STUDY OF THE ENVIRONMENTAL GEOMORPHOLOGY IN THE BALASON BASIN, DARJEELING

A Ph. D. Thesis

Submitted by
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PREFACE

Understanding the natural environment and its relationship with the ecological processes is an essential pre-requisite for undertaking any developmental planning. The escalating anthropogenic activities, coupled with poor management of land and water resources are placing tremendous stress on the environment, resulting in the steady increase of soil erosion, floods and drought, escalating urban congestion and disturbing the ecological balance of the environment. Remedies to these maladies lie in the study of the causes of these aspects and providing the prescription for sustainable development.

Consequently, the Balason fluvial environment, as part of the physical environment demanding considerable attention vis-à-vis development and planning, has been selected for detailed study.

The fluvial environment, as a synthesis of geological, pedological, hydrological and geomorphological conditions and processes, includes a wide spectrum of aspects pertaining to these fields. Incorporating these aspects in the proper perspective will contribute greatly towards a better understanding of the fluvio-environmental adjustments and ecological balance in the study area.

This present study therefore correlates the various aspects of the fluvial environment with the existing geo-environmental scenarios of the basin for evolving a suitable strategy for environmental planning and resource management.

Acknowledgements

First and foremost, I would like to extend, in all sincerity, the deepest sense of gratitude to Dr. Subir Sarkar, (my Mentor and Guide) – without whose infallible support, constant supervision and guidance my "dream" would not have turned into "reality". In the years that I have worked under the supervision of Dr. Sarkar, I have come to realize, that in a world that is over crowded with "educated heads", Dr. Sarkar truly stands out as one of the few "educated hearts"!

I would also like to take this opportunity to dedicate my work to Rev. Mother Damien, IBVM, and my family: to Rev. Mother Damien for inspiring me, motivating me and encouraging me to always "strive for excellence" in all my endeavors and to my parents for all the sacrifices they have undergone for me; for motivating me and supporting me through all the difficult times in my life; my brother Dorjay and sisters Devika, Sangita and Nima for always being "there" whenever I needed them.

My little daughter Menlum and son Vivek for all the time that I should have , but could not spend with them. I beg forgiveness for those moments and may God bless these little hearts for such unconditional love and support.

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Last but not the least, to all my friends and well-wishers, whose names may not be printed here – but are surely carved in my heart with gratitude. I would like to thank them all for helping me "hitch my wagon to a star" and realize that the "sky is the limit"!

Indira Lepcha

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INTRODUCTION

The Balason river, one of the most important right bank tributary of the river Mahananda arises near Lepchajagat, (Latitude 27°3'55" N and Longitude 88°14'12" E), at an elevation of 2416 meter a.s.l., on the Ghum - Simana ridge. It flows through the southern part of the district of Darjeeling almost parallel to the 88°13"E meridian, till it reaches the plain at an altitude of 305 metre from where it turns towards the southeast and meets the river Mahananda near Siliguri town.

The important right bank tributaries include the Pulungdung Khola, Rangbang Khola, Marma Khola, Dudhia Jhora, Chenga and Manjha Khola. The Bhim Khola, Rangnu Khola, Jor Khola, Pachhim Khola, Rinchington khola, Rungsung Khola, Rakti Khola and the Rohini Khola are the major left bank tributaries. The tributaries have carved out deep gorges in the hilly section even though they have very small catchments.

A. Problems

Environmental degradation and associated phenomena are the most pervasive of natural problems that undermine the economic and cultural development of the Balason catchment in the Darjeeling district of Sub-Himalayan West Bengal. Deforestation along with high intensity rainstorm induced accelerated soil erosion, mass movements in the upper catchment and massive flood and aggradation in the lower part of the catchment area.

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, tea plantation, quarrying, on the Himalayan immature geology trigger the disaster, huge and complex, never encountered before.

The situation was different even 150 years before. The hills were densely covered by natural vegetation with very thin population and the harmonious relation between the upper and lower catchment was well preserved. Extensive heedless deforestation, haphazard construction of roads and settlements, unscientific and illegal quarrying, over grazing, 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 (400,000 m^3 of suspended load and over 600,000 m^3 of bed load) from the upper part of the catchment to the river Balason.

Incapable of transporting the load efficiently under the existing hydrological condition, especially along its lower reaches, the riverbed is rising at many places at an alarming rate along its lower reaches. The channel pattern is thus, characterized by braiding even along the lower hilly section. The reduced cross section being incapable of arresting the unusual monsoon discharge (940.3 cumecs in 1998) caused heavy devastating flood.

In the non-monsoon period, however, the paucity of water is so acute that the local people are unable to reap any benefit from the river itself. It therefore, becomes imperative to suggest remedial measures and actively implement these suggestions. Only then can the geo-political and ecological stability of this extremely vulnerable region of the Darjeeling Himalaya be protected.

B. The Study Area

The area under study includes the south western part of the Darjeeling hills and a section of the North Bengal *terai* falling within 26°41' N to 27° 01' N latitudes and 88°7' E to 88°24' E longitudes covering an area of 367.42 sq. km (figure 0.1).

The Balason basin is still without major artificial control, and thus affords an ideal situation for making a direct observation of the various geo-environmental processes. The study area was confined upto the confluence with the river

LOCATION OF THE STUDY AREA

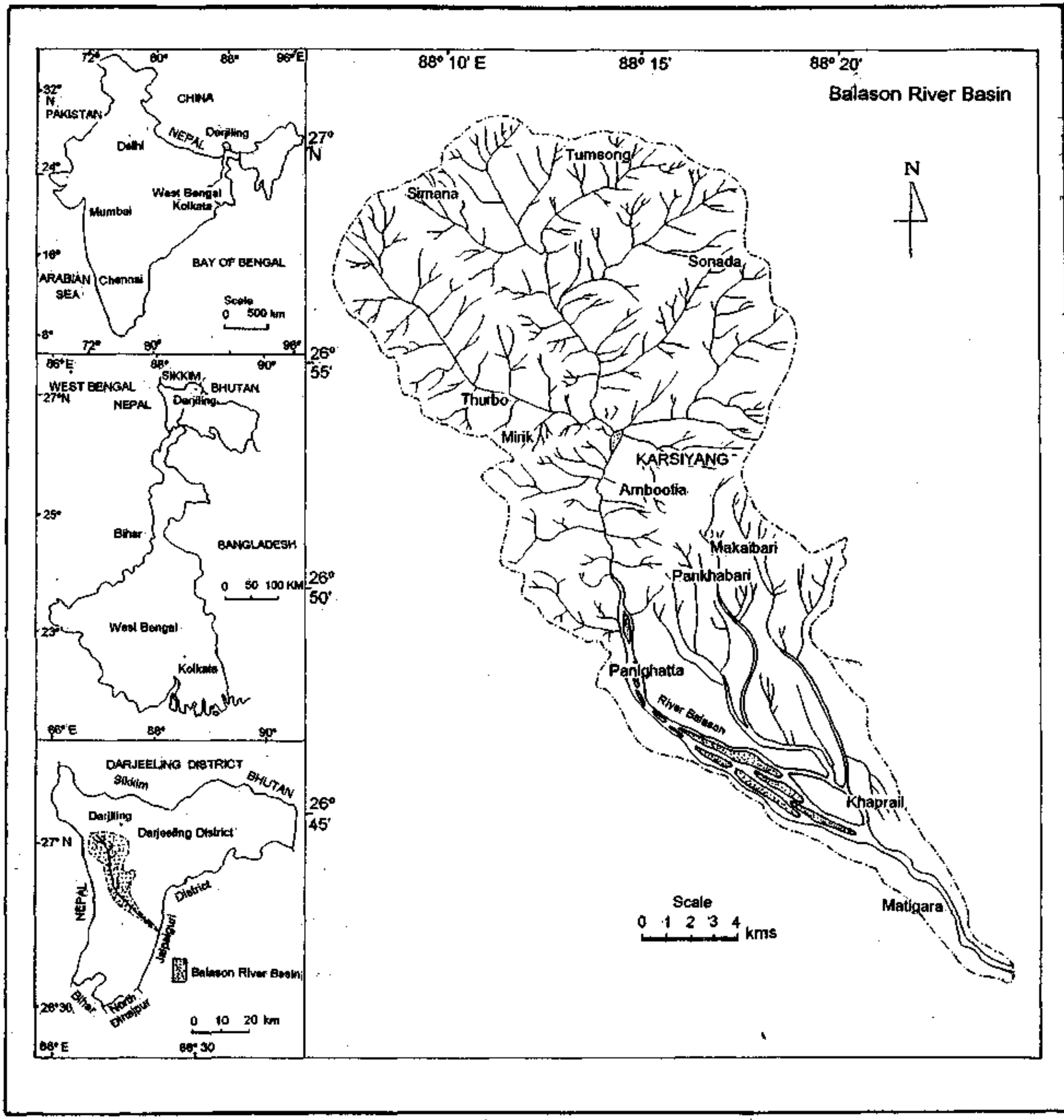

Figure 0.1

Mahananda, a little below Siliguri (latitude 26°48'37" N and longitude 88°18'30" E), as it is considered as one of the environmental hot spot of the country.

C. Methodology

In order to study the above-mentioned problem, a rationalistic methodology comprising of quantitative integration of geological, geomorphological, meteorological, pedological and hydrological parameters of the study area has been undertaken. the detail of which is outlined below:

The basic aerial data has been obtained from the Survey of India topographical sheets no.78B/1, B/5 and B/6 and 78A/4 and A/8 (1:50,000) and aerial photographs (Run nos, 78 4-A/ 19-5 to 10, 78 4-A/ 21-5 to 10, 78 4 –A/ 22-3 to 8, 78 4-A/ 23-5 to 10, 78 4/24-5 to 10). Maps published by the Geological Survey of India and Forest Departments have also been used for preparing the detailed programme of the present research work, specially the surveying plan, the layout of cross sections and test pits. Comparison of the old and new documents has been made to follow chronological depletion of the natural resources.

Basic data on geology, topography, climate, vegetation, land-use pattern have been collected from secondary sources like topographical maps, G.S.I. records, Revenue maps, Satellite Imagery and maps and reports published by individuals and Institutions.

Meteorological data i.e. rainfall, temperature, humidity etc. in and around the study area has been collected from Regional, Meteorological Office, Alipur, Planters Club Darjeeling, Agricultural Department, Forest Department and individual tea gardens.

Data on soil, vegetation, geology, geomorphology and hydrology have been collected from primary sources by intensive traverse and field studies.

Various hydrological data regarding cross-sectional area, velocity, discharge, data were collected directly from field survey and wherever possible these have been verified with the official data and records of Central Water Commission.

The geomorphological information along with the morphometric data of the basin and sub-basins (55 third order basins), have been collected from the topographical maps at a scale of 1:50,000. Both bivariate and multivariate statistical analysis of morphometric data have been carried out using:

i. Correlation analysis
ii. Regression and
iii. Multiple regression

Quantitative analysis of various geomorphic forms and processes have been attempted to find out the nature and form of micro-topographical units in addition to slope, relative relief, drainage density, dissection index etc. traditional methods.

Pedological information have been gathered from the 50 sample sites selected randomly and analyzed in the Pedological laboratory of the Department of Geography and Applied Geography, North Bengal University. The following soil properties have been assessed:

a. Soil colour (Munsell colour chart);
b. Soil texture (International pipette method);
c. Hygroscopic moisture (Ignition method);
d. Soil porosity, permeability, specific gravity, water holding capacity etc. (Keen Box method);
e. pH (pH Meter);
f. Soil organic carbon (Walkey and Black's Rapid Titration method);
g. Base exchange Capacity (Saturation method);
h. NPK (Kit Box)
i. Soil Plasticity Index (Liquid Limit device method);
j. Compressive strength of soil (Vane Shear Meter);
k. Penetration limit by cone penetrometre;

The rate of infiltration was measured with the help of a galvanized steel tube with a diameter of about 20 cm. This was inserted into the soil and a head of water of 6 mm was maintained to record the rate of infiltration.

Primary data related to various other geo-environmental parameters was collected through direct field observation and either by questionnaire or checklist.

Assessment of soil loss by water erosion has been carried out based on the existing standard methods (Wischmier and Smith, 1965, 1978; Fournier 1972; FAO/UNEP, 1978; Arnoldus, 1980, Requier, 1980 and Sarkar, 1987 and 1991), Universal Soil Loss Equation (USLE) with the necessary modifications have been applied based on the diagnostic criteria of rain erosivity (R); topographic erosivity (L.S); soil erodibility (K) and biotic erosivity (C.P). Based on these the potential and the predicted soil loss have been assessed. A comprehensive soil conservation plan for the study area was laid out keeping in mind all possible interactions among the variables.

The study of landslide and related problems were entirely field based through intense traverse method and field observation with the help of check lists. Each landslide has been examined carefully under the heading of bedrock, climate, soil, forest cover, and human interference to find out the trigger mechanism. After apprehending the processes, mechanism and causes of the movement, the investigator has tried to offer the corrective measures for them.

Various information related to the hydrological regime have been collected from the field stations at NH 31 bridge, near Matigara. In order to have an idea about the changing nature of the channel and specially the impact of huge flood water on the channel form, a detailed study at the following three different sites were made: the central station gauge (C/G) located 100 metre north of NH 31 Bridge across the river Balason, near Matigara, the up-stream gauge (U/G) 500 m north of the central station gauge and the down-stream gauge (D/G) 700 m south of the central station gauge. Hydrological records of the Central Water Commission station at Matigara have also been consulted wherever necessary. An attempt has also been made to assess the bed load of the river indirectly from the information of gravel extraction from the river at four different sites between Dudhia to Matigara.

The water resource of the basin has been determined by Khosla's method through the study of rainfall, runoff and rate of evaporation. Water resource has also been assessed based on discharge and run off of the river. An attempt has also been made to have a comparative study of the water resource estimates based on empirical method and discharge-runoff method.

Modified Leopold matrix (1971) has been employed to assess the environmental impact of development projects in the Balason basin. It involves 39 development activities under 9 broad headings and 58 environmental components under 4 broad and 12 sub-headings. Environmental impacts have been identified under the headings of impact magnitude and impact significance. The matrix has been applied on checklist in 45 different sites. Two case study have also been performed one on the monoculture of Dhupi plantation and the other on cutting of hill tops and dumping of materials on slope.

To compile the bibliography as well as the reference work, the libraries of North Bengal University, Calcutta University, National Library, Kolkata, Geological Survey of India, Kolkata, Natural History Museum, Darjeeling, River Research Institute, Haringhata have been thoroughly consulted.

In order to understand the problems under study, all the data collected from the field and various institutional and other sources have been processed, analysed and computed in the Department of Geography and Applied Geography, North Bengal University to predict the exact sequence of events and to provide a workable formula for their control and finally to offer corrective measures for the over all environmental stability of this extremely vulnerable part of the country.

CHAPTER 1

PHYSICAL BACKGROUND OF THE STUDY AREA

1.1. Geology

The Balason basin of the Darjeeling Himalaya, geologically speaking, is a complex region composed of rocks belonging to Archean to sub-recent age. The earliest systematic geological mapping of the Darjeeling Himalaya was carried out by Mallet (1874) followed by a large number of workers that include Gansser 1964, Singh, 1971; Acharya, 1972; Lahiri and Gangopadhyay, 1974; Pawde and Saha 1982. A geological map of the study area (figure 1.1) has been prepared by the investigator based on the previous works, to show the regional distribution of rocks, while the chronological order of various geological formations of the study area has been depicted in table 1.1.

a). Archaeans:

The Archaean group of rocks are composed of

i) Darjeeling gneiss and

ii) Daling series.

i) Darjeeling Gneiss:

Stratigraphically, the Darjeeling gneiss has been classified as: (I) Golden silvery mica schist, (ii) Carbonaceous mica schist, (iii) Granetiferous mica schist and (iv) coarse-grained gneiss (Pawde and Saha, 1982). Opaque feldspar and layers of colourless or grey quartz appear to give the intensely sub-folded rocks a banded appearance. It varies in texture from fine-grained to moderately coarse-grained rocks. At the source region of the river Balason, i.e., around Ghum Sukhia Pokhri region, the gneiss is rich in kyanite along with graphite and sillimanite.

