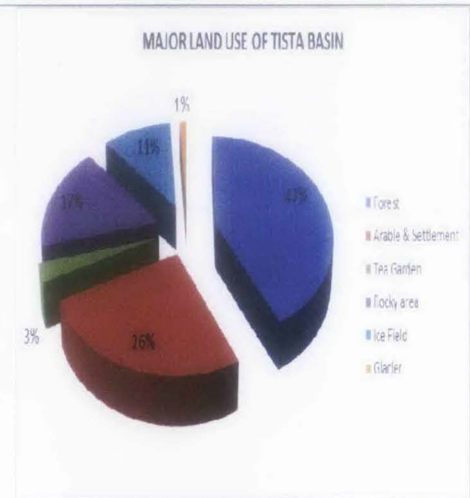
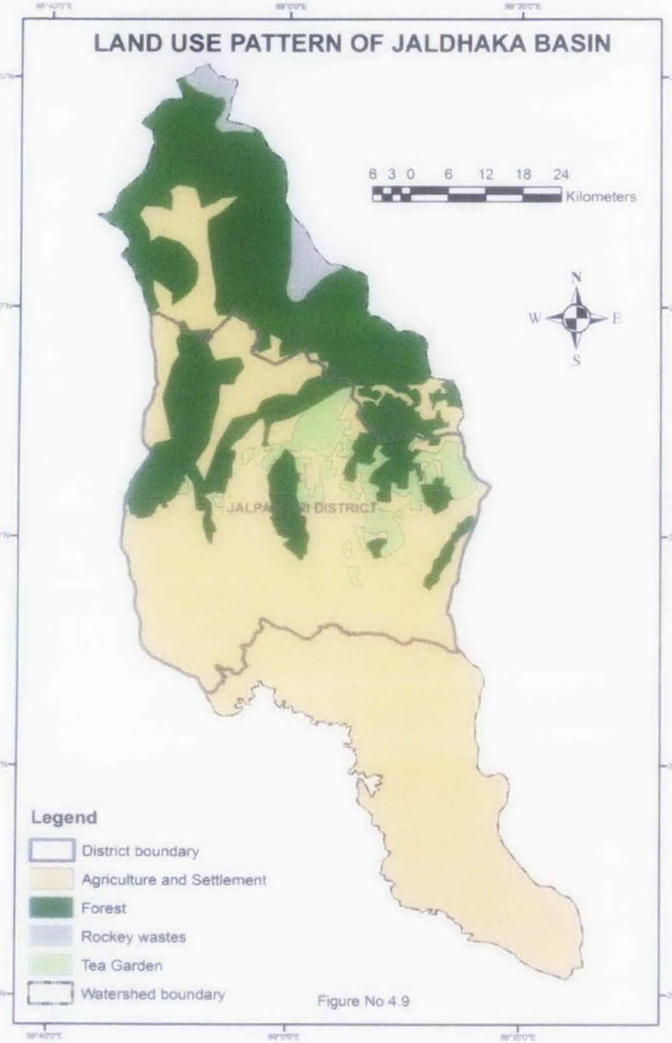


Figure 4.8B Land use of Tista Watershed

Land use of Tista watershed situated within Jalpaiguri district is tabulated in table 4.7 and diagrammatically represented in figure 4.8A. Only 16% of the total watershed area situated in Jalpaiguri is covered by forest and another 25% is under tea plantation. While 59% of the total area under direct utilization in the form of settlement and under cultivation.