The Darjeeling gneiss is highly foliated, with the foliation dips being oriented generally from north to north west. The dips are irregular and range from 30° to 50°. There are two prominent sets of joints in the gneiss: one running roughly NW to SE and the other NNW to SSE. Both the joints have a steep westerly dip,

GEOLOGICAL SET UP OF THE BALASON BASIN

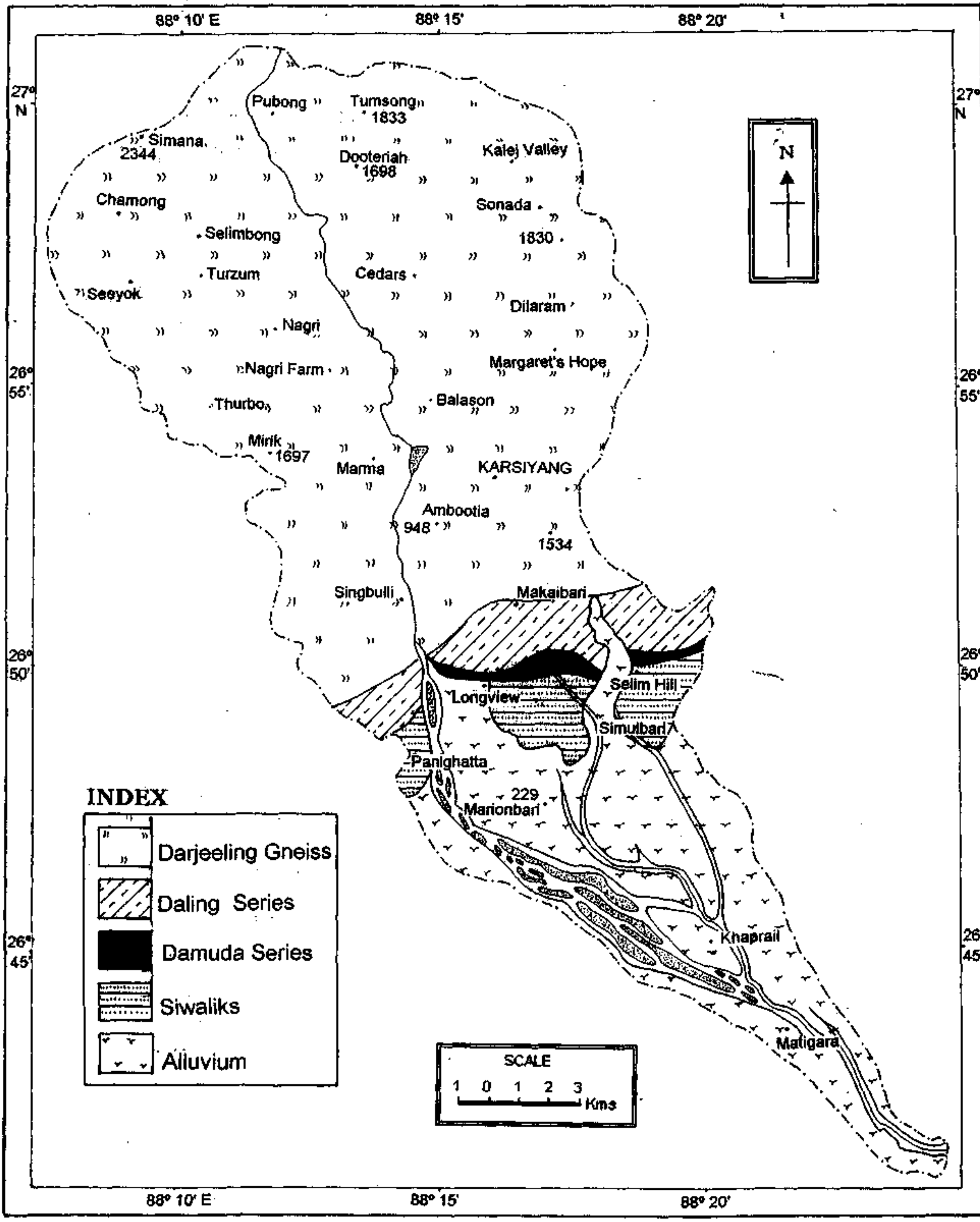

Figure 1.1.

varying from 40° to 70°. The Darjeeling gneiss covers most of the northern part of the Balason basin which amounts to 59 % of the study area (around Lepchajagat peak, Chamong and Gaurisankar tea estate).

ii) Daling Series:

Lying to the south of Darjeeling gneiss are the rocks of the Daling series comprising of grey sericite and chloritic slates, phyllites and schists. Quartz and quartz-felspathic veins traverse the rocks (photo 1.1). These veins, which had intruded prior to the deformation, are now noticed as lenticles and shreds, whereas the other intrusions that occurred during the post deformation period are quite intact and have cut across the earlier veins. The rocks are often highly metamorphosed and jointed (photo 1.2).

Slates form the lowest bed of the Daling series. These are greenish to grey, exhibiting a perfect slaty cleavage. The slates develop a phyllitic character with the prominent development of chlorite and sericite containing rounded to sub-rounded pebbles of quartz in some places (Powde and Saha 1982). The transition from slates to chlorite-sericite schists is gradual. These rocks are very much crinkled, criss-crossed with chlorite, sericite and quartz. Tourmaline and iron ore occur as accessories.

The Dalings are remarkable for their consistent development and monotonous lithology over a great thickness. They are the representative of late Pre-cambrian to early Cambrian argillaceous sequence. The rocks have dip ranging from 30° to 80° N and NE. This formation covers about 11% of the total area under study.

b) Permian

The coal-bearing Gondwana rocks of the Damuda series rest against the Dalings to the north, as a thin belt, extending almost in an east west direction and sandwiched between the two thrusts: namely, the Daling Thrust in the north and the Main Boundary Fault to the south. The Damudas are characteristic coal-

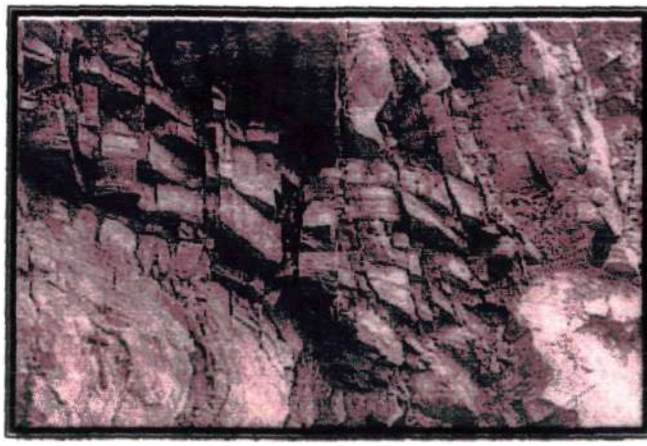

Photo 1.1. Highly Jointed feldspathic veins.

Photo 1.2. Highly jointed Darjiling gneiss

bearing detrital rocks of lower Gondwana age as proved by its fossil-flora. The predominant rocks are feldspathic, partly micaceous brownish sandstone, shaly micaceous sandstone, carbonaceous shale and coal seams. Generally, the coal is highly sheared and frequently altered to anthracite (Acharya, 1972), with further reduction of volatile elements, some of the carbonaceous shales change into carbonaceous or even graphitic schists. The semi-anthracite coal seams in this rock belt are found to be continuous from Pankhabari to Tindharia within the area under study. The beds have a generalized strike of ENE-WSW, with dip varying between 40° and 90° towards northwesterly direction. These rocks have undergone great crushing and disturbance along with a great change in lithological characters. Starting from the eastern bank of the river Balason, this rock has been extended eastward with an enlarging width. The Gondwana rock covers about 3% of the total area of the Balason basin. In the western part of the Balason river however, the Gondwana rocks are not exposed.

c) Miocene

The Miocene group of rocks is characterized by the Siwalik system. The foothill belt expose the rocks of the Siwaliks system, comprising of soft greyish sandstone, mudstone, shales and conglomerates along with their bands of marly shales and lignites. The Siwalik sandstones show well-developed laminations and contain sedimentary dykes of same material, but often showing a contrast in colour (Mallet, 1874). The top beds of this formation are usually pebbly and contain rounded to sub-rounded pebbles of quartz, having either a random orientation or are aligned parallel to the bedding plane. The sandstones are usually thick (3000 m), often massively bedded and frequently characterized by current bedding and graded bedding (Mallet, 1874). The general strike of this rock is either NNE-SSW or NW-SE with dips varying between 30° to 60°.

The east-west continuation have been interrupted by the northerly extension of the alluvium deposits that divides it into small segments, all of which are situated along the foot-hill zone of the Himalaya. The river Mechi represents the extreme western part from which it begins and ends in the western bank of river Balason.

The middle part proceeds along the Hill Cart Road, from Sukna Forest Rest House towards the north, upto Rangtong Railway station and comprises of soft grayish sandstones, mudstones, shales and conglomerates along with their bands of marly shales and lignite. The general strike is WNW-ESE. The dip ranges from 30°–70° NNE. The area under this rock system comprises about 7.5% of the total study area.

Table1.1

The geological succession of the Balason river basin

Geological periods	Geological structure	Age of beginning (million years)	Type of rocks
Pleistocene or sub-Recent to Recent	Alluvium (older & recent)	2	Boulders beds and other sands and gravels; drift formation; younger flood plain deposits comprising sand and gravel, pebble etc.
——Himalayan Front Tectonic Line——			
Miocene or lower Tertiary	Nahan group; Lower Siwalik	26	Soft greyish sand tones; mudstones; shales and conglomerates along with the bands of limestone, shale and lignite
——Thrust fault (Main Boundary Fault)——			
Permian	Damuda Series (Lower Gondwana)	280	Quartzitic (hard & soft) sandstones with slaty bands; shales and slates; semi-anthracitic (Graphitic coal; Lamprophyre sills and minor bands of limestone
——Thrust fault——			
Achaean	Daling Series	3800	Daling series: slates (greenish to grey with perfect slaty cleavage); phyllites surrounded by the pebbles of quartz; Chlorite-sericite schists with bands of grity schists injected with gneiss (crinkled); Tourmaline & iron occur as accessories, granites pegmatites and quartz veins.
	Darjeeling Gneiss		Darjeeling gneiss: golden-silvery mica schist; carbonaceous mica-schist; granetiferous mica-schist; and coarse grained gneiss

Based on Mallet,1884; Ganser,1964; and Pawde and Saha,1982.

At the foot of the Siwalik, the river flows through raised terraces, which are of recent to sub-recent origin. These comprise of gravels, pebbles and boulders mixed with ferruginous sand and clay. The formation is somewhat consolidated and stratified, and shows evidence of upheaval at places (Gansser, 1964). The reddish colour of the formation is due to oxidation and thereby proves its antiquity when compared to the alluvium of recent age, noticed further south.

d. Pliestocene:

South of the Siwalik system and within the basin is the alluvial plain that is a part of the vast extension of the North Bengal plain. The hill-wash, consisting of gravels and coarse sands, occur along the foot of the Darjeeling Himalayas forming several alluvial fans, which often merge to form the vast W-E extending piedmont plain of *terai* landscape. The terraces rise due to the deposition of rivers that often change their course. The lithology of the plain suggests that everywhere the rock fragments are either fluviatile or the product of sub-aerial erosion in nature.

Field investigation suggests that the alluvium is composed of successive layers of sand, silt and clay with some bands of gravel and lenses of pitty organic matter. The thickness of the alluvium is variable. The places that fall within this formation are Garidhura, Panighatta, Simulbari, Marionbari, Phulbari Patan, Chamta, Tutinbari, Khaprail, Matigara etc. covering about 19.5% of the total basin area.

1.2. Topography

The basin, under study, comprises of a section of the hilly region of Darjeeling Himalaya and its adjacent piedmont plain called *terai* of the Darjeeling district, in West Bengal. The hills of Darjeeling Himalaya rise abruptly over the *terai* which is composed of alluvial fans (Basu and Sarkar,1990). The elevation increases from 121 metre at Matigara to 2416 metre at the northernmost apex of the basin i.e., Lepchajagat, with the relative height of the hills fluctuating between 1000 to 2000 metre. The edges of the hills are dissected, with steep slopes inclined between 30° to 40°.

The network of ridges and valleys shows a dendritic pattern. Several narrow ridges in the form of structural scarps rise between 1500 to 1800 meter above sea

CONTOUR MAP OF THE BALASON BASIN

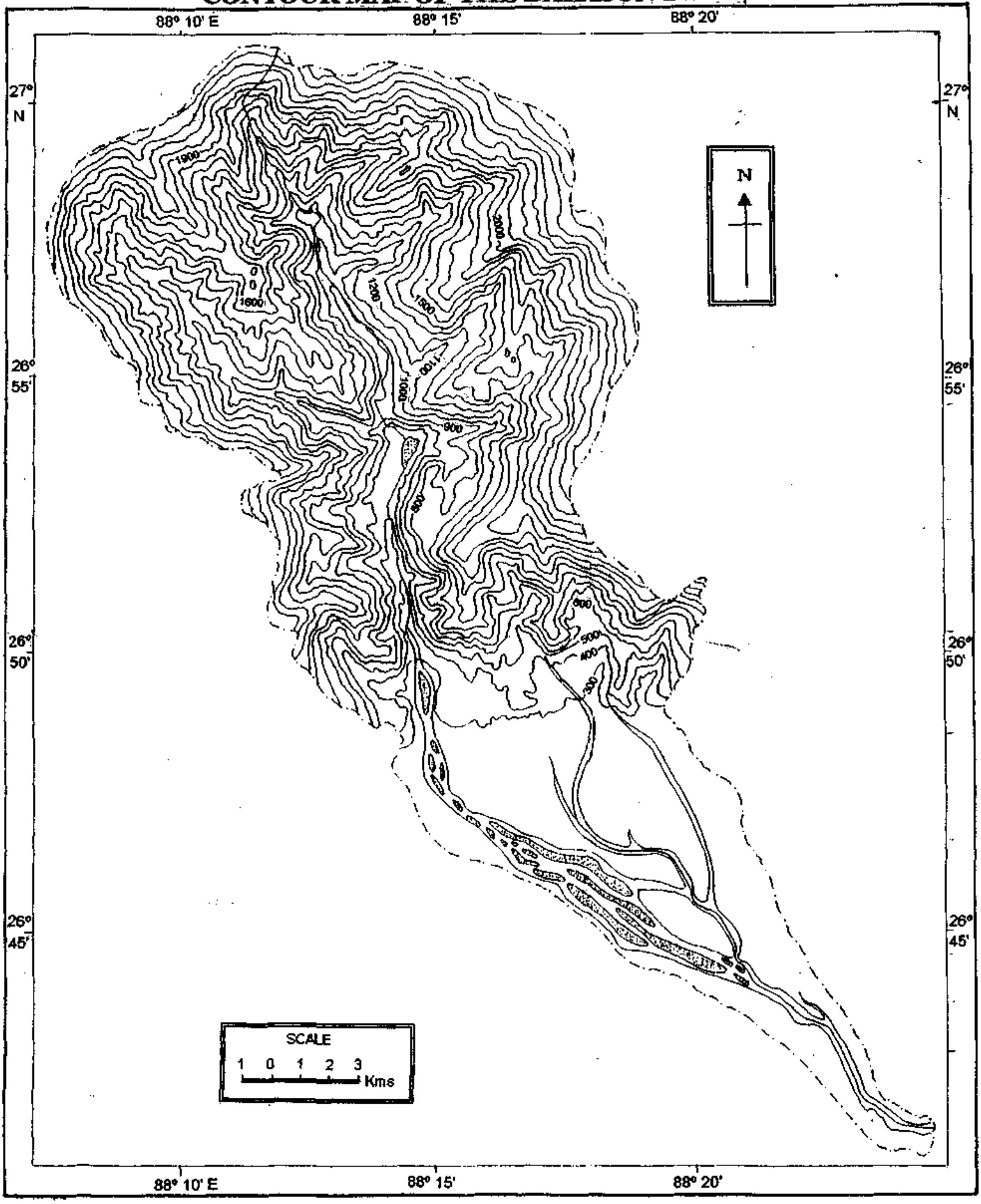

Figure 1.2

level, being connected to the more resistant Darjeeling gneiss. Along the main valley, continuous flat segments along with flattening over slope breaks, mark its vast destructional level (Starkel, 1972). These surfaces rise to elevations of about 500 to 600 metre above the valley of the Balason, at an altitudes between 1000 metre to 1500 metre above sea level. While the northern part of the basin consists of resistant gnessic rock, the southern part is composed of slaty and schistose rocks, which are less resistant to weathering and erosion.

The rivers are mainly south-flowing and erode more along the Dalings and Damuda areas. However, the density of dissection by deep valleys is very low and do not reach 0.5 km / km^2. This is due to the great depth of valleys and length of slopes that reach 1-3 km or more. A number of relatively flat, areas with visible undulations including shallow (0.5 – 2 meters) depressions, connected with mass movements have been identified. This indicates the dominance of back weathering of slopes over the fragmentation (Starkel 1972).

The general topography of the Balason basin shows a prevalence of young convex slopes, with weakly developed concave basic parts. While the steeper portions, inclined at 30° to 45° are mainly rocky, the more gentle slopes, inclined at 15° to 30°, are covered with regolith. The relief of the valley floor and river channels exhibit the features of the young stage of evolution with steep ungraded channels, narrow floors and steep valley sides. The longitudinal profile shows that the valley has directly dissected the mountain edge. The gradients of headwaters are steep and controlled by lithology and mass movement, but going downstream, the valley floors start to broaden out and aggradations prevail, despite the relatively high gradient. Finally in the alluvial fans of the *terai* zone, they are dissected at their apex (figure 1.2).

Numerous streams traverse the *terai* area, which is formed due to the coalescing of several alluvial fans (Banerjee and Banerjee,1982). Along the course of the river the sediment fraction declines from boulders (0.5 – 1m. in diameter and more) to sandy-gravel at a distance of 15 km. The channel width of the Balason also diminishes from 2 km to 0.5 km.

A great colluvial fan, in October 1968, pushed the main river towards the right bank and the boulders (1-4 meters in diameter) were exposed on the channel sides. The fan surface was built up by finer debris during the reactivation of landslides in 1983 and was later dissected several meters deep at its margin. The infill of the coarse material in the Balason channel caused aggradation downstream, in the form of wide side-bars, up to the outlet of Balason from the mountains (Starkel et al, 2000).

Rivers and streams which have cut gorges, have also given rise to terraces, across the undulating and low plateau-like drift deposits, thereby forming a typical piedmont landscape over looking and often merging with the plains to the south. Along the extreme south, the topography is characterized by flatness. The rivers often describe a braided nature and are filled with sandy bars (Banerjee, et al 1982).

1.3. Climate

The nature of river network depends to a great extent upon climate, since the geometry of river channel is controlled by discharge, which in turn, depends upon the balance between all the components of the hydrological cycle. Rainfall input to the hydrological system is modified by temperature, humidity and wind condition. The climate of the Balason Basin is characterized by a greater degree of seasonality, brought about by the latitudinal extension and the wide altitudinal variations that also contribute to the vertical zonality of temperature. Thus, the climate of the study area owes its distinctness due to its position, wide differences in altitude and the precipitation caused by the humid air masses from the Indian Ocean carried by the Southwest monsoon, accompanied by **break phases**, combined with heavy and continuous precipitation. Moreover, as a result of the shifts of the monsoon troughs, towards the mountain margin, and the peculiar configuration of the ridges and valleys also contribute very high intensity rainfall along the parts of southern slopes, causing flash flood.

1.3.1 Seasons

The following seasons are noted in the Balason basin:

a). The winter season (December to March),

b). The hot weather season (April to May),

c). The rainy season (June to September) and

d). The transitional period (October to November).

However, the duration and extent of the seasons are not similar. The hilly regions experience a longer monsoon, with mist and almost continuous rainfall, starting in some years, from the first week of May. The maximum number of cloudy days occurs in this season. The winter is usually cold and unpleasant and continues till February, while spring and autumn are the most pleasant seasons. In the southern part, the climate is characterized by prolonged hot and humid summer.

Table 1.2.

Rainfall and temperature characteristics of the Balason basin.

Months	Hills		Plains		Basin	
	Rainfall in mm.	Temperature in °C	Rainfall in mm.	Temperature in °C	Rainfall in mm.	Temperature in °C
January	13.89	10.55	20.16	17.39	17.03	13.97
February	20.16	12.28	22.34	19.67	21.25	15.98
March	47.97	15.55	56.34	23.46	52.17	19.51
April	112.89	18.67	129.82	26.32	121.36	22.50
May	321.67	19.79	248.98	27.77	285.33	23.78
June	631.45	20.85	598.44	28.62	614.95	24.74
July	867.59	21.72	865.26	29.41	866.43	25.57
August	659.89	21.98	634.66	29.82	647.28	25.90
September	556.24	19.99	487.21	27.44	521.73	23.72
October	167.39	18.37	145.99	26.69	156.69	22.53
November	36.96	15.69	48.98	23.03	42.97	19.36
December	10.88	11.98	14.46	19.21	12.67	15.60

Source: Collected from different Tea Garden Records.

1.3.2 Rainfall

The southwest monsoon contributes about 85% of the total annual precipitation. July is the rainiest month, followed by August. Thunderstorms, accompanied by rain occur in April, May and in October. On an average, the number of rainy days,

REPRESENTATIVE RAINFALL AND TEMPERATURE OF THREE BROAD REGIONS OF THE BALASON BASIN

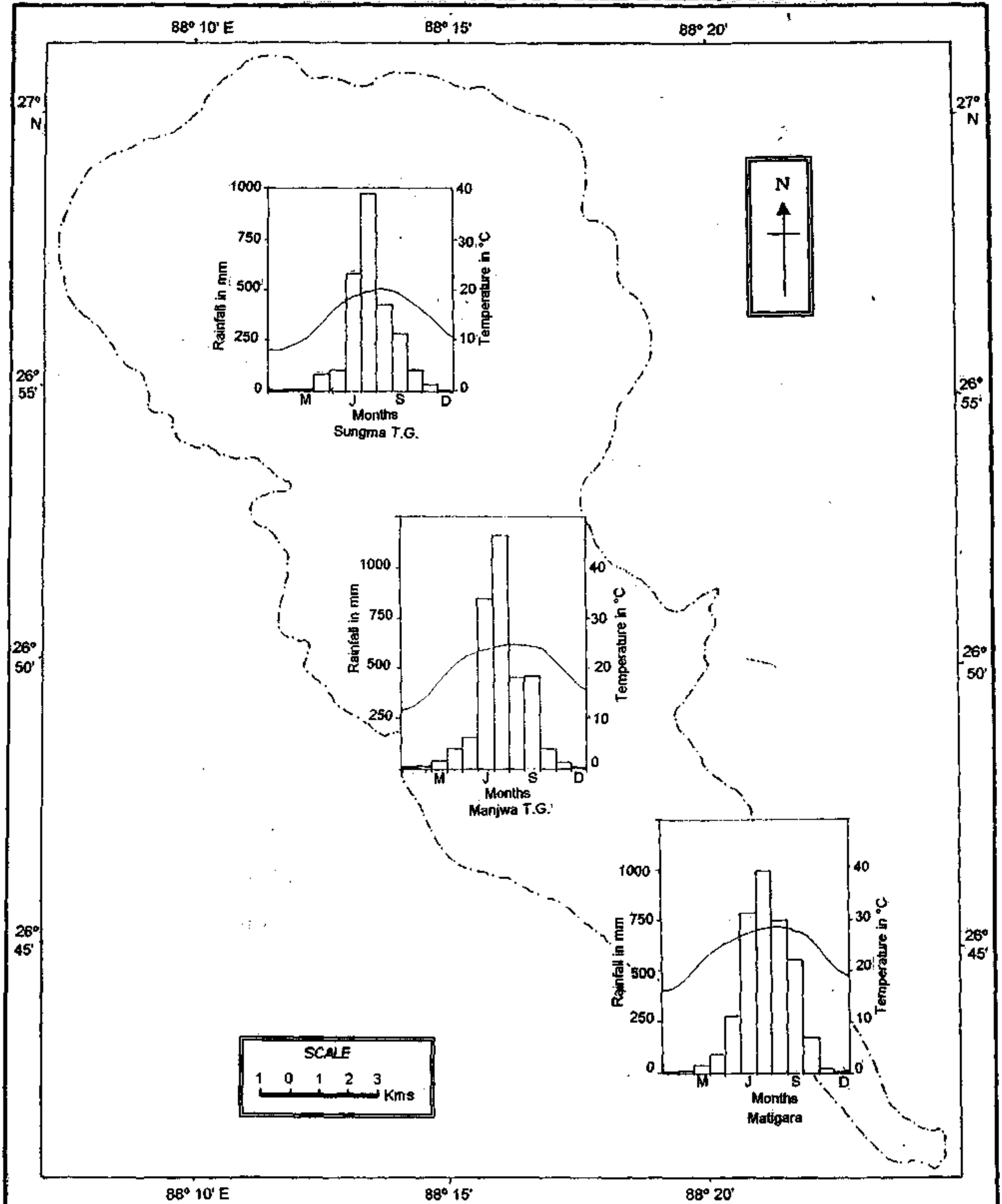

Figure 1.3

with more than 2.5 mm. of rain, varies from below 100 days in the plains to 124 in the higher slopes of the basin. The annual precipitation fluctuates from 2000 mm to more than 5000 mm within the study area. The highest monthly rainfall occurs in the month of July, for both the hills (868 mm) and plains (866 mm). The southern hilly part of the basin receives more rainfall (3446 mm), than the plains (3272 mm). The average annual rainfall for the basin, as a whole, is 3359 mm. (table 1.2 & figure 1.3).

1.3.3 Temperature

The hilly region of the Balason basin has a mean annual temperature of 12°C, while those of the plains record 24°C. During summer, the mean temperature range between 16°C to 17°C and 27°C to 28°C respectively; while the mean winter temperatures fluctuate between 5°C to 6°C in the hills and 12°C to 13°C in the plains. The lowest recorded winter temperature in the hills range between -1°C to -5°C. The air humidity fluctuates in the plains from 58% in March to 87% in summer, but in the higher reaches, humidity is generally high, as a result of excessive cloudiness.

1.4. Soil

The soil, in the Balason basin of the Darjeeling Himalaya, has long and complex history. The geographical and climatic factors made the region suitable for the spread of the tea plantations. With the increase of population, forests were greatly exploited. Forests were cleared for making cultivable land available and forest produce such as timber were used, both as fuel and building material, along with fodder for domestic animal.

Thus, the original soil of the region has undergone changes, resulting in the alteration of its nature. In many cases, the soil has actually undergone more than one cycle of formation. The records of its past history have been mostly obliterated, either by the formation of new soil on the truncated top of the older soil or by the complex removal of the original soil by erosion (Sarkar, 1990).

1.4.1. Pedogenesis

Soil is the product of the action of climate and organisms upon the geological foundations which constitute the soils patent material. The ultimate character of soil is further conditioned by factors like topography, drainage, time and human activities. All these factors are important soil controls in the study area, although some are more important than others, which need special mention.

The study area is characterized by a general hot-warm and humid climate, with strong seasonal distribution of rainfall, leading to the general bleached nature and silica dominated surface soil. Human activity on vegetation, leading to deleterious effects on the soil (Sarkar, 1990), is highly evident in the study area. Heavy deforestation with increased pressure on the soil resource, by continuous arable cropping, tea plantation, overgrazing, monocultural plantations and changes in the past and present landuse practices have led to accelerated erosion. The truncation of soil profiles is spectacular and serious throughout the study area, especially along the northern hilly tracts. Profile studies show that topsoil removal is widespread and the present use. is often being carried out on former sub-surface horizons. The progressive break-down of structure and tilth is one of the factor which aids soil panning and subsoil compaction in some places.

The parent materials and topography, especially the slope gradient and orientation, have predominant role in governing the soil variability within the watershed. The variation in lithology obviously govern the characteristics of the weathering products and hence, soils of the different strata. Due to very high rainfall, moderately high temperature and high micro-biological activity, very high rate of chemical weathering is found almost everywhere, almost all rocks and at all altitude regime. The effect of the slope needs to be superimposed on lithology soil-type correlation. Field observations indicate that soils are active even on the gentler slopes. Colluviation and slope wash are the most active process operating on valley sides and ridge flanks. On the steep slopes, the soil profile reveals features like solum mixing, truncation and the presence of colluvial stone horizons.

1.4.2. Soil Classification :

The soil-mapping units recognized and described in this study are based on the USDA, Soil Taxonomy (Sarkar, 1990). The taxonomic orders, sub-orders, great-groups and sub-groups have been recognized and shown on the soil map (figure1.4) and also represented in the table 1.3 below:

Table 1.3.

Taxonomic soil groups of the Balason basin

Soil order	Sub order	Great groups	Sub groups	Area covered in sq. km.	% area to total area
Entisols	Orthents	Udorthents	Typic Udorthents	56.81	15.46
	Fluvents	Topofluvents	Typic Tropofluvents	53.26	14.50
Inceptisols	Umbrepts	Haplumbrets	Typic Haplumbrets	31.21	8.49
			Lithic Haplumbrets	25.98	7.07
			Typic Dystropepts	144.29	39.27
	Tropepts	Dystropepts	Umbic Dystropepts	38.12	10.38
			Fluventic Dystropepts	17.75	4.83

For a generalized idea of the nature and characteristics of the soil of the study area some salient features of the taxonomic units have been described below:

1.4.2.1. Entisols:

These soils have little or no evidence of pedologic profile development either due to short duration or receiving of new deposits of alluvial at frequent interval from the higher tracts. The only evidence of pedologic alteration in these soils is a small accumulation of organic matter in the upper 30 cm.

The order Entisols have been found to comprise the southern undulating to gently sloping terrain, covering 29.96% of the study area. Small pockets are found around Marma and Nagri farm along the Balason valley, Singbuli, Makaibari,

SOIL MAP OF THE BALASON BASIN

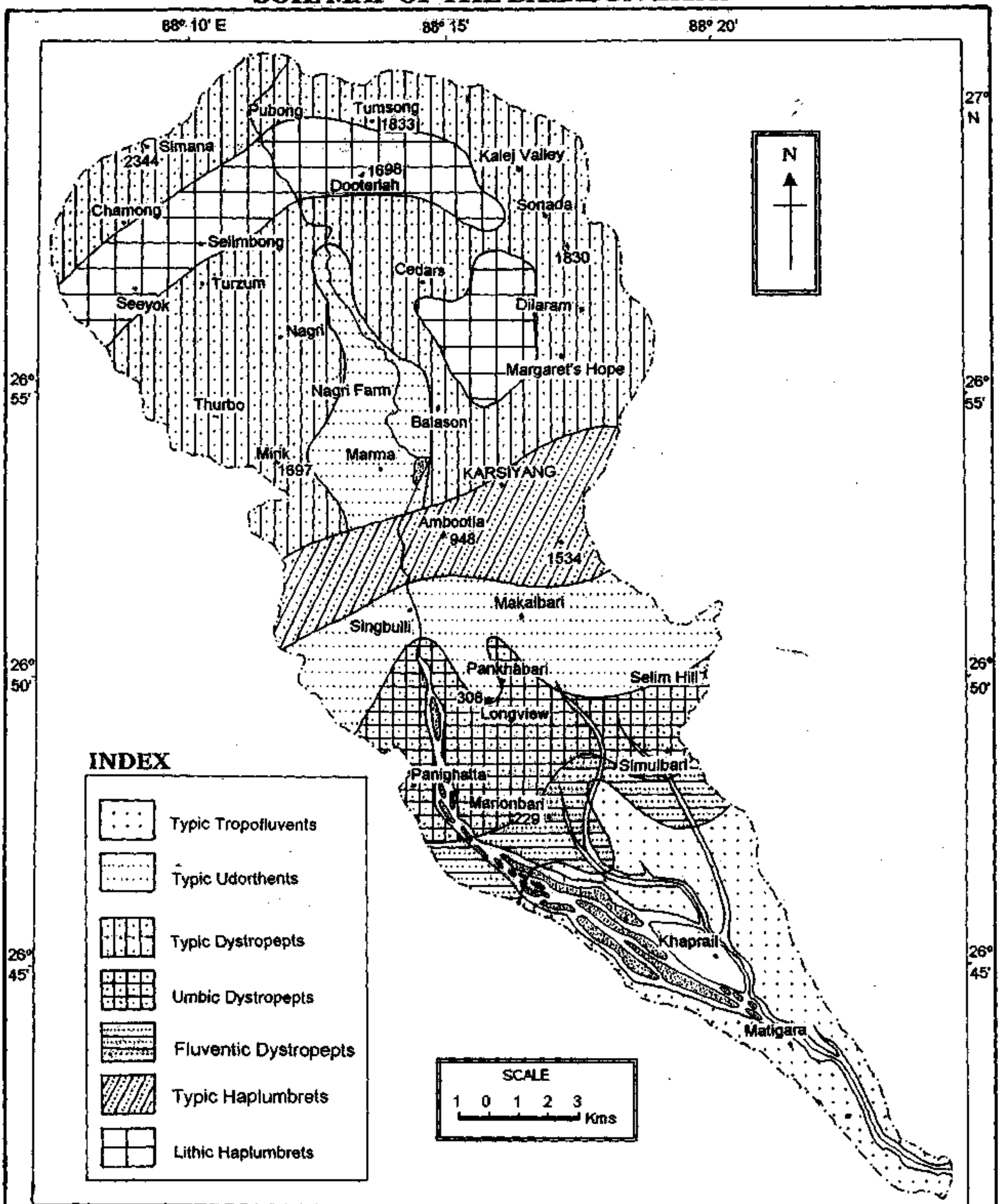

Figure 1.4

Pankhabari, Longview, Khaprail and Matigara. Two sub-orders namely a) Fluvents and b) Orthents have so far been identified in the study area (figure 1.4).

a) Fluvents:

These are light grey to pale brownish soils, formed in recent water borne sediments, found mainly in the flood plains and alluvial fans. The fluvents occupy a large portion of the southern part of the study area, in and around Matigara and Khaprail (figure 1.4). They have low organic carbon percentage (1.0 -1.5%), with a coarse sandy texture, with granular structure. The fluvents of this region belong to the tropofluvent great group i.e., udic soil moisture regime and have some amount of weathered clay. The sub-group is recognized as typic tropofluvents.

b) Orthents :

The orthents belonging to the great group udorthents and sub-group typic udorthents, have been found to occur along the eastern, northern and north western parts of the Tropofluvents in Nagri farm, Marma, Singbuli, Makaibari, Pankhabari and Longview (figure 1.4). They are primarily entisols on recent erosion surfaces, where, the former soil has completely or partially been removed or truncated to such an extent that the diagnostic horizons for the other orders remain absent. The interfluves are generally composed of older alluvium and/or alluvial fan materials which are situated 5-10 metres above from the flood plains. They have developed on very recently exposed regoliths, mostly as unconsolidated sedimentary deposits.

1.4.2.2. Inceptisols :

They constitute the most extensive soils, covering approximately 70.04% of the area under study. They are widely distributed in the hilly tracts, where the slope-gradients range form 10 to 65%. These soils are typical of the humid regions, possessing a wide variety of physical and chemical properties, that vary with respect to their depth, colour, texture, structure, organic carbon, porosity, permeability etc. They share a common feature as they have lost bases, but they retain some weathered minerals. Normally, they lack an illuvial horizon, which is enriched with silicate clay that contains either aluminum or organic carbon.

This soil presents a variety of management problems to farming and forestry, as the temperature regime is thermic to meso-thermic with the soil moisture regime being udic to ustic, with strong seasonal precipitation. Two sub orders i.e. tropets and umbrepts have been identified in the study area:

a) Tropets :

These are brownish, more or less freely drained Inceptisols of humid tropics, that occur in the northern part of the basin, with a thin to moderately deep profile (50 to 120 cms), developed mostly on steep slopes along the northern hilly area and along the foothill around Marionbari, Simulbari and Panighatta. The soils have an isothermic or warmer iso-temperature regime, with the soil moisture regime being udic to ustic, with broad-leaved vegetation. Three great groups have been recognized: i). typic dystropepts, ii). umbric dystropepts and iii). fluventic dystropepts.

b) Umbrepts :

They have developed along the slopes of Selimbong, Seeyok, Pubong, Dooteriah, Tung, Karsiyang and Ambootia (figure 1.4). These are acidic in reaction (pH 5 – 5.5), being dark reddish to brownish in colour, freely drained, carbon rich inceptisols of humid tropics and sub-tropics and developing from varied types of parent materials, which are mostly coarse-grained jointed schist and gneiss.