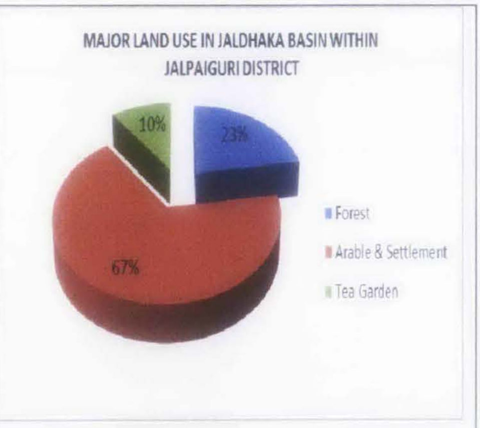


Figure 4.10A Land use of Jaldhaka watershed in Jalpaiguri District

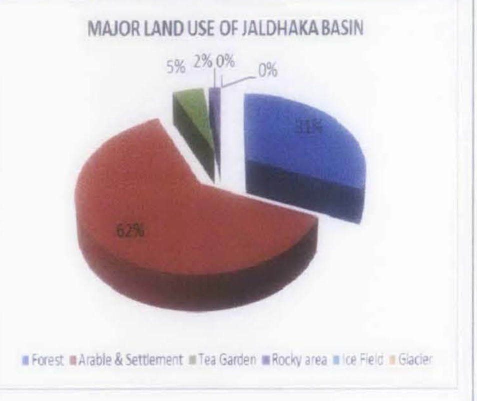


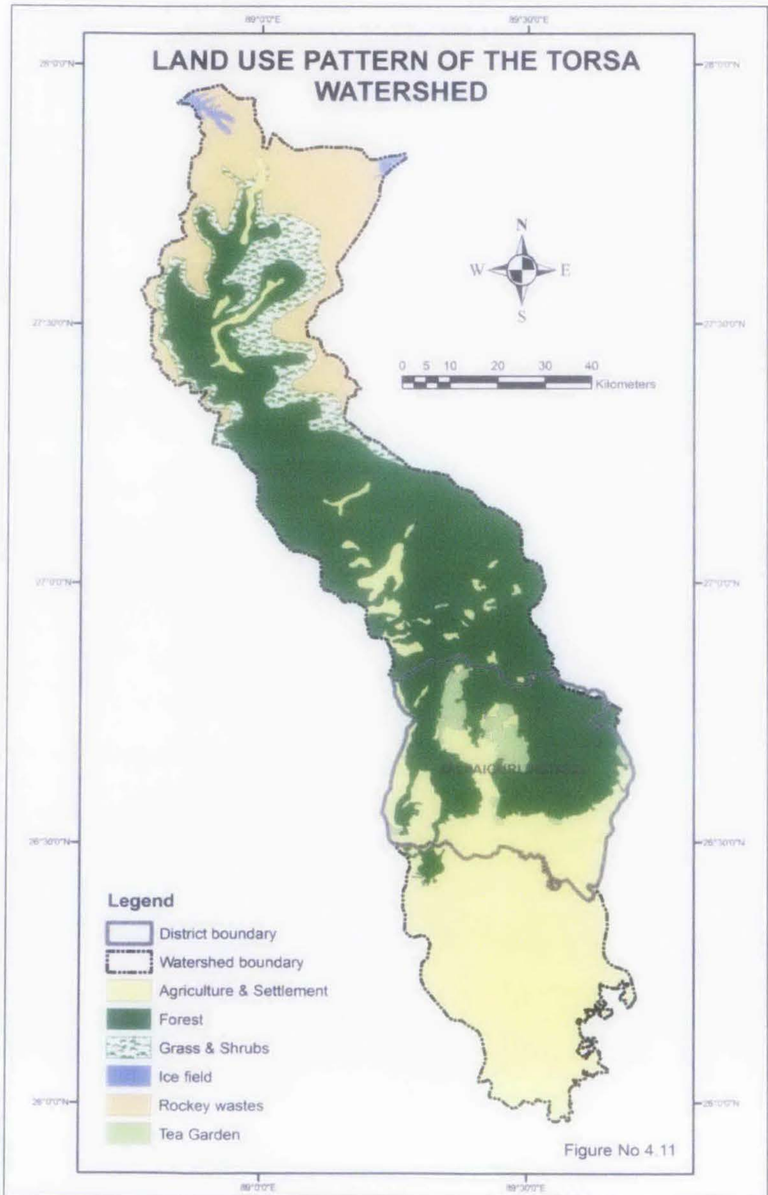
Figure 4.10B Land use of Jaldhaka watershed

4.3.2 Land use in Jaldhaka watershed

Land use pattern of Jaldhaka watershed has been assessed based on Satellite images obtained from IRS and Google Earth (2007) on standard GIS platform (Global Mapper 8.0). The analytical result has been represented in table no. 4.6 and 4.7. It is interesting to note that only 67% of the watershed has been under the influence of human interference of different levels, whereas 31% of the total watershed area is being under natural forest cover. Only 2%

area of the watershed has been identified as rocky wastes. The spatial distribution of major land use/cover zone of the Jaldhaka watershed has been shown in figure 4.9 and diagrammatically represented in figure 4.10B.

However the land use of Jaldhaka watershed within Jalpaiguri district is rather interesting and has been diagrammatically represented in figure 4.10A. It is found that 67% of the total area is covered by arable farming and settlement and another 10% is under tea plantation. While, forest cover an area of 23% of the total watershed in Jalpaiguri district.



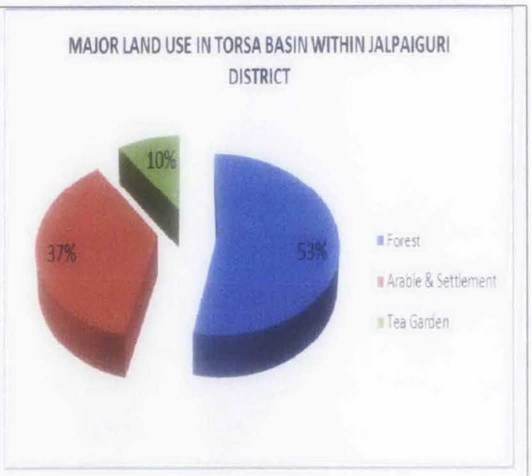


Figure 4.12A Land use of Torsa watershed in Jalpaiguri District

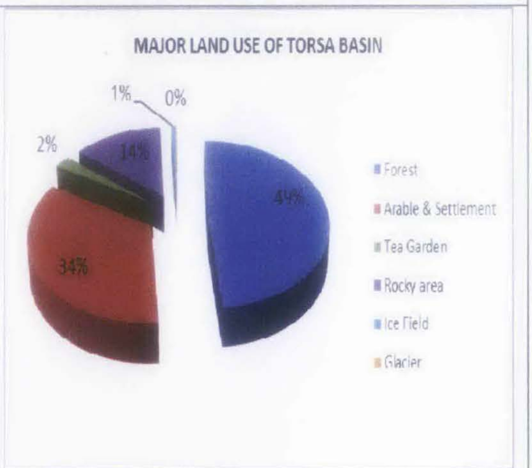


Figure 4.12B Land use of Torsa watershed

4.3.3 Land use in Torsa watershed

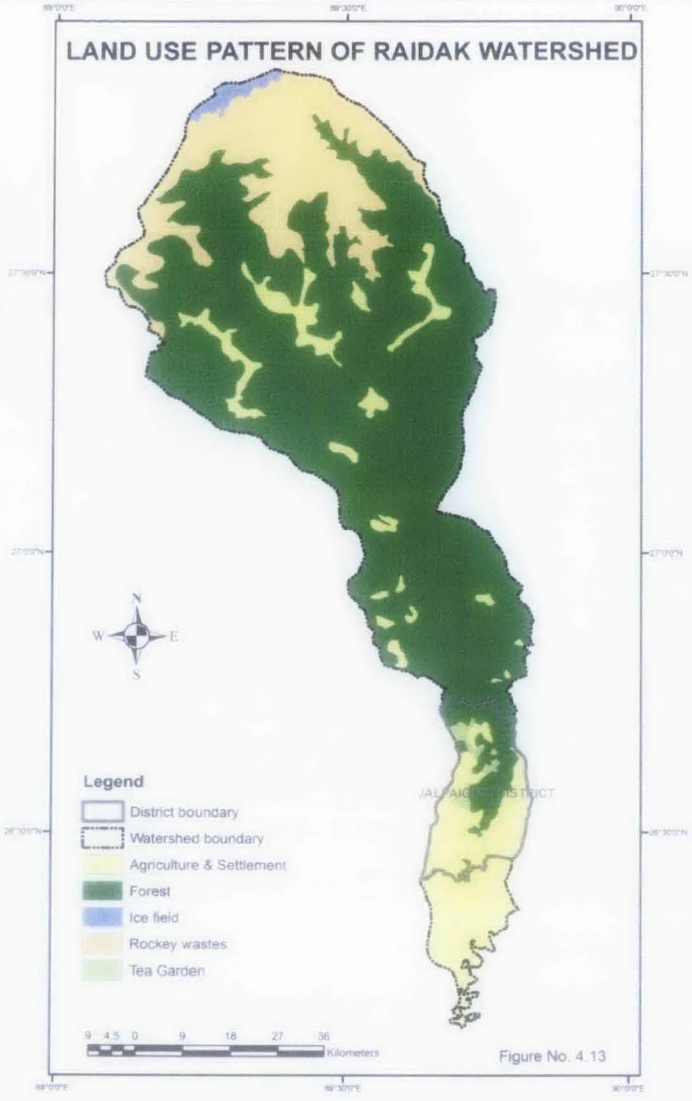
Land use pattern of the Torsa watershed has been assessed based on Satellite images obtained from IRS and Google Earth (2007) on standard GIS platform (Global Mapper 8.0). The analytical result has been represented in table no. 4.6 and spatial distribution of major land use/cover zone of the Torsa watershed has been shown in figure 4.11 and diagrammatically represented in figure no. 4.12B. It is noticeable here that only 36% of the watershed has been under the influence of human interferences of different levels. On the other hand, 49% of the total watershed area is being under natural forest cover and the remaining 15% area remains beyond the limit of human interference includes rocky area, ice field and glaciers.

However the land use of Torsa watershed within Jalpaiguri district is rather interesting and has been diagrammatically represented in figure 4.12A and tabulated in table 4.7. The Torsa watershed retains the largest area of Jalpaiguri, is famous for pristine forest which is over 53% of the area. Tea garden covers an area of another 10%. The remaining 37% of the watershed is under arable farming and settlement.

4.3.4 Land use of the Raidak watershed

The land use pattern of Raidak watershed is shown in table 4.6 and the spatial distribution of major land use/cover zone of the Raidak watershed has been shown in figure 4.13 also diagrammatically represented in figure 4.14B. It is observed that 67% of the total watershed is still under natural forest cover which is mostly situated in Bhutan and another 16% is identified as rocky land of high hills and steep scarps again situated in Bhutan. Only 15% of the total watershed area has been identified under direct human interference in the form of either agriculture or settlement (figure 4.14B).

However the land use of Raidak watershed within Jalpaiguri district is rather interesting and has been diagrammatically represented in figure 4.14A and tabulated in table 4.7. The Raidak watershed also retains 35% under forest and another 7% area covered by tea garden. While, the settled and arable use covered an area of 58% of the total.



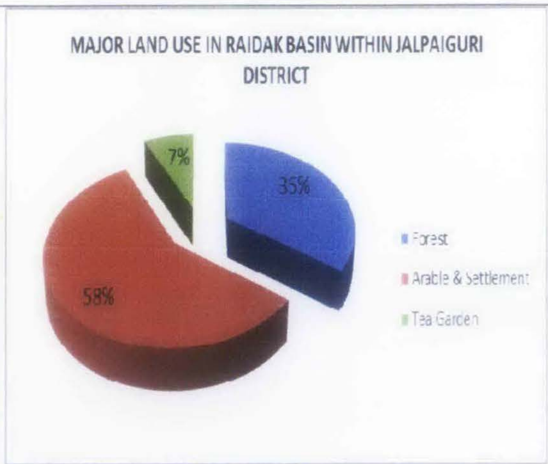


Figure 4.14A Land use of Raidak watershed in Jalpaiguri District

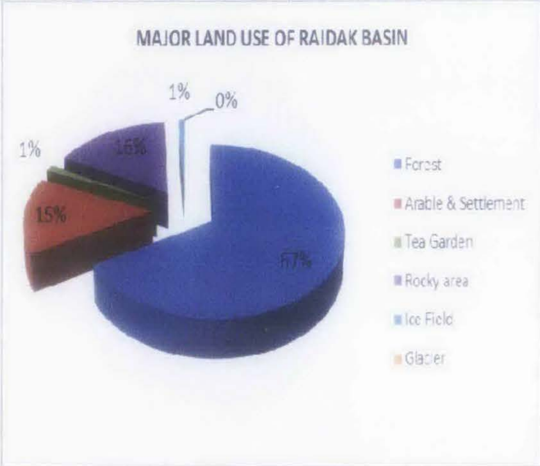
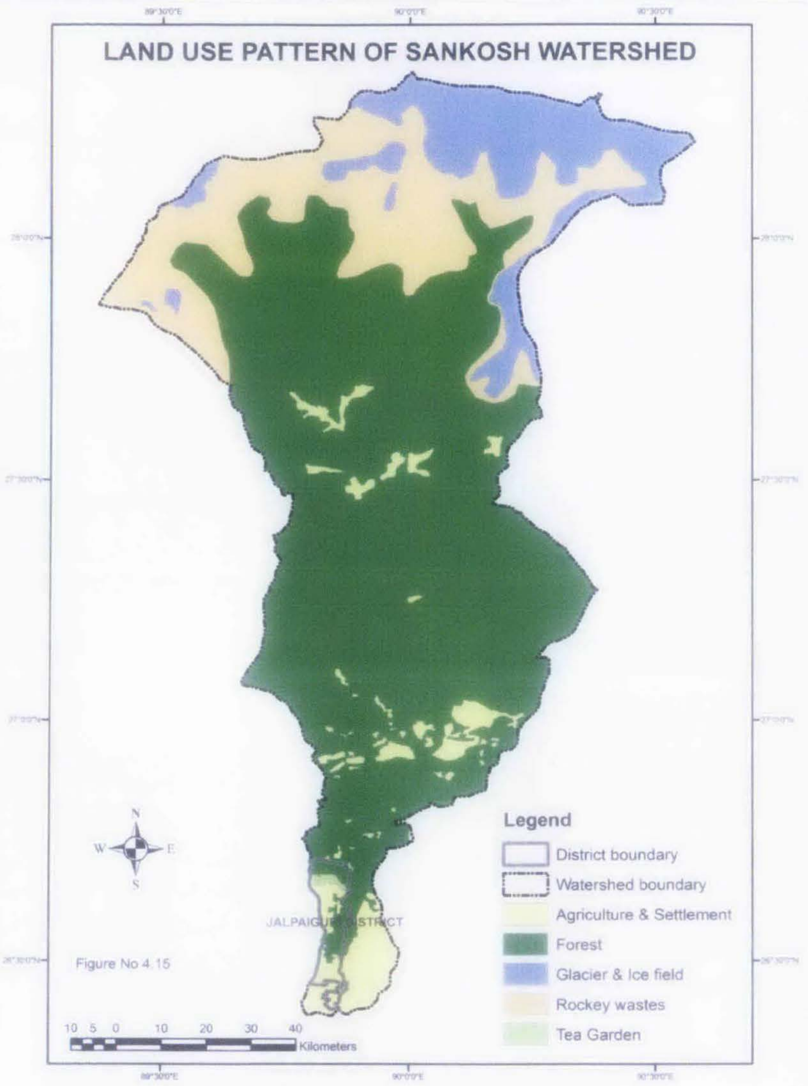