The most striking feature of pedogenesis is the natural umbrella to the surface soil, provided by the thick vegetal matter, accumulating on the surface. The vegetation are mostly mixed, but coniferous forests with frequent falls are common at higher altitudes. The soil temperature regime varies from mesic to thermic. The umbrepts of the study area have been classified into two sub groups: i). typic haplumbrepts and ii) lithic haplumbrepts.

1.5. Natural Vegetation

The Balason basin is a region of wide variety of forest resources. The most remarkable feature of the forest of this region is the wonderful variety of species that it contains. Few places in India command range of variation of forest types as found in such a small area of the Balason basin. It is perhaps, in fitness of things, that forest conservancy was initiated in this part of the country more than hundred years age.

Many researchers have so far classified of the natural vegetation of this region which includes workers like Hooker (1854), Champion (1936), Banerjee, 1964; Bhujel (1996) etc. Among the various factors responsible for spatial differences of forests, pedological and climatic factors are by far the most important. Champion and Seth classified the forests of Darjeeling area based on rainfall and temperature. Three major types of vegetation which are further subdivided into sub types can be recognised:

1.5.1. The Tropical forests:

High temperature and heavy rainfall in this area generally helps the development of dense vegetation. The Tropical vegetation is characterized by the presence of deciduous forests with *Shorea robusta* as a dominant species. Bhujel (1996) further divided it into four sub types:

a). Riverain forest,
b). Sal forest,
c). Dry mixed forest and
d). Wet mixed forest

(a) **The Riverain forests** can be observed in small patches along the riverbeds of the Balason, Rakti, Rohini and Mechi. The common tree species found in this region include, *Meliosma pinnata, Albizia procera, Albizia lebbeck, Acacia lenticularis, Alstonia scholaris, Lagerostroemia parviflora* with *Acacia catechu* and *Dalbergia sissoo* occurring as distinct patches in planted forests. *Saccharum spontaneum, Mikania micrantha, Clerodendrum japonicum, C. infortunatum, Buddleja asiatica, Oroxylum indicum, Globba* spp. cover the forest floor.

b) Sal *(Shorea robusta)* forest *Shorea robusta* is the conspicuous species growing in Lower Siwalik foothill and *terai* and well-drained loamy plains. The main associates of sal in this region include *Terminalia alata, Aglaia lawii, Duabanga grandiflora, Eugenia kurzii, Dillenia pentagynai, Chukrasia tabularis, Meliosma pinnata, Lagerstroemia parviflora, Tetrameles nudiflora, Stereospermum chelonoides, Anthocephalus chinensis* along with *Pavetta indica, Clerodendrum japonicum, Phlogacanthus thyrsiflorus, Barleria cristata, Pinus roxburghii.* These plants are also seen associated with species like *Shorea robusta, Ficus oligodon* and *Pheonix humilis* in some drier valleys.

c) The dry mixed forest is represented by the presence of *Gmelia arborea, Tetrameles nudiflora, Beilschmiedia dalzellii, Erythrina stricta, Bombax ceiba, Alstonia nerifolia, Merremia emarginata, M. hederacea, Artocarpus lacucha, Eugenia kurzii.*

d) The wet mixed forest is dominated by semi-evergreen trees, along with a very large number of shrubs, climbers and herbs. This zone is rich in epiphytes and stem-parasites giving it a distinct characteristic. The major tree species of this sub-zone include *Terminalia myriocarpa, Michelia champaca, Sygzygium formosa, Cinnamomum glaucescens, Litsea monopetala, Beilschmiedia roxburghiana, Pterospermum acerifolium.* The lower strata and ground vegetation include *Beaumontia grandiflora, Bauhinia vahlii, Entada pursaetha, sinohimalensis, Cryptolepis buchananii, Mikania micrantha, Ipomea quamoclit, Boerhavia diffusa, Argyeria roxburghii, Ageratum conyzoides, Blumea balsamifera, Sonchus asper, Sauropus pubescens* etc.

1.5.2. Sub-tropical forests (800-1600 m)

The vegetation of this region is affected by seasonal climate of dry winter and a wet monsoon and thus consists largely of the tropical genera and species. The mixed forest is mostly deciduous in nature. This includes regions like upper Balason, Rangbang khola, Marma khola, Manjwa Jhora, Rakti khola and Rohini khola. Several species blend into this zone from the tropical and plain areas. *Castanopsis indica, Schima wallichii, Gmelia arborea, Adina cordifolia, Duabanga grandiflora*, *Gynocardia odorata, Bischofia javanica*, *Callicarpa arborea*, *Alangium chinensis*, *Terminalia alata*, *T. bellirica, Sygzygium ramosissmum* constitute the dominant trees in this region. In addition *Castanopsis tribuloides*, *Cinnamomum bejolghota*, *Magnifera sylvatica*, *Phoebe lanceolata*, *Litsea cubeba*, *Fraxinus floribunda*, *Helicia nilagirica*, *Phyllanthus emblica*, *Mallotus philippensis, Engelhardtia spicata* can be seen in some places.

The undergrowths include *Mussaenda roxburghii, Dendrocalamus hamiltonii, Osbeckia nepalensis, Osbeckia stellata*, *Buddleja asiatica*, *Embelia floribunda*, *Croton caudatus, Thysanolaena maxima*, *Imperata cylindrical, Holmskioldia sanguinea, Woodfordia fruticosa*, *Boehmeria glomerulifera.* This forest is characterized by the presence of a good number of climbers such as *Bauhinia vahlii, Tinospora cordifolias*, *Cissampelos pareira*, *Mucuna pruriens*, *Thunbergia fragrans, Vitex negundo.* The common herbs are *Commelina benghalensis, Cyanodon dactylon*, *Pilea hookeriana*, *P. smilacifolia, Elatostema lineolatum, Ageratum conyzoides, Oxalis corniculala*, *Urena lobata*, *Triumfetta rhomboidea.*

Exotic weeds like *Euptorium odoratum* and *Mikania micrantha* grow profusely in disturbed forests, while thickets of the tree-fern *Cyathea brunoniana* are found in moist and shady places.

1.5.3. Temperate Vegetation (1600-2400m)

The temperate vegetation comprises of dense forest that includes areas extending from Karsiyang, Toong, Sonada, Darjeeling, Mirik, Sukhia Pokhri, Maneybhangyang, etc. The richness of the vegetation is displayed by the presence of the largest number of species and the widest diversity occurring in this region. J.D. Hooker (1854), remarked that the temperate vegetation of this region is *'roughly divisible into lower non-coniferous and upper coniferous and Rhododendron belt, but the line of demarcation between these varies so greatly with the exposure and humidity of the locality, that they cannot be dealt apart'*. The temperate forest of the region is sub-divided into three subtypes:

a) Temperate Deciduous forest : is characterized by the presence of trees like *Betula alnoides, Exbucklandia populnea, Eleocarpus lanceifolius, Eleocarpus sikkimensis, Acer campbellii, A. sikkimensis, Engelhardtia spicata, Lindera neesiana, L. pulcherrima, Prunus nepaulensis, Alnus nepalensis, Rhododendron grande, Rhododendron arboreum, Eurya acuminata etc.*

b) Evergreen Oak forest : comprises of trees like *Quercus lamellose, Q. lineata, Q. oxydon, Lithocarpus pachyphylla, Acer hookerii, L.elegans, Cinnamomum impressinervium, Eriobotrya petiolata, Eurya acuminata, Pentapanax fragrans, Litsea elongata, Litsea sericea, Juglans regia, Leucosceptrum canum, Lithocarpus pachyphyllus, Poplus ciliata*. Shrubs like *Dichroa fabrifuga, Viburnum erubescence, Jasminum dispermum, Nellia thyrsiflora, Arundinaria maling, Hypericum hookeriana, Norysca urala, Notochaete haemosa* with climbers like *Dicentra scandens, Edgaria darjeelingensis, Holboellia latifolia, Sechium edule, Smilax ferox, Codonopsis affinis, Streptolirion voluble, Rubia manjith* etc.and herbs like *Achyranthes bidentata, Anaphalis contorta, A.triplinervis, Artemesia japonica, Bidens pilosa, Potentila fulgens, Plantago erosa, Rumex nepalensis, Clinopodium umbrosa, Gallium asperifolium, Swertia chirayita, S.bimaculata, Impatiens arguta, Lysimachia alternifolia, Poulzolzia hirta, Hypoestes triflora, Hemiphragma heterophylla, karwinskianus, Fragaria nubicola* to name a few, forming the ground cover.

However, the introduction of exotic species like *Cryptomeria japonica* in the upper and middle hill has adversely affected the natural vegetation in the region, since such a move has resulted in the decrease of species diversity, especially in areas where the said species has been established as a monocrop.

1.6 Landuse

The study area until 1835, was mostly covered by dense forest and inhabited by a few migratory Lepchas in the hills and the Meches in the foothills and was *'completely clothed with forest from the very top to the bottom'* (Hooker, 1854). The degradation began with the construction of a road connecting Darjeeling to the plains in 1839. Soon large tracts of forests were replaced by roads, tea-gardens, railway lines and settlements.

Experimental planting of tea started from 1841 under the supervision of Dr. Campbell, Superintendent of Darjeeling. The success led to rapid growth of the plantation and soon tea gardens like Ambootia, Makaibari, Soureni, Phuguri etc. were established between 1860 and 1864. By 1871, nearly 20 tea gardens with approximately 890 hectares of forested area was leased out for tea cultivation. At present, the maximum area (within the study area) is occupied by tea plantations, which covers an area of 99.33 sq. km constituting 27.03% of the area, within the Balason basin.

With time, a pronounced decrease in the forest cover became apparent and at present the forest is mainly restricted in the north and north-eastern section of the study area with small natural patches at Singbulli, Selim Hill, Manjwa and between Pankhabari and Longview. The forest area, today, occupies an area of 96.18 sq. km approximately (figure 1.5). Settlements with cultivated waste cover 29.92 sq. km within the study area.

1.7 Conclusion

It can be seen that the study area is geologically young and fragile region, with intensely metamorphosed rocks like phyllite, schists, slates and gneiss covering most of the area. These rocks are highly weathered, fractured and jointed and have a tendency to produce slope instability during intense rainstorm.

LANDUSE MAP OF THE BALASON BASIN

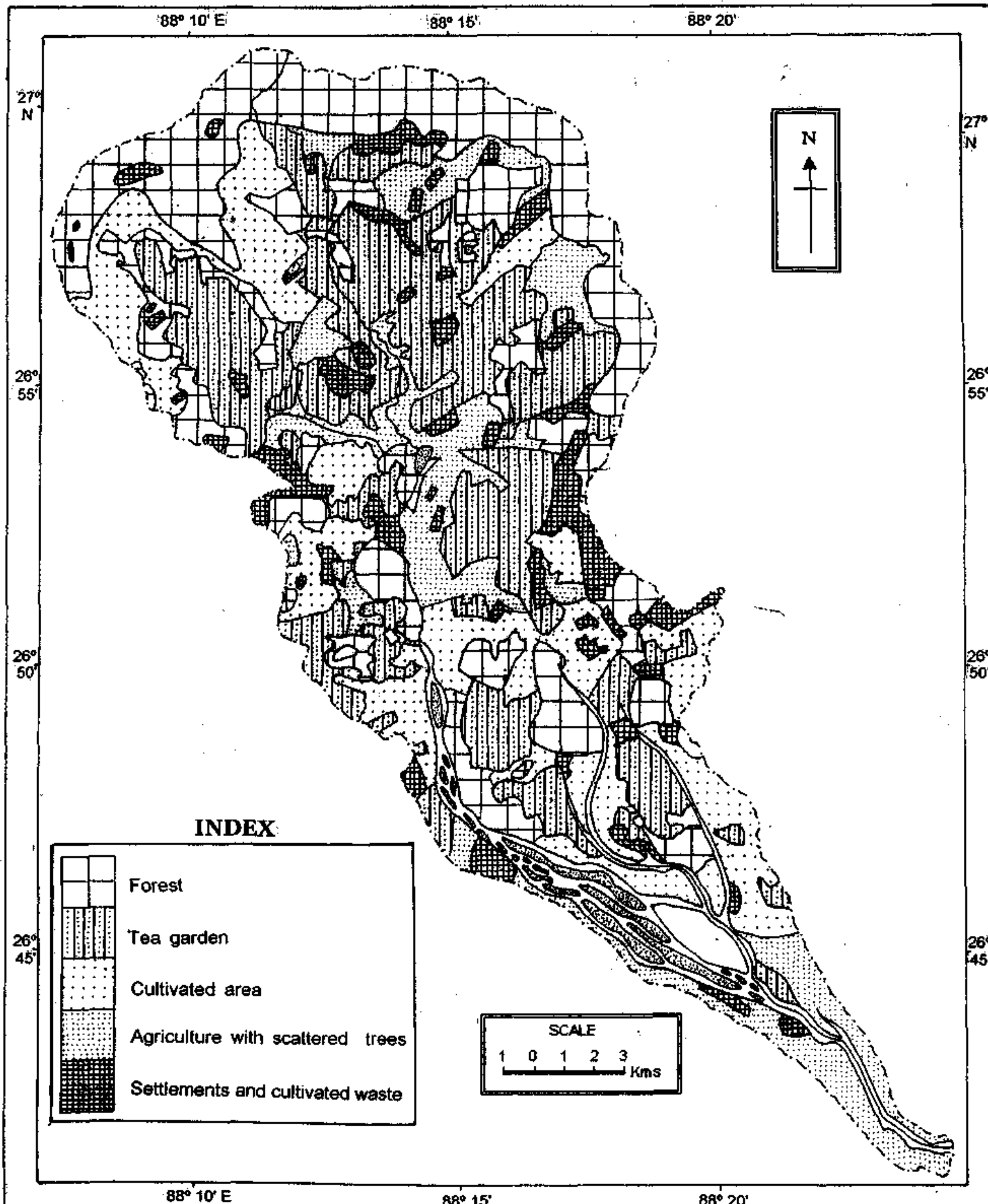

Figure 1.5

Topographically, the area may be sub-divided into the northem hill region with steep slopes and the southem terai area, exhibiting convex slopes and fan formation due to aggradation. The temperature shows very wide variations, which are directly dependent upon the altitude.

The soils of the Balason basin can be sub-divided provisionally into 2 orders, 4 sub-orders, 4 great – groups and 7 sub-groups. The above soils have an inherent low nutrient status. The entire southern half of the study area shows deficiency in organic matter, nitrogen and phosphate. The dominant soil taxonomic order has been recognized as the Inceptisols, which cover the entire northem hilly tracts and show deficiency in phosphate and potassium.

The drastic reduction of the natural forest, combined with the high annual rainfall exceeding 3000 mm in most part of the basin, makes the area highly vulnerable to soil erosion and landslides, reducing the soil fertility, choking the streams and leading them to change their courses. Thus, it can be concluded, that the study area, which is geologically highly vulnerable, and experiences very high precipitation coupled with heedless deforestation and unscientific changes in the land-use pattern, poses a threat to both the lives and properties of the local inhabitants.

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CHAPTER 2
GEOMORPHOLOGY OF THE BASIN

2.1 Introduction

Drainage basin is the most convenient unit for the study of environmental problems and its management. These basins form the natural backdrop for hill slope processes and river channel behavior, within which, most fluvio-geomorphological processes operate. The drainage network and the basin morphology are measures of fluvial processes operating in the basin. It has been established that river flows are related to the topographic and climatic characteristics of a drainage basin, which in turn control the amount, time and space distribution of the stream flow. The stream-flow reflect the precipitation variations and surface and sub-surface characteristics. To make a geomorphic study, it is thus necessary to obtain quantitative expressions of landform characteristics and then to develop quantitative relations between geomorphic and hydrological variables.

2.2. Slope

'Slope' may be defined as 'an angular inclination between different elevations and the slope gradient defines the stage of development of a landscape'. Terrain morphology is characterized by slope conditions, which are governed by a number of factors – climatic, geologic and tectonic. There is a close relationship between slope conditions and morphometric attributes of terrain viz. absolute relief, relative relief, dissection index and drainage density. An attempt has been made here to analyze the slope morphology of the Balason basin (figure 2.1).