Figure 4.14B Land use of Raidak watershed

4.3.5 Land use of the Sankosh watershed

The existing land use of Sankosh watershed has been assessed based on Satellite images obtained from IRS and Google Earth (2007) on standard GIS platform (Global Mapper 8.0). The analytical result has been represented in table no. 4.6 and spatial distribution of major land use/cover zone of the Sankosh watershed has been shown in figure 4.15 and also diagrammatically represented in figure no. 4.16B. It is interesting to note that only 6% of the watershed has been under the influence of human interference of different levels. On the contrary, 64% of the total watershed area is being under natural forest cover. Rocky wastes and ice field cover 18% and 12% of the total catchment respectively.

However the land use of Torsa watershed within Jalpaiguri district is rather interesting and has been diagrammatically represented in figure 4.16A.



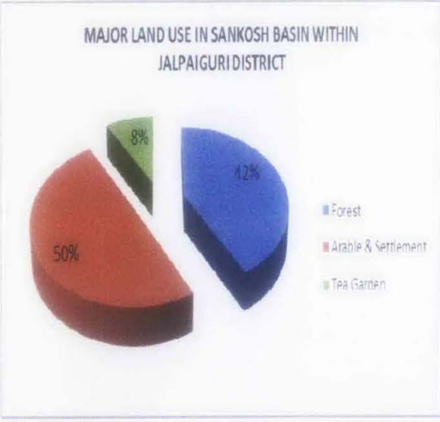


Figure 4.16A Land use of Sankosh watershed in Jalpaiguri District

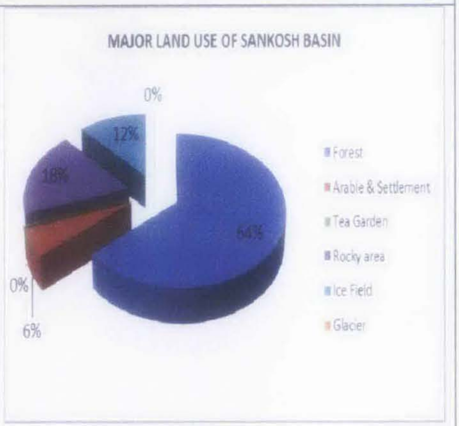
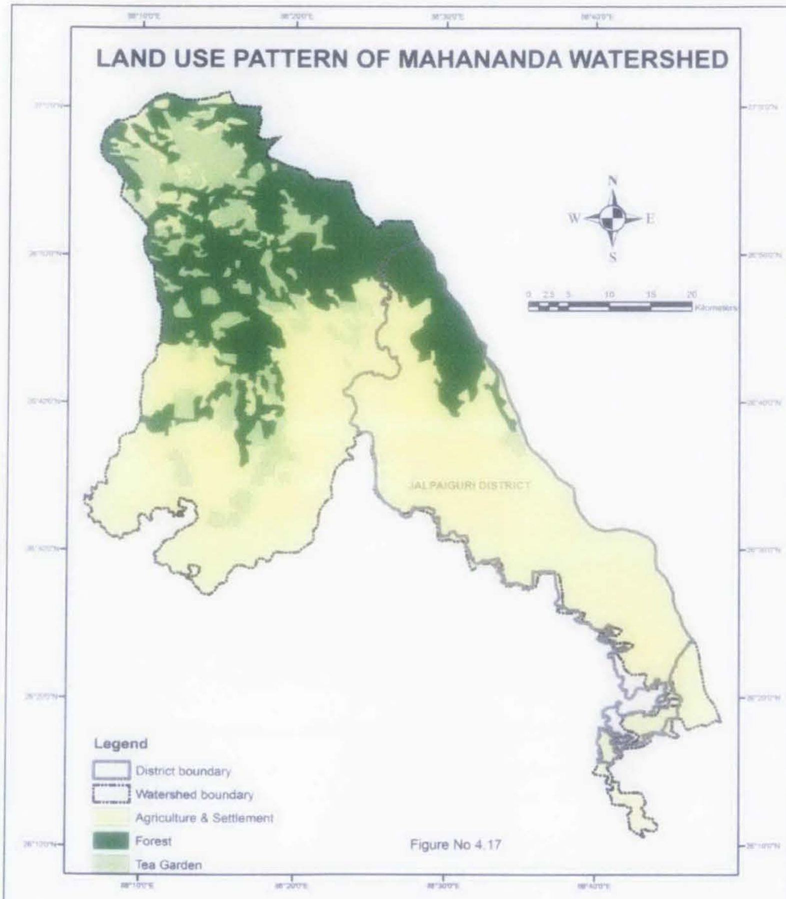


Figure 4.16B Land use of Sankosh watershed

4.3.6 Land use in Mahananda watershed

The land use of Mahananda watershed has been assessed based on Topographical maps and Satellite images obtained from Google Earth (2007) on standard GIS platform (Global Mapper 8.0). The spatial distribution of major land use/cover zone of the Mahananda watershed has been shown in figure 4.17. The analytical result has been represented in table no. 4.6 & 4.7 and diagrammatically represented in figure no.4.18B.It is to be noticed that 73% of the total watershed has been under the influence of human interference of different levels. On the contrary, 27% of the total watershed area is being under natural forest cover.

However the land use of Mahananda watershed within Jalpaiguri district is rather interesting and has been diagrammatically represented in figure 4.18A. It is observed that 85% area of the watershed in Jalpaiguri district is under the impact of human interferences of different degrees. Only 15% area of Mahananda watershed in Jalpaiguri district is still under forest cover.



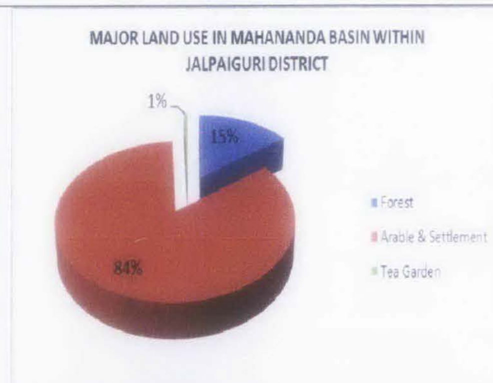


Figure 4.18A Land use of Mahananda watershed in Jalpaiguri District

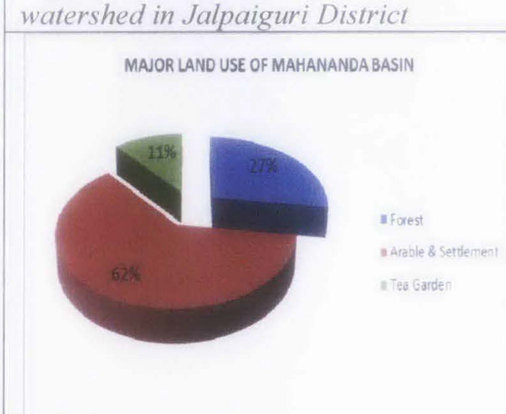


Figure 4.18B Land use of Mahananda watershed

4.4 Land use transformation

Data for the assessment of land use transformation in the studied watersheds has been obtained from multiple sources. The topographical of SOI of different editions within Indian territory representing forest, tea gardens and other land uses. For the Bhutanese part, mainly forested and detail information does not exist. These were supplemented by satellite pictures, which served to calculate the main land use types in the piedmont zone and hilly part of particular river catchments. Google image also been used for updating under GIS platform. Among the major land use types forest, arable and settled area, tea garden, rocky wastes, ice field and glacier are identified and depicted in different maps and diagrams.

Gradual depletion of the forest from north to south at the expense of agriculture is the most remarkable feature of present day land use. The land use pattern reflects the relief of three large geomorphic units: mountains, alluvial fans and plains (Starkel, L., Sarkar, S., Soja, R., Prokop, P. 2008). Each of them has different climatic conditions, lithology, and soils. These determine human activity, which is realised mainly through development of the various forms of agriculture, settlement and in minor extent mineral extraction. Present day land use is the result of human impact ongoing from centuries but its changes were accelerated when the British East India Company took control of Bengal in the mid-19th century. Since then large scale heedless deforestation initiated due to foundation of tea plantations and heavy demand of timber for railway and building construction. The 20thcentury was marked by demographic explosion. Population was additionally increased through migration of people from Nepal and Bangladesh to the Indian part of Himalayas and migration from Bengal plains to tea plantations located close to the Himalayan foreland.

4.4.1 Mountains

Most of the mountain area is grown by various types of natural forest. It changes from moist deciduous with dominant *Shorearobusta* up to 1000 m. through tropical evergreen with *Quercus* and *Castanopsis*up to 2000 m. and Rhododendron pure stand in between 2500-2800 m, to temperate coniferous at the elevation 3000-3500 m. Only upper part of the Jaldhaka and Torsa catchments is covered by sub-alpine fir forest, which gradually changes to alpine grasslands above the upper timberline at approximately 4000 m (Champion, Seth 1968).

The margin of mountains is usually densely populated and human impact on environment is more visible compare to upper part of Himalayas. This relationship is less evident only in Siwalik zone of Lish and Gish catchments built up of unconsolidated sandstones and pebbles not suitable for settlements. In both catchments the most deforested area is shifted 5 km northward, where deep weathered Daling,quartzite and phyllites are dominant (Basu, Ghatowar 1988). This area has long been turned into cultivated fields or quarrying coal from thin belt of Damuda series and has the highest population density (200 persons/km^2).

Deeper into the mountains the relationship between major river valleys and deforestation is visible. The river channel widths in their upper and middle courses are stable but closer to the mountain margin they extend laterally. The settlement in this area is confined to the gentle slopes of intermountain valleys suitable for agriculture and close accessible transport routes. This is due to road construction along river courses, which was a dominant feature in the colonization process. The population density in this area is still high but it gradually decreases towards the east to 120 persons/km^2 in the Chel and Jaldhaka catchments near Bhutan border. The irregular, small deforested patches are connected with dispersed settlement of people which practice slash and burn agriculture till now. The area of Bhutan has lowest population density in the whole investigated area. It comes to 40 persons near the border with Indian plains where Phuntsholing, the largest town in the mountains with 20000 inhabitants is located. The quarrying of dolomite along the base of Indo-Bhutan hills has only local influence on forest cutting but increase the instability of slopes causing large scars of vegetation. The population density decreases towards the north to 7 persons/km^2 in the middle part of Torsa catchment and to 1 person/km^2 in its upper part. The small catchments east of Pana river in Bhutan are less settled and forested by more than 90%.

4.4.2 Alluvial fans of Terai and Duars

The mountain foreland is built up of alluvial fans and higher elevated terraces. The extension of fans is roughly bounded by the 100 m contour. A significant part of this area is covered by sanctuaries and reserved forest. It consists mainly of *Shorearobusta* the most valuable commercial tree. This forest is mixed with patches of pure deciduous forest with *Schimawallichii* or Acacia Catechu (Champion, Seth 1968). The largest reserved forests are located along Jaldhakariver - Tondoo Forest, Torsa - Barajhor Forest and between Dima and Jainti - Buxa Forest. Thus the area under forest increase from 13-33% in Lish, Gish, Chel, Jaldhaka, Reti, Torsa and Pana catchments to above 76% in Dima, Bala and Jainti catchments.