The Balason basin displays a spectacular association of different slope and its inclination. The slope morphology map is thus, prepared based on topographical maps (figure 2.1). The major break of slope is identified along the southern margin which separates the study area into two broad segments : northern hilly area and the southern undulating terrain. Both convexity and concavity in slope form are

SLOPE MORPHOLOGY OF THE BALASON BASIN

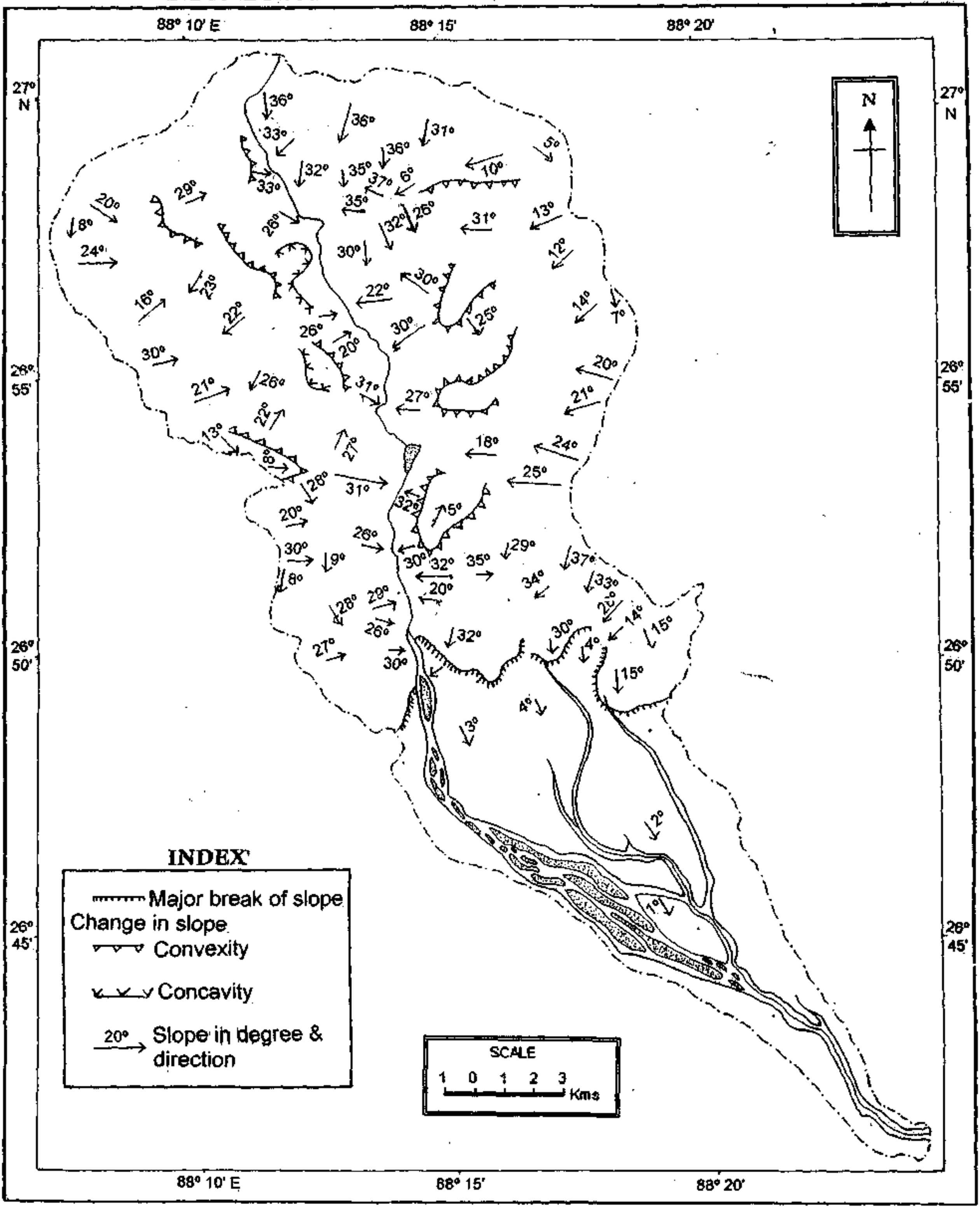

Figure 2.1.

found everywhere in the northern hilly section. However, concavity is more pronounced along the mid-slope due to massive mass movements.

Slope inclination is measured from the topographical map along with the field verification. Based on slope angle, the following slope class have been proposed:

Class I. Very steep slope zone (>30°) lies in a small wedge right across the center of the region around Phuguri and Gayabari and extending in a narrow strip away from Makaibari towards the eastern periphery. A small section in the north around Milling and Rungmook also exhibits steep slopes of >30°.

Class II. Steep slope zone (20° - 30°) is found to be the most widespread zone in the study area with a very large section in the north having slope between 20° to 30°. Steep slopes are noticed in Gopaldhara, Pubong, Tukvar, Kalej Valley, Margaret's Hope and Phulbari tea gardens. Slope inclination range between 20° to 30° also in the north western section of the region, extending from Pubong, Selimbong, Seyok, Nagri, Nagri Farm, Simripani, Dilaram, Rington, Soureni and Phuguri to the west..

Class III. Moderate slope zone (10° -20°) is found in a broad undulating wedge towards the north and northwest around Thurbo, Nagri farm, Nagri and Dhajia. A narrow strip occurs across the central portion of the study area below Panihatta and in and around the ridges i.e. Mahaldiram, Lepchajagat, Ghoom – Simana etc.

Class IV. Moderate to gentle slope zone (below 10°) are found around Mirik dome, Lepchajagat, Longview tea estate, Panighatta, Marionbari, Phulbari and Khaprail area.

Thus, from the above analysis it can be seen that most of the northern part of the study area is characterized by steep to moderately steep slopes, which is an indicator of youthful stage, where the moderately active erosional processes have not yet been able to turn the steep slope into gentle categories.

2.3. Relative Relief

Relative relief represents the difference in elevation between the highest and lowest points falling within a unit area. It is also termed as 'local relief' or 'amplitude of relief' (Hammond, 1958). Relative relief is closely associated with slope and is more expressive and useful in understanding the morphogenesis.

The relative relief of the Balason basin has been prepared, based on one sq. km. grid, from the relevant topographical maps of the Survey of India (1:50,000). The relative relief map of the Balason basin (figure 2.2) broadly divides the study area into two zones: i) high relative relief and ii) moderate to low relative relief. For a better understanding of the spatial distribution of different relative relief zone, the following classes have been identified:

Class I. Very high relative relief zone (> 500 metres) is found in very isolated patches towards the western, eastern, northern sections and central section of the study area around Ambootia.

Class II. High relative relief zone (400 – 500 metres) is concentrated in the entire northern section and the north eastern section.

Class III. Moderately high relative relief zone (300 – 400 metres) is predominant in the central region running in a broad belt from west to east in the north western of the study area .

Class IV. Moderate relative relief zone (200-300 metres) runs parallel to Class III towards the south, in a narrow strip mostly around the foothill zones.

Class V. Moderately Low relative relief zone (100-200 metres) runs parallel to the Class IV zone in a narrow strip running from west to east.

Class VI. Low relative relief zone (<100 metres) engulfs the entire southern section.

RELATIVE RELIEF OF THE BALASON BASIN

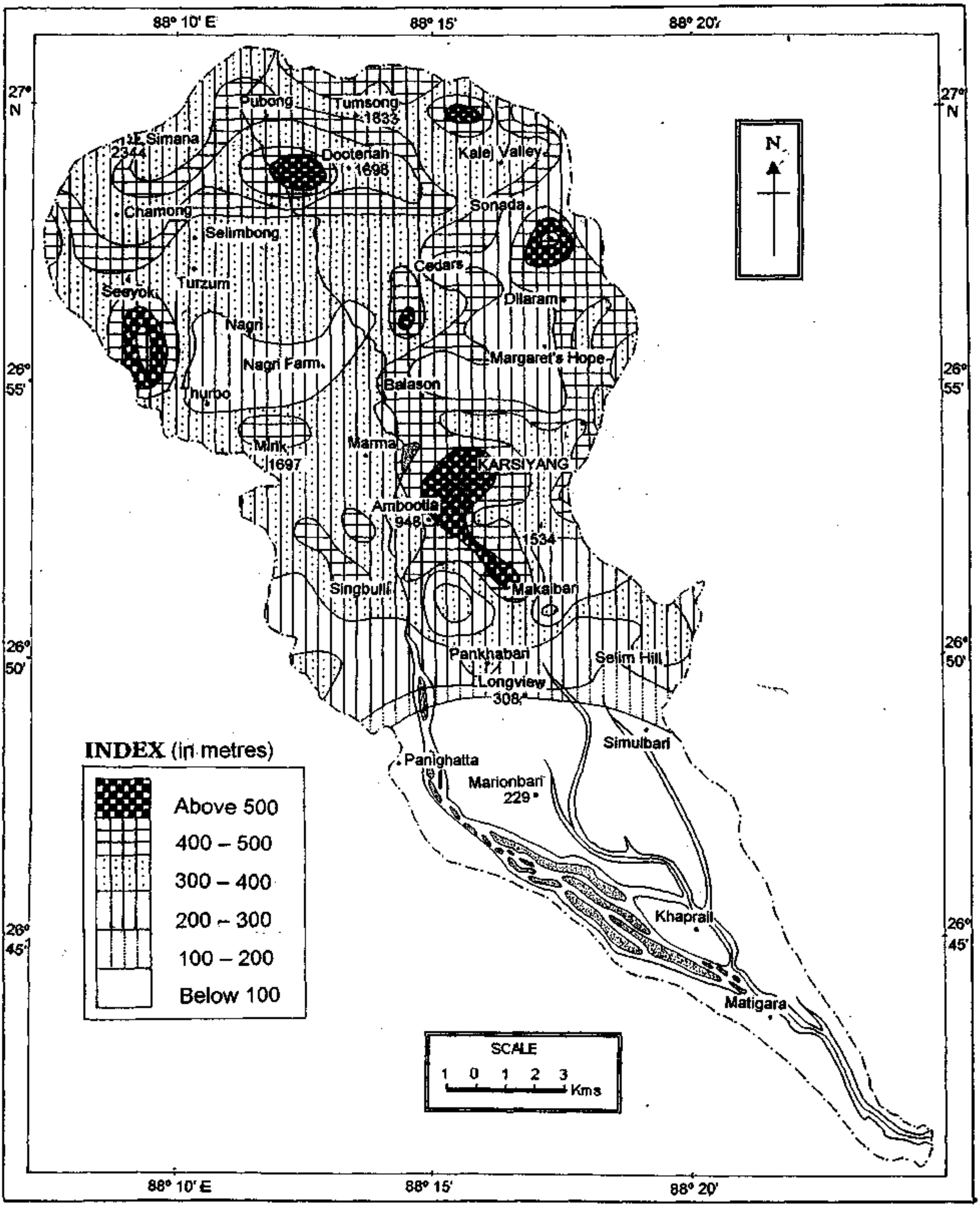

Figure 2.2.

Thus, it can be seen that the northern half of the study area is covered by high to moderately high relative relief. Hills with high altitudes and steep slopes are responsible for the development of this particular pattern of relative relief found. Structural disturbances and selective weathering in the normal course of the sculpturing processes, particularly along the boundary zones of different geological formation have played a decisive role in the attainment of such variation, in the amplitude of relief. The high amplitude of relief over the hill portion explains the possibility of high, degree of valley-side slope along the river course, which indicates that the rivers are associated with high intensity of erosion in the hilly area. Thus, it can be said that the landform of the hilly region of the basin is in the youthful stage in its erosional processes.

2.4 Dissection Index

The dissection index is a ratio between relative relief and absolute relief, and it gives a better understanding of the landscape. Dov Nir (1957) states, '*as a criterion of relative energy, the concept of relative height is not entirely satisfactory. Equal relative heights are not always of equal importance since their absolute altitudes may vary. The picture gained from relative altitudes only is static, because it fails to take into account the vertical distance from the erosion base i.e. the dynamic potential of the area studied*'. Thus, relief, in terms of the ratio between absolute relief and relative relief can be obtained by the following method of dissection index:

$$\text{Dissection Index (DI)} = \frac{\text{Relative Relief (RR)}}{\text{Absolute Relief (AR)}} \quad \text{.............2.1}$$

From the calculated values, the following six dissection categories have been identified (figure 2.3):

Class I. Very high dissection index (>0.5) forms isolated peaks in the central part of the study area around Marma and Balason.

DISSECTION INDEX OF THE BALASON BASIN

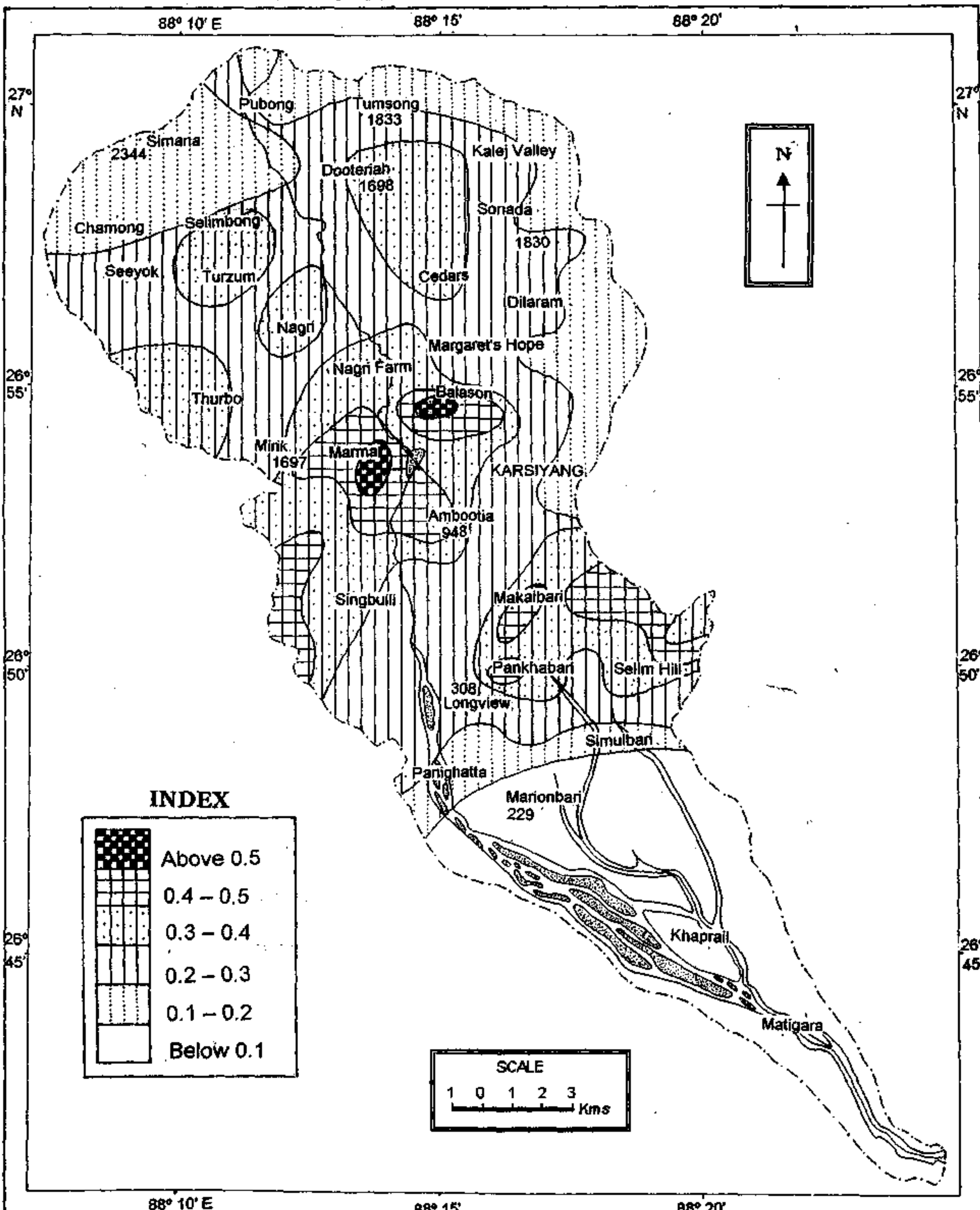

Figure 2.3.

Class II. High dissection index (0.4 – 0.5) is found in small isolated patches encircling very high dissection zone in the central eastern part of the basin around Tilndharia, above Makaibari and above Manjwa.

Class III. Moderately high dissection index (0.3 – 0.4) is found in the extreme eastern section of the central region around Makaibari. Towards the northwest a smaller irregular patch is found extending from Manjwa eastward towards Ambootia and in smaller pockets in the north around Nagri, Thurbo, Selimbong and Turzum and around Dooteriah and Cedars.

Class IV. Moderate dissection index (0.2–0.3) is found as a broad wedge in the central, north western and north eastern section of the study area extending from Gayabari and ending just short of Kalej Valley, and Tumsong in the north. A broader area in this class is found encompassing Seyok, Phulbari and winding down to Karsiyang, Singubuli and extending upto Panighatta.

Class V. Low dissection index (0.1 –0.2) lies north of moderate dissection index zone below Longview in a narrow strip running west to east, from south of Panighatta to Simulbari.

Class VI. Very low dissection index (< 0.1) occurs in a tapering wedge south of Panighatta and Simulbari across Khaprail and towards Matigara and further south.

The dissection index map of Balason basin (Fig.2.3) reveals high dissection ratio in the northern parts, due to varied nature of slope, relative relief, vegetation growth and distribution of rainfall which exhibits relatively youthful stage in morphological evolution. Low dissection index over the lower southern part of the basin shows lack of structural differences as well as instability over the terrain and conforms with the low categories of other morphometric attributes.