Tea plantation occupies the largest part of the alluvial fans of the Lish, Gish, Chel, Rethi and Pana catchments. The forest clearance under tea plantations combined with the building of roads and railways has given rise to settlement and trade. The rural population density reaches now 300-500 persons/km^2. The roads and railways were built above normal flood levels. Many embankments were constructed along transport lines that were cross the rivers. These gave impulse to development many of small urban centres as local administrative headquarters often at the junctions of rivers and new transport routes.

Decrease in the river gradients at the outlet from the mountains causes decrease of transport capacity and cause extensive deposition of material eroded from mountains. The overloaded rivers are liable to shift their braided courses significantly. In many places land surrounding the rivers built of boulders and gravels is covered by grasses with sparse trees or swampy vegetation. The wide braided channels cover 10%, which is substantial part of the total area.

Annual floods cause direct loss of forest, tea gardens and settlement lead to changes in land use/cover. Study in the Buxa Reserve Forest in Jainti catchment show that 850 ha of forest and 75 ha of tea garden was destroyed by bank failure and shifting river courses between 1993 and 1999 (Sarkar, 2008). One of the most important indirect effects of floods is change in soil properties in terms of productivity. During devastating floods of 1954 about 10 sq. km of cultivated land had been wasted by deposition of silts in the Gish catchment (Basu, Ghatowar 1988). Accumulation of calcium by floodwater over alluvial fans causes alkalinity of the soil that decreases productivity and quality leading to abandonment tea plantations and dead trees (Sarkar, 2008).

4.4.3 Alluvial plain

At the distance of 20-25 km from the mountain front the fans coalesce in extensive alluvial plain, gradually lowering from 100 to 50 meter and built up of fine grained sediments over bank deposits. The river gradients and channels width diminishes and they turn from braided to meandering. The area covered by active channel decrease to 4% of the total plain area. Along major rivers there are elevated parts of levees or embankments, which are several kilometres in length. These are favoured sites for larger settlements. River banks are not completely protected as a result some parts of floodplain are inundated every year. Alluvial soils offer one of the most productive agricultural lands in the region. As a result, this area experienced the massive transformation of land use/cover system. Nearly all of the natural forests of the plain have been cleared by a process of agricultural colonisation ongoing for centuries. Tea plantations and forest preserved only on higher river terraces or remnants of alluvial fans in the north-eastern part of the plain. Almost the whole area was converted to intensive settled paddy/rice cultivation. Rural population density exceeds 500 persons/sq.km and in some places reaches 1000 persons/km^2, which is among the highest known in the human history.

4.5 Land degradation

The sub-Himalayan North Bengal is a region of wide variety of renewable and non-renewable resources. Of late, this repository of natural wealth has been subjected to virtual plunder. In consequence, the watershed ecosystems are fast loosing their resilience and regenerative capacity. Since the British occupation, the physico-cultural set-up of this region has been seriously disturbed. Extensive heedless deforestation, tea plantation, haphazard construction, huge population influx induced illogical slope cultivation, inadequate drainage, in other words, unscientific and unplanned use of land has led to the establishment of vicious cycle of degradation. As a result, during heavy and concentrated rainfall, catastrophic soil erosion and innumerable landslips are caused, contributing huge sediment load to the rivers which are incapable of transporting the load efficiently under the existing hydrological conditions especially along their lower courses beyond the foothills. The river beds are rising, resulting in lessening of cross sectional area, which being incapable of arresting unusual monsoon discharge and cause devastating floods, endangering the vital line of communication, human habitations, farm lands and forests (Sarkar, S. 2007& 2008).

The picture is just opposite during non-monsoon months, when paucity of water hinders the local people from reaping any benefit out of the soils, in conjunction with the rivers themselves.

Erosion, transportation and deposition are primarily nature's way of adjusting fluvial dynamics within its watershed system. Such an adjustment has been found to be deleteriously disturbed by the human interference particularly in the sub-Himalayan watersheds. Implementation of various development schemes, construction of human settlement and road to cater the ever-increasing population, exploitation of forest produce to generate work potential, boosting of agricultural growth, tourism, mining and quarrying, on the Himalayan immature geology trigger the disaster, huge and complex, never encountered before (Sarkar, 1999).

The situation was not so desperate even 100 years back. The hills were densely forested with very thin population and the hormonal relation between the upper and lower parts of the watersheds were well preserved. Extensive heedless deforestation, haphazard construction of roads and settlements, unscientific and illegal mining activities, inadequate drainage, in other words – unscientific and unplanned usage of land, has led to the establishment of vicious cycle of degradation. During heavy and concentrated rainfall, catastrophic soil erosion and innumerable landslides are caused to transport huge amount of sediments from the upper part of the catchment to the parent river. These rivers are incapable of transporting the load efficiently under the existing hydrological conditions, especially along their lower reaches. The river beds are thus elevating at many places at an alarming rate resulting in lessening of cross sectional areas. The reduced cross sections being incapable of arresting the unusual monsoon discharge caused devastating flood, causing heavy damage to the land and properties. It also endangered the priceless forest lands, wild life vis-à-vis bio-diversity and vital line of communication and strategic infrastructure (Starkel L., 1972).

Effect of watershed degradation

The effects of contemporary watershed degradation in the sub-Himalayan West Bengal have been demonstrated most visibly. Some of the striking effects are listed below:

(i) visible edaphic drought
(ii) deterioration of quality and quantity of surface water
(iii) drying up of springs and jhoras
(iv) reduction of ground water recharge
(v) deterioration of soil quality
(vi) increased frequency and magnitude of floods in the lower sections
(vii) increased frequency and magnitude of accelerated soil erosion and mass movements
(viii) river metamorphism vis-à-vis avulsion
(ix) enlargement of river valley
(x) loss of forest resources including biodiversity
(xi) climatic change.

4.5.1 Soil erosion

At global scale on an average 115 metric tons of soil and other slope materials eroded in every sq. km. of surface area. The countries belongs to Asia recorded the highest amount of 220 metric tons/km^2/y-^{1} and Australia accounts for the lowest amount of only 90 metric tons per sq. km. per year. Highly developed countries in Europe in spite of their high population density and high intensity land use practices could able to keep a low rate of soil loss of only 77 tons/km^2/y-^{1} . Thanks to adequate watershed management practice adopted by the European countries especially since the World War II. Comparatively higher degree of illogical human interferences in watersheds of Latin and South American countries yielded 148 tons/km^2/y-^{1} in compare to its counterparts of North America which recorded about 113 tons/km^2/y-^{1} . Presence of virgin forest in large parts of central African watersheds is responsible for less soil erosion in the African countries which is estimated to be 92 ton/km^2/y-^{1}.