2.5. Drainage Density

Drainage density is defined *as the total length of stream segments per unit area.*

DRAINAGE DENSITY OF THE BALASON BASIN

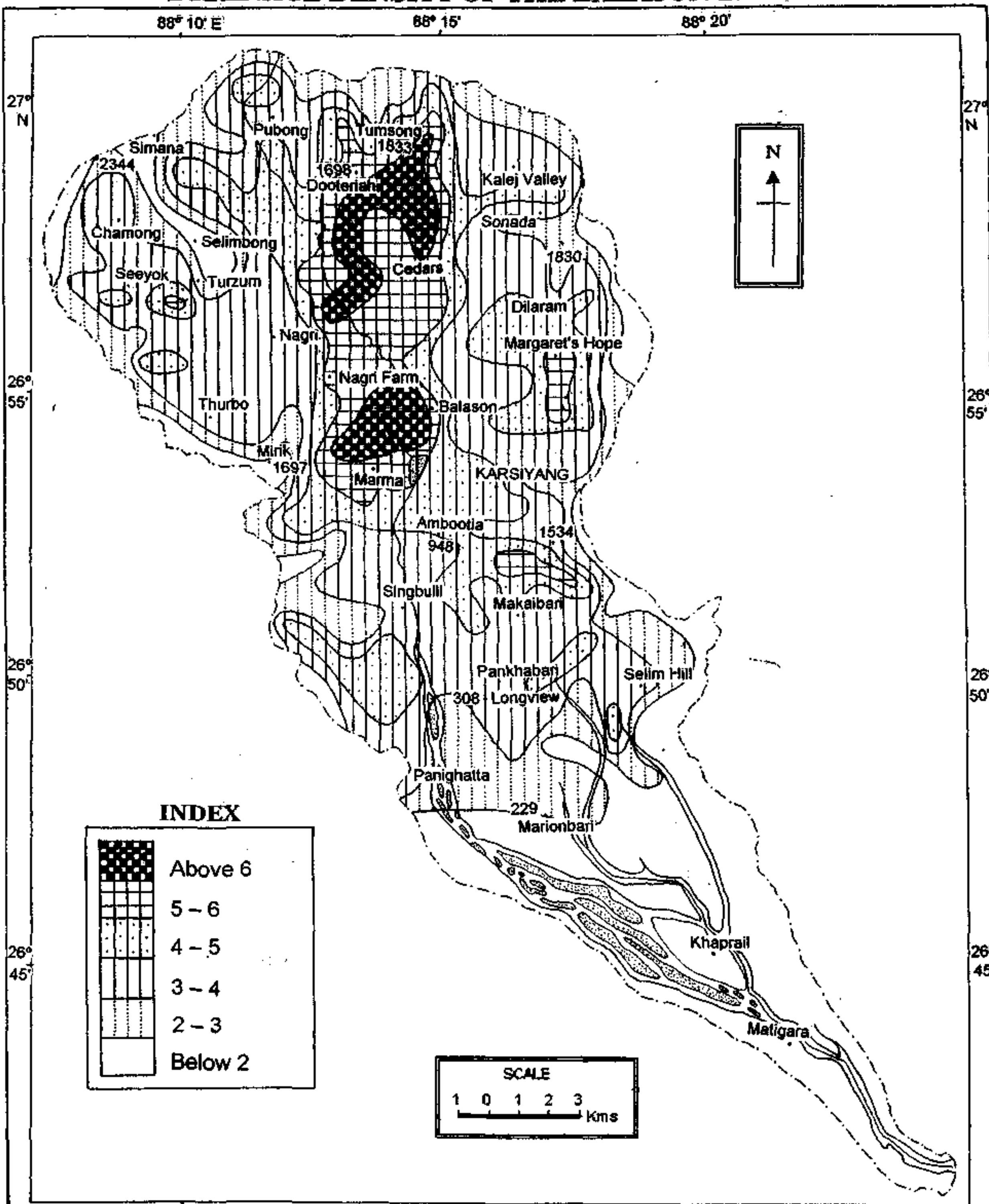

Figure 2.4.

It is a function of the intensity of run off, erosion, relief, density and absolute viscosity of the fluid. Drainage density is given by the quotient of the cumulative length (El) of the stream and total drainage area (Ad).

$$\textit{Drainage Density} = \frac{El}{Ad} \quad \text{.........................} 2.2$$

Drainage density has been calculated in one square grid and isopleths have been drawn with different values (figure 2.4) The following drainage density zones are identified in the Balason basin:

Class I. Very high density (> 6 km/km^2) are found in two isolated pockets, in the northern and central portion of the study area. The northern pocket forms an arching loop, just south of Dooteriah; while the second pocket lies between Nagri Farm and Marma.

Class II. High density (5-6 km/km^2) surrounds the Class I zone in a broad belt, and are also found in isolated patches around Margaret's Hope and Castleton.

Class III. Moderately high density (4-5 km/km^2) extends in a narrow strip, almost throughout the entire hilly section of the study area. This class seems to predominate over the central portion, extending from just south of Tumsong in the north, running through Nagri, Karsiyang and Ambootia and ending just above Makaibari. Isolated patches are also found in the western side near Seeyok and Singbulli and further south in the foothill zones around Pankhabari, Longview and Simulbarie.

Class IV. Moderate density (3-4 km/km^2) completely surrounds the three previous zones, right from the higher reaches of the hilly section, to the undulating foothills.

Class V. Low density (2-3 km/km^2) is found in a very narrow strip fringing the boundary of the study area in a wide arch, starting from the west of Singbulli, and extending northwards through Mirik, passing through Tumsong in the extreme north of the basin and running southwards through the eastern periphery from Sonada to Selim Hill. A bigger triangular wedge is seen in the undulating plain, between Longview, Panighatta and Marionbarie.

Class VI. Very low density (< 2 km/km²) is restricted, essentially, to the southern extremity of the basin which is the zone of the southern alluvial fan. However very narrow isolated patches are also found in the western, northern and eastern section of the study area.

The drainage density map of the study area shows a higher degree of consistency with the spread of other morphometric attributes and reflects the nature of variation in relief, soil, rock, vegetation etc. along with the changes of infiltration rate of different segments. It is concerned mainly with the alignment and frequency of streams. Lower values of drainage density are also found along the ridges of the Balason basin.

2.6. The Major Geomorphic Units

The Balason basin of the Darjeeling Himalaya exhibits a wide variety of geomorphic forms and indeed a complex geomorphic area. Among the processes, the fluvial is of paramount importance although, slope wash, mass movement along with the continual high degree of weathering process are found to be responsible for the evolution of fascinating assemblage of landforms. Extreme events including extreme flood also modified and produce a great variety of geomorphic forms. Geomorphology of the Balason basin may broadly be sub-divided into the following 3 major units (figure 1.2).

2.6.1. The Southern Alluvial Fan:

Gently undulating plains lie on the south of the basin, where the Balason river and its tributaries have deposited huge amounts of eroded materials that are transported from upstream. The sudden decrease in velocity as the river enters

GEOMORPHIC UNITS OF THE BALASON BASIN

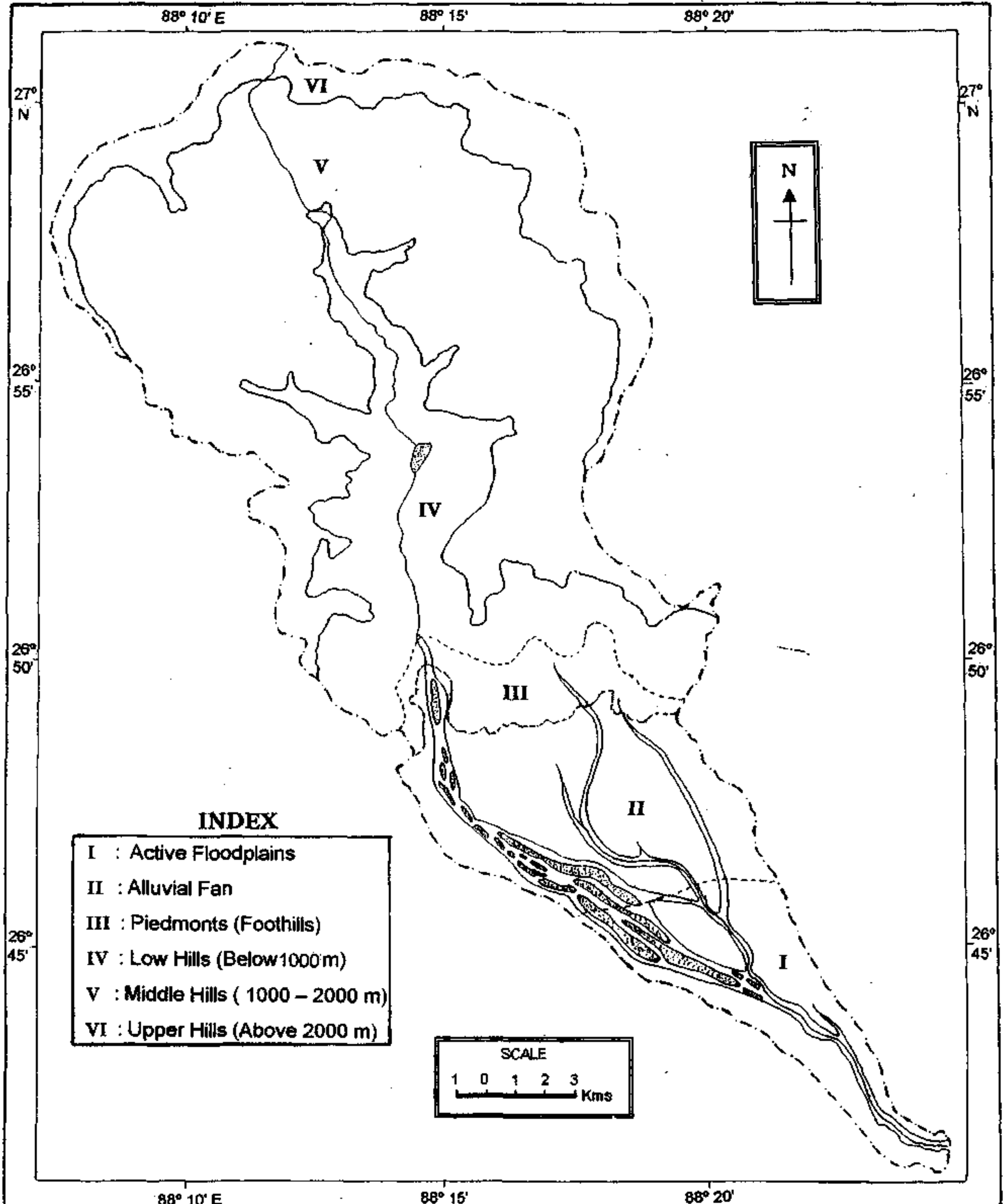

Figure 2.5

the flat lands results in an increase in deposition. Thus, the sudden fall in slope results in the development of a series of alluvial fans that occur mainly between 120 m to 400 m covering about 97.53 sq. km. approximately, over the entire alluvial plain area of the present basin of study. A piedmont zone is formed when the alluvial fans coalesce (photo 2.1). This piedmont zone exhibits some textural diversities and different sediment patterns. These alluvial fans fall on the right bank of the river Tista, the main river system of the region.

2.6.2. The Foothills / Piedmonts:

Immediately above the gently undulating plains lies the dissected foothill topography. A higher dissection is noted in this region, in comparison to the plains, which is chiefly associated with the active exogenetic process and geological disturbances which have extended upto the sheared, thrusted and folded transition zone of the Damuda series. A series of ridge and valley forms characterize the landform of the foothill areas. These features are the result of fluvial process and slope acting on the litho-techno structure of the Darjeeling Himalaya. The region is associated with the Siwalik-Damuda sandstone and shale with occasional coal bearing seams of the Permo-Carboniferous periods, distinct thrusts have been depicted between the Siwalik-Damuda and Damuda-Daling series contacts and the resultant sheared, crushed and folded litho-techno set-up prevails over the area. The occurrence of the sandstone and shale in the area facilitates a greater degree of incision giving rise to prominent valley side slopes and ridges. This geomorphic unit is characterized by steep mass wasted slopes, eroded fault scarps etc. which can be considered to be related to the manifestations of the regional episodic uplifts (Kar, 1962; Nakata, 1972). Thus, this geomorphic unit exhibits highly dissected land surface confined between 400 to 800 metre elevation.

2.6.3. The Rugged middle and upper hill tract :

A rugged zone, which however, is comparatively less dissected than the foothills, characterizes the middle and upper hill tracts. These hill tracts are composed of

Photo 2.1 The foothills overlooking the coalescing alluvial fans

Photo 2.2 The rugged upper catchment

the harder rocks of the Daling series and of Darjeeling gneiss with comparatively low amplitude of relief (photo 2.2). This zone is clearly separated from the foothills by a distinct break of slope at 800 metres. This zone is characterized by comparative lesser steep valley-side slopes and widely spaced ridges, since the Daling series and the Darjeeling gneisses of the area exert better resistance to the drainage incision. Moreover, the episodic uplifts that have been so effective in the foothills have exerted little influence on these harder rocks of the Archean period. Hence, geological deformities have been much restricted in this region, where relatively low amplitude of relief and dissection prevail.

2.7. Major Geomorphic Forms

The Balason basin in the Darjeeling Himalaya exhibits a unique assemblage of multifaceted landform. Numerous geomorphic processes produce these landforms. An attempt has been made to map the great variety of landforms (figure 2.5) found in the Balason basin. The geomorphological map provides information, which is relevant to management needs. The geomorphological map thus produced also includes information about the nature and location of features formed by denudation, fluvial action as well as those features created by slope wash. The map is prepared based on intensive field survey and topographical maps (1:50,000 and 1:25,000) using conventional symbols (Demek, 1972).

2.7.1. Landforms created by destructive action of denudation agents:

- **Denuded outliers** are found on the ridge tops of Mahaldiram range, Mirik dome, and Selim hills. These are generally, erosional remnants of the Lesser Himalayan ranges.

- **Dome like summits** are common along the Mechi-Balason interfluves. Mirik dome is the most significant example of such landform

- **Broad ridges** consist of major ridges like Simana (2355m), Mahaldiram (2061m), Giddapahar (1803m), Manjha (970 m) and Selim Hills (540 m).

GEOMORPHOLOGICAL MAP OF THE BALASON BASIN

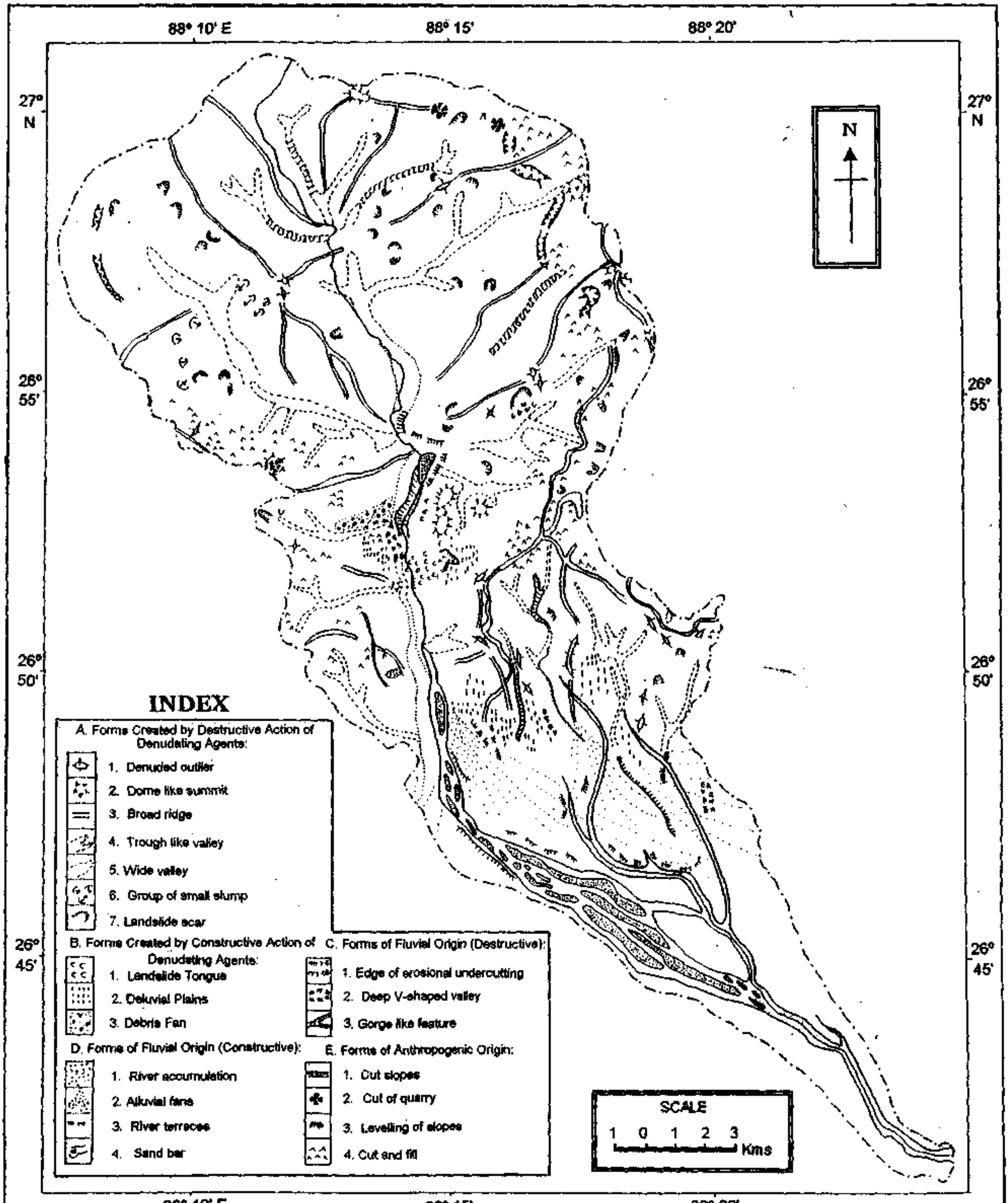

Figure 2.6.

- **Trough like valleys** are found along the right bank tributaries to Balason (Marma, Manjwa, Dudhia, Rangbang) and left bank tributaries of Balason (Rinchingtong, Rakti, Rohini, Rungsung, Pacchim, Rangmuk, Bhim Khola).

- **Wide valleys** are found along the extreme southern part of the study area, Here, broad valley with terraces have also been identified which is perhaps the product of massive aggradations due to major landslide in and around Ambootia (Starkel et al, 2000).

- **Landslide scar** is the most common form of micro-landform produced by the destructive processes. Landslide scars are very common along the Pankhabari-Mirik area. However, the biggest landslide has been found near the Ambootia tea garden, which is the biggest active landslide within the study area.

2.7.2. Landforms created by the constructive action of denuding factors:

- **Landslide tongues** are found mostly in association with landslide scars. The detached materials move down slope and are deposited at the break of slope. Such deposition looks like tongue of a landslide.

- **Debris fans** formed by paleo catastrophic events i.e. mass wasting are found in two distinctive separate zones: along the foothills and lower slopes i.e. near Bamanpokhri-Pankhabari area and the upper part of the hill slopes i.e. Bunkulung, Ambootia Tea Garden, Nagri farm, Pubong, Phuguri-Mirik area. Such landforms are the product of slope wash and exhibit moderate slope (4° - 6°) surrounded by steeper slopes (>15°). An case study of the Bunkulung debris fan is presented in the following section.

2.7.3. Landforms of fluvial origin (Destructive):

- **Edges of erosional undercutting** are the landforms of very recent origin and mostly found along the southern margin of the study area i.e. piedmont slopes and in the Balason alluvial fan. The Balason, Rohini and Rakti rivers are found noteworthy for such undercutting which varies form 6 meters to 50 meters in height. Such undercutting may be treated as an indication of post-pleistocene upliftment i.e. Neo-tectonic activities (Nakata, 1972).

- **Gorge like features** are very common along the valleys of the Balason and its tributaries along the hilly section of the study area. However, it is more common in the valleys of Marma Khola, Rinchintong, Rangbang Khola, Pacchim Khola, etc.

- **Deep V-shaped valleys** are found in the northern hilly part of the study area. Such valleys are identified in Rinchintong Khola near Singell tea garden and near Balason Pacchim confluence.

2.7.4. Landforms of fluvial origin (Constructive):

- **River accumulative** landforms are mostly found along the valleys of the Balason in the southern part of the study area. The river borne sediments are deposited in the area as a typical undulating landscape.

- **Alluvial fan plains** are perhaps the most typical landforms found along the piedmont plains. Alluvial fans are very well developed and well preserved in these areas, and are identified in between Balason and Tista rivers (Basu & Sarkar, 1990).

- **River terraces** are not very well developed in the study area. They are identified along the foothills in between Balason and Mahanadi rivers.

2.7.5. Anthropogenic landforms :

- **Cut slope** is common all over the hilly terrain of the study area, particularly along the roads and railway lines. Such cut slopes are often found to be prone to slope instability.

- **Cuts of Quarry** are common mostly around the towns like Karsiyang and Mirik from where the building materials and stones were collected for construction.

- **Leveling of slopes** is very common in most towns and tea gardens.

- **Cut and fill** for urban use along hillslope is perhaps the commonest of anthropogenic landform. Most land-use in hilly terrain needs cut of upper hill.

2.8. Case Study of Bunkulung Debris Fan

The steep slopes of the Balason basin, Darjeeling Himalaya, with considerable and uneven gradients are particularly sensitive to precipitation of a catastrophic type. Records since 1850 reveals 3 such major events (1899, 1950 and 1968) caused considerable change in topographic form on hill slopes and valley bottoms (Starkel, 1972).

Such extreme rainfall events normally induced massive mass movements (landslides as it happened in 1968 when the gigantic Ambootia landslide initiated. In the valley bottoms incision and lateral erosion lead to the removal of masses of the order of several hundred thousand m^3 per sq km of the course of a river. Accumulation of landslide debris at the base of slopes is also common and thereby, forming a fan likes landform.

Such catastrophic events are also found to have occurred during the recent geologic past i.e. the Holocene. There exist numerous evidences of such paleo events in the Balason basin. However, the investigator has selected the Bungkulung debris fan for detail analysis (figure 2.6).

The Bungkulung debris fan has been identified at the Bungkulung DGHC Rest House near the river Balason at an elevation from 450 meter to 650 meter a.s.l.

and to the west of the river Marma Khola, covering an area of 400 hectares. The average thickness of debris deposits has been estimated to be 45 metre (maximum 81 metre near Balason valley and minimum of 3 metre near the apex of the fan).

2.8.1. Genesis and morphology of the Bunkulung debris fan

Incessant high intensity rain induced gigantic landslides in the upper Marma catchment along with many other parts of the lower Darjeeling – Sikkim Himalayas during the beginning of Holocene (Sarkar, 2000). Such paleo-scars are still clearly visible in many areas (photo 2.3). The huge amount of slided materials (debris) amounting to over 20 billion m^3 (conservative estimated based on present deposition), deposited along the lower Marma valley i.e. Marma-Balason confluence and infact chocked the river Balason temporarily. Recent incision of the Balason valley into the bedrocks of the opposite site proves such contention.

The Bungkulung debris fan is a triangular shaped deposit with the maximum basal width of about 3250 metre and the maximum length of 3750 metre. The thickness of the deposits varies from 81 metres near the Balason valley to only 3 metres to the apex (figure. 2.7). Generally, the lower fan segments have greater depth. Along the eastern margin of the deposit, the river Balason cut deep gorge with an altitude varying from 70 to 90 metres, with very steep slope scar (45°–50°). The gradient of the Marma valley, near its confluence with the Balason suddenly increased from 15 to 30 %. Valley head segments dissecting slopes with a gradient of 20°–30°, constitute furrows in which material of all size were transported. Headcuts with waterfalls formed on hard bed rocks (often 5 – 10 metre high). At the outlet, valley fan was not formed, since the removed mass often eroded and was transported away by the water of the river Balason.

The Bungkulung fan is composed of materials of different size from gigantic gneissic boulders (7 metres diameter) to fine sand fragments (photo 2.4 & 2.5). An assessment of debris size was made by the investigator during field survey. A good number of large gneissic boulders of over 4 meter diameter are found to

CONTOUR PLAN OF THE BUNGKULUNG DEBRIS FAN

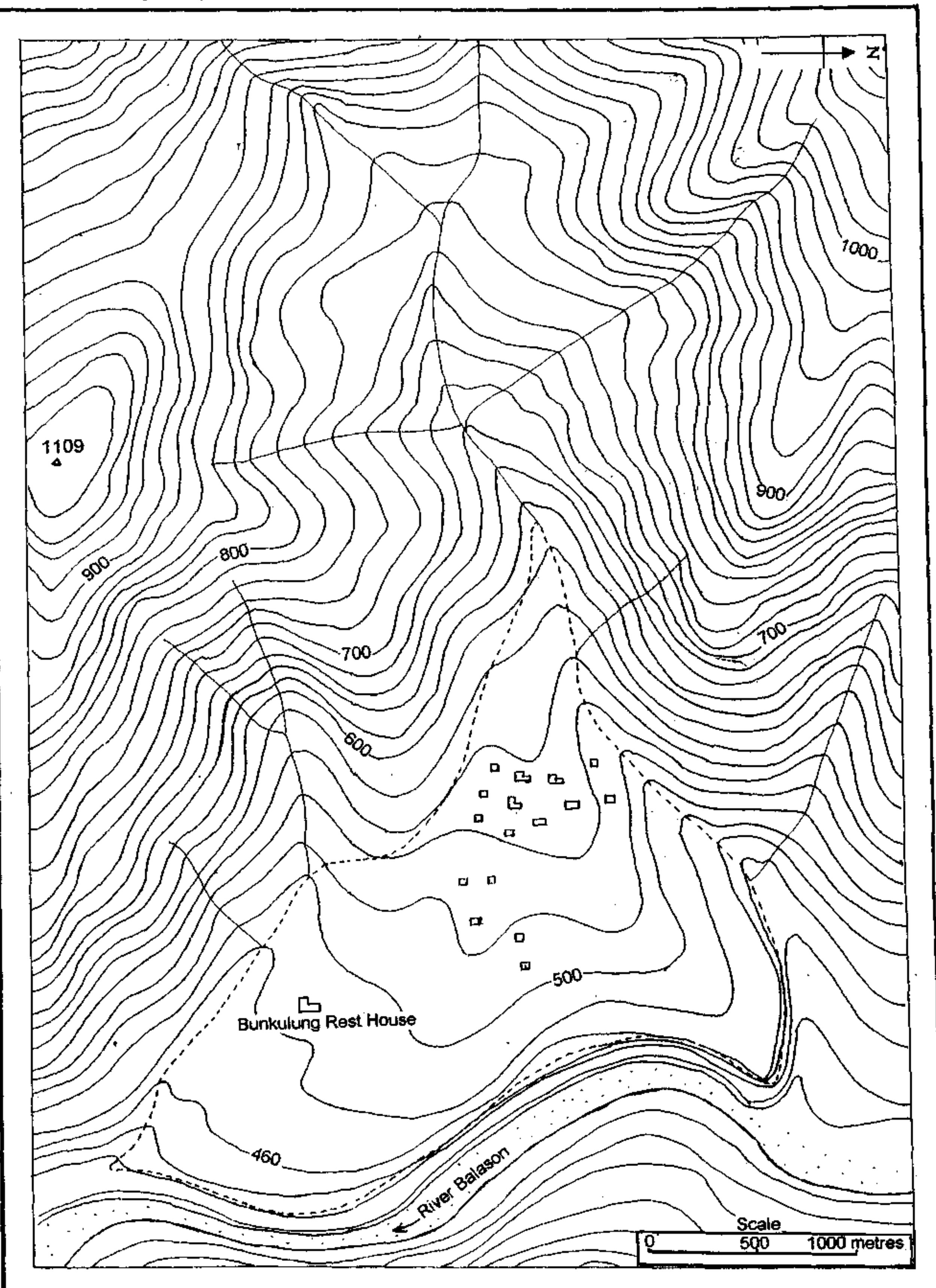

Figure 2.7

GEOMORPHOLOGICAL MAP OF THE BUNGKULUNG DEBRIS FAN

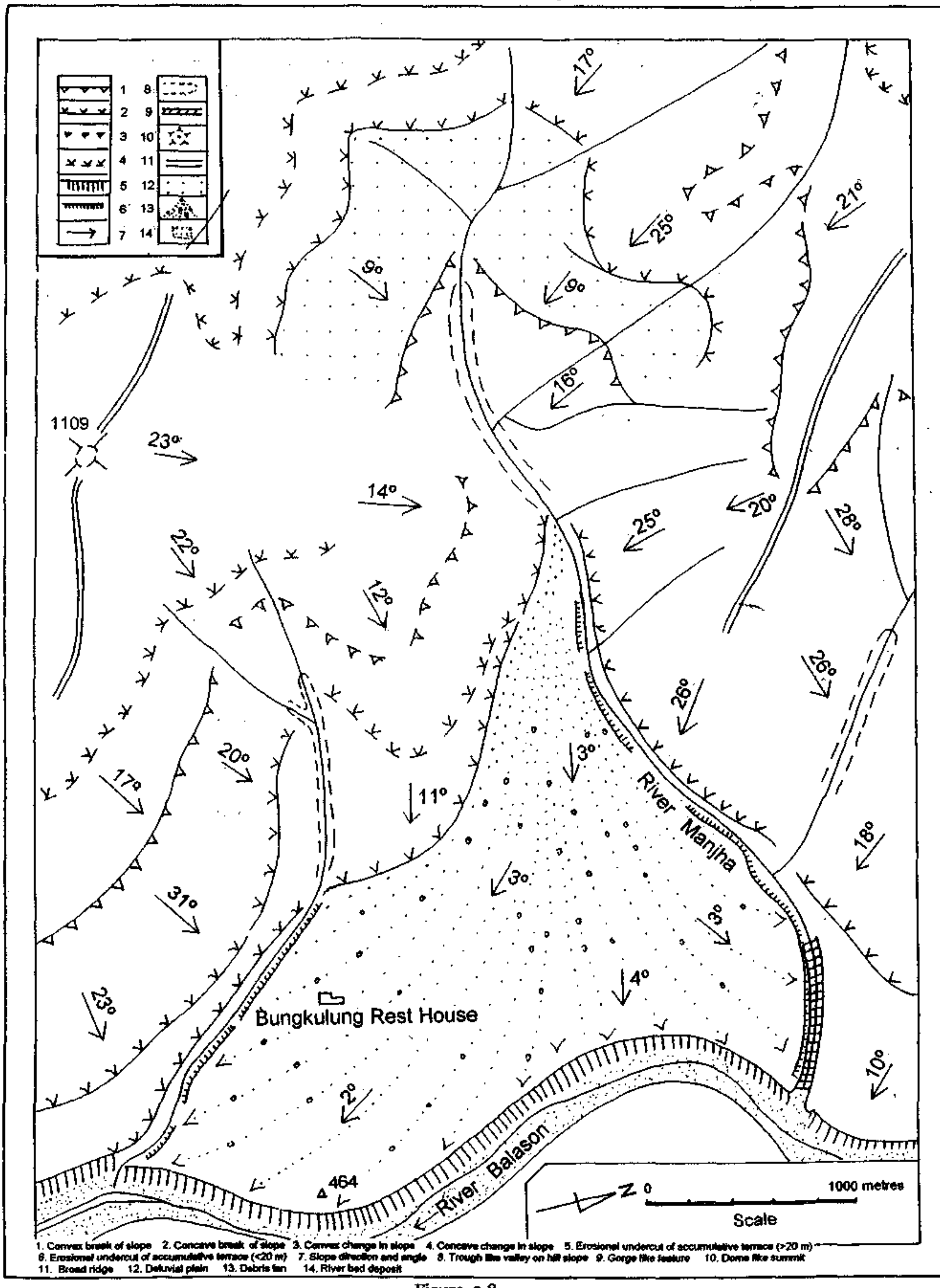

Figure 2.8

Photo 2.3 The Bungkulung debris fan : note the Palaeo scars

Photo 2.4 Gigantic gneissic boulders on the lower Bungkulung debris fan

Photo 2.5 Gigantic gneissic boulders on the lower Bungkulung debris fan

occur on the fan. However, a visible concentration of large boulders are noticed in the upper segments of the fan and along the channel of former waterways. Sample survey conducted at 3 different sites reveals some interesting features regarding the grain size composition of the fan deposits and are shown in the following table (table 2.1).

Table 2.1

Grain-size composition of the Bunkulung fan deposits.

	Occurrence in percentage to the total			
Grain size in metre	*Upper fan segments*	Middle fan segments	Lower fan segments	Mean
Above 1	15.3	10.4	4.3	10
0.5 – 1	19.7	23.1	9.4	17.4
0.1- 0.5	28.0	25.6	15.9	23.2
0.01-0.1	18.4	19.2	30.7	22.7
0.001 – 0.01	10.1	8.1	21.6	13.3
Below 0.001	8.5	13.6	18.1	13.4

It is thus revealed that the Bungkulung debris fan is composed of materials having all size. However, there found a definite concentration of material having diameter between 1 to 50 centimeters. The materials are also found very poorly sorted throughout the fan deposit. This conclusively proves that the Bungkulung fan materials are the product of a gigantic paleo mass movement.

Geomorphic forms of the Bungkulung debris fan have been depicted in the figure 2.8 which reveals that the slope of the upper fan segment is between 4° – 5°, in the middle fan segment the slope has been estimated in between 3° to 4° and that of the lower segment has been in between 2° to 3°. Thus, a gradual decreasing of slope gradient is noticeable from the upper to lower fan segment. Approaching to the Balason valley, the fan deposits form an impressive scarpment of 40° to 50° slope caused by the toe erosion of the river Balason. Minor incision of 1 to 2 meter by the Bungkulung jhora has also been noticed along the western margin of the deposits. The fan area is separated from the surrounding hills by a distinct break

CROSS SECTION ACROSS THE BUNGKULUNG DEBRIS FAN

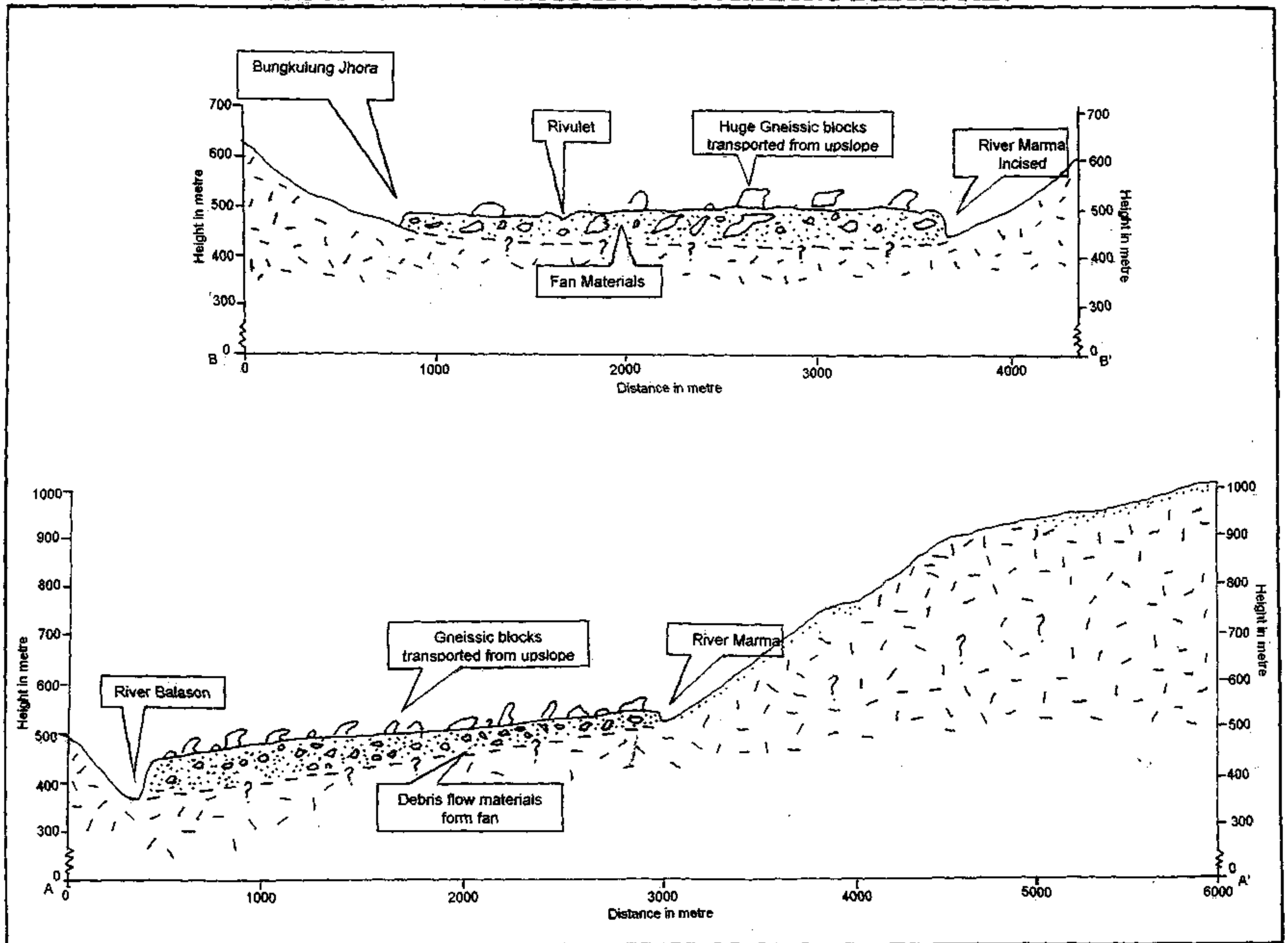

Figure 2.9

of slope, (figure 2.9) beyond which the slope varies in between 11° – 23° towards the southern side and between 16° – 28° towards the west northern side.