Table 4.8 Sediment yield from the major watersheds

Rivers	***Watershed (km^2)****	***Load (ton/hect/y^{-1})***	***Total sediment in m.ton***
Sankosh	8521	4.25	3.62
Raidak	4570	9.26	4.26
Torsa	3920	6.96	2.73
Jaldhaka	1590	25.35	4.03
Tista	7900	20.12	15.89
Mahananda	245	32.65	0.80

* *Basin area estimated up to the respective gauging sites*; ** Based on Sarkar, S, 2008.

Mean denudation rate at the global scale has been estimated to be 0.34 mm per year. Denudation rate in Asian countries is two times more than global rate i.e., 0.70 mm per year. India is the leader among the Asian countries accounts for 1.21mm/y-^{1} which is about 4 times more than global scale. The Himalaya watersheds again account 3 times more than the national rate i.e., 3.75 mm/y-^{1}. East Himalayan watersheds accounts the highest rate and observation made in Mahananda watershed in Darjeeling Himalaya recorded a massive high rate of 5.56 mm/y-^{1} which is 4.5 times more than the national rate and 16 times more than the global rate of denudation (Sarkar, S., 1991).The following table (No. 4.8) depicts the rate of sedimentation in some major watershed in the world along with sub-Himalayan watersheds.

It is observed that the eastern Himalayan watersheds recorded very high rate of sediment yield as the Mahananda watershed recorded as high as 32.65 ton per hectare per year followed by the Jaldhaka with 25.35 ton, Tista with 20.12 ton per hectare per year. The Sankosh watershed is least inhabited and recorded 4.25 ton of sediment yield/hectare/year.

It is already mentioned that sub-Himalayan rivers in North Bengal are producing largest amount of sediment (per unit area) at global scale. The mean annual sediment yield from these rivers would be estimated about 30 million metric ton or 15.76 million cubic meter suspended load. The magnitude of such a huge load may be visualized when the materials if spread uniformly will create a hill with dimension of 250x250x250 meter. The frequency and magnitude of sediment load depends on the magnitude of extreme event i.e., in 1968 flood estimated 3.5 million ton sediment transported in 3 days (3-5th October). Bed load transport in these watersheds has been found enormous. Recent study on thermoluminscence & radio-nuclii dating in Tista watershed reveals an estimated amount of 15 million ton of bed load of huge dimension (up to 25 meter diameter) transported during the said period (Starkel L et. al., 2000).

Table 4.9

Base flow and mean maxima ratio of major rivers

Sl. No.	*River*	*BF:MM Ratio*	*Watershed situation*
1	Sankosh	35.29	Mostly natural
2	Tista	166.67	Moderately degraded
3	Raidak	150.00	Moderately degraded
4	Torsa	50.00	Marginally degraded
5	Jaldhaka	192.00	Moderately degraded
6	Mahananda	300.00	Highly degraded
7	Balason	222.22	Highly degraded

Suspended load concentration is also found very high and a maximum of 1.5gm/liter has been recorded in the river Jaldhaka during 2002 flood. The Jainti watershed in western Duars recorded the highest amount of suspended load of 7570 metric tons per sq. km. per year which is nearly 3 times more than that of Yellow river the highest at global scale. The Torsa watershed is producing the least amount of suspended load among the major watersheds in North Bengal which is only 520 metric tons per sq. km. per year i.e., about 14 times less than that of the Jainti watershed. Another degraded watershed of Mahananda yielded about 3265 metric tons per year per sq.km area.

The fluctuation of water flow in these rivers also found noteworthy which reflects the overall health of the respective watershed. The ratio between the base flow and mean maxima is of interest in this regard. The table 4.9 shows such ratio along with generalized watershed pattern.

It is observed that the Mahananda watershed is one of the most degraded in sub-Himalayan North Bengal which reflects with huge base flow mean maxima ratio of 1:300. In fact, massive human intervention into the delicate hill slope hydro-geomorphic system along with heedless deforestation drastically reduced rain water retaining capacity in the watershed. The consequence of such destructive intervention demonstrates through the increase in frequency and magnitude of mass movements in the hill slopes and devastating floods followed by avulsion and aggradations in the piedmont and plains.

On the contrary, the Sankosh watershed which is mostly situated in less habited Bhutan hills still retain its natural set up which has been reflected by its ten times less base flow mean maxima ratio i.e., 30.

4.5.2 Landslides

Landslide is the most pervasive of natural hazards that undermine the economic and cultural development of Darjeeling and Sikkim Himalaya. The diversity in slope components, geometry, site and situation, micro-regional susceptibility to degradation processes, micro-geology, micro-climate, depth of soil, its physical and chemical properties, vegetation with differential canopy and root system, unplanned growth of settlement, road and sewer systems, have led to recurring landslides. Extensive heedless deforestation, slope cultivation, haphazard construction, inadequate drainage had led to the establishment of vicious cycle of degradation, heavy and concentrated rainfall aggravating the problem further(Sarkar, S. 1999; Starkel L. et. al., 2000).

It is found that each landslide has its own peculiarities and its initiation is not due to any single factor. Of the various factors, water has the most deleterious effect. The toe erosion has admittedly caused some of the landslides. Many recent landslides are caused due to unscientific and unplanned usage of hill slopes and valleys. Every landslide is an individual problem, despite the fact that most of such cases have found to be initiated by common trigger mechanism. The solution to each problem has to be determined for individual site, though it may lie in combination of a few well established methods viz. retaining structure, drainage, afforestation, rock bolt, sheet pile, restriction of settlement and unplanned construction along the vulnerable hill slopes.

Landslides occur in almost all types of slopes composed of various rocks in the Darjeeling Himalaya. Composite slides also take place involving soil or talus and underlying rocks. Slope failure is caused by shearing where the plane-of-shear, taking the form of an arc of a circle; in section leaving a parabolic outline of the slipped portion. The most common occurrence of landslide is found along the springs (locally known as *Jhoras*), where rock debris gets detached from their parent body along the slope and form channels. Later, such channels, while carrying drainage water are gradually widened by lateral erosion. Innumerable *nalas* (drainage channels) on hill slopes develop due to slope failure and many landslides in tea gardens and forests look like scars from a distance (Sinha, BN, Verma, RS & Paul, DK, 1975, Starkel L et. al., 2000).

Landslides on rocky surfaces seem to be primarily influenced by the structural elements of the parent rock. Sliding also occurs in bedding and foliation in rocks with prominent joints and shear planes along the slope. Observations in the soil-covered slopes reveal that slopes having an angle below 30^0 were not generally affected by slides. The talus materials are formed due to weathering and loosening of rocks along the joints and foliation planes of the parent rocks. Such material, whether dry or in a permanently drained state, are stable at an angle of even 45^0 and the stability is not necessarily impaired by an occasional wet spell. Slope failure in such materials, however, occurs by seepage pressure of percolating water during heavy precipitation.

The tea garden slopes are generally formed of talus materials with a thin soil cover. Most of the slides have affected the materials but at some places, slides along the joints of the underlying rocks have also been observed. Generally, the displaced materials scour long channels down the slope, which are visible as scratched scars on hill slopes. The width of these scoured channels originally does not exceed more than 25m or so but by subsequent erosion, they are further widened. Thus, once the slide has occurred, it generally remains a permanent feature and increases in dimension.

Identification of landslide-prone areas has been performed with the help of "Check-List" where each separate and discrete slope unit has been classified according to their stability rating. Rating has been done according to a scale from stable through the degrees of potential instability to those slopes, which have already failed. Special attention has been paid to the old slides, which could become re-activated. The excavation position and depth, drainage diversion across the hill, loading of the upper slope and valley, cutting of basal support, unscientific construction and land-use, deforestation, legacies from the past slope movement, relief, drainage, slope materials, etc. have been accounted for in the "Check-list".

Generally, deforested tracts, tea gardens, urban and other settle areas are more susceptible than the natural forested tracts. Geologically, the Daling rocks (phyllites, slates, schists, feldspar, etc.) and Damuda rocks (sandstones, shales etc.) are more susceptible to landslide. Landslides are found more frequently occurred along the major roads in Darjeeling, Sikkim and Bhutan Himalaya and also along the major waterways. Among the studied watersheds, the Tista and Mahananda are the worst affected by landslides followed by the Jaldhaka watershed. The Sankosh watershed is the least affected by landslide menace as most part of the watershed is uninhabited in Bhutan.

The analysis of landslide in the eastern Himalaya reveals that each of the slides has its own characteristics and is not induced by any single factor. Of the various factors, water has the most deleterious effect. Some of them have admittedly been caused by toe erosion of the drainage elements and the others due to the effects of unscientific and unplanned human interferences. The choice of remedial measures thus, should be made after careful analysis of the causative factors. The design of the preventive structures should depend on the geomorphologic, geo-hydrological and geo-technical framework of the site.

In view of the ever-increasing problem of landslides in the Himalaya, man must be aware of the possible dangers that he is inviting, due to his careless dealing with nature. It is true that one has to make room for the growing population and in this pursuit he has to utilize every piece of land available. But the precautions that have to be adopted should not be neglected. In many places revetments are not maintained properly, the weep-holes are choked, the drains are dumped with garbage, restricting free drainage of water. Moreover, the present land-use system should be properly evaluated. The construction of high-rise buildings should be stopped immediately. The people should be provided with alternative source of energy, may be through mini-hydel project, tapping the perennial springs, and perhaps this can be the only option to prevent them from cutting down more trees. It is of utmost priority to develop mass awareness among both local people and tourists, so that they become aware of the possible dangers that they are inviting by interfering with the natural laws.

4.6 Conclusion

Gradual depletion of the forest from north to south at the expense of agriculture is the most remarkable feature of present day land use in all the studied catchments. The structure and relief together with climatic and soil conditions determine human activity, which is realized mainly through development of the various forms of agriculture, settlement and in minor extent mineral extraction.

Present day land use pattern is the result of human impact ongoing from centuries but its changes were accelerated when the British East India Company took control of Bengal in the mid-19th century. Since then large scale heedless deforestation initiated due to foundation of tea plantations and heavy demand of timber for railway and building construction. The 20thcentury was marked by demographic explosion.

Most of the mountain area is grown by various types of natural forest. It changes from moist deciduous with dominant *Shorearobusta* up to 1000 meterthrough tropical evergreen with *Quercus* and *Castanopsis* up to 2000 meter and *Rhododendron* pure stand in between 2500-2800 meter to temperate coniferous at the elevation 3000-3500 meter. Only upper part of the Jaldhaka and Torsa catchments is covered by sub-alpine fir forest, which gradually changes to alpine grasslands above the upper timberline at approximately 4000 meter (Champion, Seth 1968). The margin of mountains is usually densely populated and human impact on environment is more visible compare to upper part of Himalayas.

Deeper into the mountains the relationship between major river valleys and deforestation is visible. The river channel widths in their upper and middle courses are stable but closer to the mountain margin they extend laterally. The settlement in this area is confined to the gentle slopes of intermountain valleys suitable for agriculture and close accessible transport routes. This is due to road construction along river courses, which was a dominant feature in the colonization process.

The mountain foreland is built up of alluvial fans and higher elevated terraces. The extension of fans is roughly bounded by the 100 m contour. A significant part of this area is covered by sanctuaries and reserved forest. It consists mainly of *Shorearobusta* the most valuable commercial tree. This forest is mixed with patches of pure deciduous forest with *Schimawallichii* or *Acacia catechu* (Champion, Seth 1968). Tea plantation occupies the largest part of the alluvial fans. The forest clearance under tea plantations combined with the building of roads and railways has given rise to settlement and trade.

The alluvial plains further south are favoured sites for larger settlements. River banks are not completely protected as a result some parts of floodplain are inundated every year. Alluvial soils offer productive agricultural lands in the region. As a result, this area experienced massive transformation of land use/cover system. Nearly all of the natural forests of the plain have been cleared by a process of agricultural colonisation ongoing for centuries.

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