Excavation for the construction of development work in the area helps the investigator to reconstruct longitudinal and transverse profiles of the deposits (figure 2.9). The figures 2.7 & 2.8 depict the thickness of the debris fan deposit which varies from 80 to 3 metre. The deposits are found thicker both near Balason and Marma valley and is found to be thinning out towards the apex and the break of slope towards both the sides.

The Balason catchment of the Darjeeling Himalaya is one of the most heavily degraded on a global scale. The phenomenal rate of soil erosion and mass movements in conjunction with the deforestation and land-use transformation has already been noticed and reported in this report. In this backdrop of the catastrophic events i.e. large scale mass movements followed by very high intensity rainstorms as it was reported in 1899, 1950 and 1968, often transformed the topographic form as well as the slope pattern of hill slope and valley. Catastrophic lowering of hill slopes often takes place at the expenses of huge aggradation along the hill margin and break of slope area. Catastrophic process producing contacts and disturbing the equilibrium of forms are the motive power of transformation of the relief.

2.9. Conclusion

From the above analysis it can be concluded that the Balason basin can be geormophologically classified into two broad zones: while the northern hilly part forms the erosional zone the lower southern peidmont zone constitutes the accumulative form. Each of these zones may be further sub-divided. Whilst the Northern erosion zone can be subdivided into the ridge, upper hills and the lower hills; the southern accumulative zone can be sub-divided into the alluvial fan and the deluvial plains. The most important geomorphic process that is operative upon the area of study is fluvial, but denudational slope wash and mass movement too, have an important role in the overall shaping of the lower regions. A number of geomorphic forms were identified in the area of study chief amongst which were: denudation outlier, dome like summit, broad ridge, landslide scars, landslide tongue, deluvial and solifuxion plains, erosional cuttings, trough like valleys, gorge, river accumulation, alluvial fan, river terrace etc. The convex form of the ridges, along with the gentler slopes towards the upper segments being steeper towards the foot, show that the region is still young and active. Active down cutting is evident in a number of places along the Balason valley. The numerous geomorphic forms that occur in the study area have also definite relevance to tectonic disturbances and neo-tectonic activities.

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CHAPTER 3

MORPHOMETRIC ANALYSIS OF THE BALASON BASIN

3.1. Introduction

The drainage basin is the most convenient unit for the study of both geomorphology and hydrology. The drainage network and composition denotes the inter-connection of the system of drainage net and the quantitative morphology of a basin through the process of stream ordering and its relation with stream number, stream length, area and relief (Horton, 1945; Chorley, 1957, 1969: Melton, 1958; Coates, 1958, Sarkar, 1997). The study of such various properties of drainage network composition for the Balason basin under study has been carried out with the help of the measured and calculated values of the aforesaid variables (table 3.2).

As the geomorphologic set up of the Balason basin offers a great scope to study the role of geomorphology in environmental management, an attempt has been made in this chapter, to visualize the extent of variations in landform contrast and their magnitude, along with their relevant processes, in proper perspective, by adopting contemporary quantitative and statistical techniques.

3.2. Morphometric analysis of the sub-basins

The morphometric properties and variables were calculated from the Survey of India Topographical sheet Nos. $78^{A}/_{4}$, $78^{A}/_{8}$, $78^{B}/_{1}$, $78^{B}/_{5}$, and $78^{B}/_{6}$ at a scale of 1:50,000. The symbols that have been used for this account are listed in table 3.1. The morphometric variables are obtained from 55 third order basin of the Balason river (figure 3.1). These third order basins have a wide range of characteristics. These include varying amount of summit surfaces, rock types, climate, vegetation along with level of human interferences. It is more likely that the relationship, which becomes apparent through numerical analysis result from forces governing the development of drainage basin in general.

INDEX MAP FOR THE THIRD ORDER BASINS

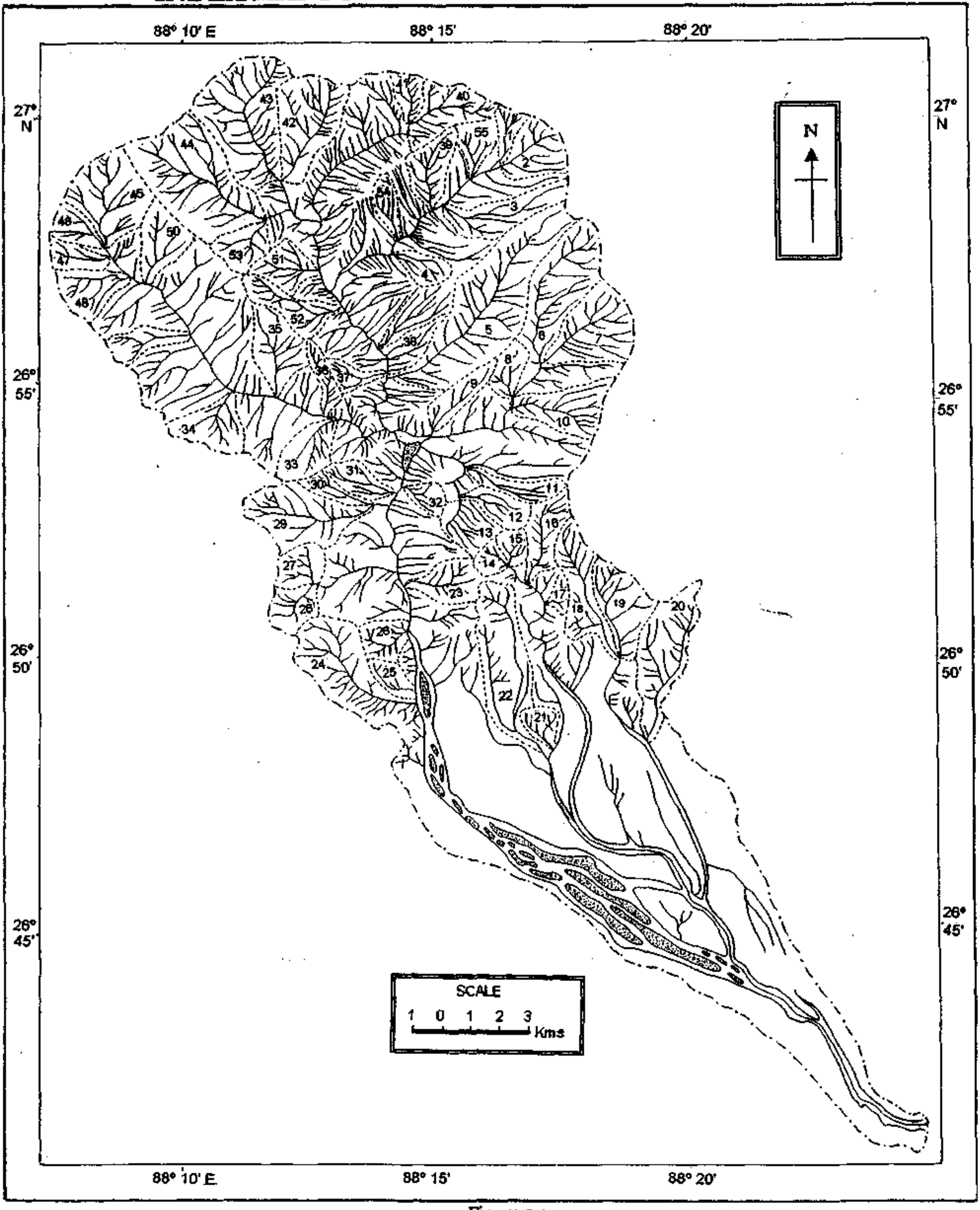

Figure 3.1

Table 3.1.

Morphometric variables, their dimensions and symbols used in the study

Variables	Symbols	Unit	Dimensions
Drainage network:		Enumerative	
Stream order (used as sub-script)	μ		O
Number of streams of order μ	$N\mu$		O
Total number of streams with basin order μ	$(\Sigma N)\ \mu$		L
Total length of streams of order μ	$(\Sigma L)\ \mu$	Km	L
Bifurcation ratio	$Rb = N\mu / N\mu\text{-}1$		
Stream length ratio	$L\ \mu$		
Basin geometry:			
Area of basin order μ	$A\ \mu$	Square km	L^2
Length of basin order μ	$Lb\mu$	Km	L
Width of basin order μ	$Br\mu$	Km	L
Basin perimeter of order μ	$P\mu$	Km	L
Basin circularity	Rc	Km	O
Basin elongation	Re	Km	O
Measures of Intensity of dissection			
Basin density	$D\mu = (L)\ \mu / A$	Km / Sq. Km	
Constant of channel maintenance	$C = 1/D\mu$	Km	L
Stream frequency	$F = N\mu / A\mu$	No/Sq.km	L^{-2}
Texture ratio	$T = N\mu / P\mu$	No sq. km	L^{-1}
Measures involving heights			
Height of basin mouth	Z	Meter	L
Height of highest point of basin	Z	Meter	L
Total basin relief	$H = Z\text{-}z$	Meter	L
Relief ratio	$Rh = H/Lb$		O
Ruggedness number	$Rn = D*H/1000$		O

3.2.1. Descriptive statement of the morphometric properties:

Descriptive statistics can be applied to morphometric data in order to summarize the data collected and from this summary it is possible to define the morphometric characteristics of the basin under study.

Table No. 3.2.

Morphometric variables of the 55 third order basin of the Balason river

No.of 3rd.Order Basin	Area in Km²	Total Length of streams in Km.	Length of 1st. Order stream	Length of 2nd. order stream	Length of 3rd. Order stream	Total number of streams	Number of 1st. order stream	Number of 2nd. Order stream	Basin perimeter in Km.	Length of 3rd. order basin	Width of 3rd. order basin	Basin circularity ratio	Basin elongation ratio	Drainage density	Constant of channel maintenance	Stream frequency	Texture ratio	Relief ratio	Ruggedness ratio	Lowest point in the basin	Highest point in the basin	Basin relief	Mean length of streams			Bifurcation ratio		
	A_3	$(\Sigma L)_3$	L_1	L_2	L_3	$(\Sigma N)_3$	N_1	N_2	P_3	$(Lb)_3$	Br_3	Rc_3	Re_3	D_3	C_3	F_3	T_3	Rh_3	Rn_3	-z	Z	H	$\bar{L_1}$	$\bar{L_2}$	$\bar{L_3}$	Rb_1	Rb_2	Rb_3
1	1.20	5.40	3.3	1.00	1.10	11	8	2	6.25	2.10	1.10	0.55	0.80	4.49	0.22	9.14	2.10	315.23	2.87	1620	2482	862	0.41	0.50	1.10	0.89	0.67	0.5
2	3.66	11.10	8.7	1.20	1.20	15	11	3	7.55	2.50	2.40	0.81	0.96	3.04	0.33	4.10	1.99	352.00	2.67	1580	2460	880	0.79	0.40	1.20	0.92	0.75	0.5
3	3.60	11.25	8.0	2.50	0.75	12	9	2	10.5	4.30	1.20	0.41	0.78	3.12	0.32	3.33	1.14	298.67	4.00	1120	2400	1280	0.89	1.25	0.75	0.90	0.67	0.5
4	1.33	5.85	3.0	1.06	0.90	11	7	3	5.25	2.00	1.10	0.60	0.84	4.42	0.23	8.30	2.10	335.00	2.96	930	1600	670	0.43	0.35	0.90	0.88	0.75	0.5
5	12.7	40.75	26.3	5.50	9.00	46	38	7	18.5	8.05	2.55	0.40	0.73	3.21	0.31	3.62	2.49	206.21	5.33	940	2400	1460	0.69	0.79	9.00	0.97	0.88	0.5
6	8.77	26.95	17.0	4.75	5.60	41	34	6	20.00	6.60	1.70	0.28	0.97	3.07	0.33	4.68	2.05	173.73	3.66	1280	2420	1140	0.5	0.79	5.60	0.97	0.86	0.5
7	5.51	18.10	12.5	3.20	2.50	24	18	5	9.75	3.55	2.40	0.73	0.67	3.28	0.30	4.36	2.46	248.89	2.89	1360	2240	880	0.69	0.64	2.45	0.95	0.83	0.5
8	1.45	4.00	2.9	0.70	0.40	9	6	2	5.00	1.75	1.20	0.73	0.91	2.75	0.36	6.19	1.80	278.29	1.34	1060	1547	487	0.46	0.35	0.40	0.86	0.67	0.5
9	1.71	6.20	4.4	1.70	0.10	9	6	2	6.90	3.10	0.75	0.45	0.71	3.64	0.28	5.28	1.30	181.29	2.04	740	1302	562	0.73	0.85	0.10	0.86	0.67	0.5
10	3.96	15.20	11.5	1.50	2.20	20	16	3	9.00	3.30	2.05	0.61	0.87	3.84	0.26	5.05	2.22	297.97	3.76	860	1840	980	0.72	0.50	2.20	0.94	0.75	0.5
11	1.63	7.20	4.5	1.70	1.00	8	5	2	7.00	3.10	0.80	0.42	0.72	4.42	0.23	4.91	1.14	33.5.55	0.46	596	700	104	0.90	0.85	1.00	0.83	0.67	0.5
12	1.69	6.30	5.0	0.50	0.80	8	5	2	6.10	2.95	1.25	0.57	0.66	3.74	0.27	4.75	1.31	203.39	2.24	940	1540	600	1.00	0.25	0.80	0.83	0.67	0.5
13	2.39	9.75	8.0	0.75	1.00	13	10	2	6.00	1.55	2.00	0.83	1.23	4.08	0.25	5.44	2.17	37419	2.37	780	1360	580	0.80	0.38	1.00	0.91	0.67	0.5
14	0.90	3.95	3.1	0.45	0.40	8	5	2	3.50	1.20	1.05	0.72	0.93	4.39	0.23	8.89	2.29	382.61	2.37	860	1280	420	0.62	0.23	0.40	0.83	0.67	0.5
15	0.72	2.75	2.0	0.50	0.25	8	5	2	3.50	1.25	1.10	0.74	0.89	3.80	0.26	11.1	2.29	507.20	2.41	900	1534	634	0.40	0.25	0.25	0.83	0.67	0.5
16	2.80	11.90	8.6	0.70	2.60	20	17	2	9.00	3.60	1.05	0.44	0.80	4.25	0.24	7.14	2.22	206.56	3.14	760	1500	740	0.51	0.35	2.60	0.94	0.67	0.5
17	0.84	2.65	2.0	0.60	0.05	7	4	2	3.50	0.85	1.40	0.87	1.31	3.14	0.32	8.30	2.00	714.12	1.91	800	1407	607	0.50	0.30	0.05	0.80	0.67	0.5
18	4.37	16.20	10.0	4.90	1.30	21	17	3	12.00	5.10	1.55	0.38	0.75	3.71	0.27	4.81	1.75	251.98	4.75	440	1820	1380	0.59	1.63	1.30	0.94	0.75	0.5
19	4.06	11.95	8.0	1.95	2.00	17	13	3	9.20	3.60	1.65	0.6	0.61	2.95	0.34	4.19	1.85	206.56	2.18	540	1280	740	0.62	0.65	2.00	0.93	0.75	0.5
20	6.16	20.75	15.0	2.00	3.75	29	25	3	13.00	5.70	1.55	0.46	0.73	3.37	0.3	4.71	2.23	164.68	3.14	240	1173	933	0.60	0.67	3.75	0.96	0.75	0.5
21	0.97	5.35	3.8	0.75	0.80	9	6	2	4.60	1.65	1.25	0.57	0.89	5.54	0.18	9.33	1.96	109.09	9.98	260	440	180	0.63	0.38	0.80	0.86	0.67	0.5
22	6.42	19.45	9.5	6.95	3.00	21	17	3	14.00	6.20	1.50	0.41	0.72	3.03	0.33	3.27	1.50	155.84	2.90	260	1220	960	0.56	2.32	3.00	0.94	0.75	0.5
23	2.69	7.65	5.75	0.70	1.20	14	11	2	6.60	2.10	1.50	0.78	1.00	2.84	0.35	5.20	2.12	310.48	1.85	600	1252	652	0.52	0.35	1.20	0.92	0.67	0.5
24	6.33	21.80	15.6	3.10	3.10	37	30	6	11.50	4.60	2.15	0.60	0.80	3.44	0.29	5.84	3.22	913.30	1.45	760	1180	420	0.52	0.52	3.10	0.97	0.86	0.5
25	0.98	4.05	2.1	1.25	0.70	8	5	2	4.50	1.80	0.90	0.61	0.80	4.14	0.24	8.18	1.78	327.67	2.44	200	1788	1588	0.42	0.63	0.70	0.83	0.67	0.5
26	1.67	8.55	5.4	1.20	1.95	18	14	3	5.10	1.65	1.50	0.81	0.98	5.14	0.19	10.80	3.53	642.42	5.44	280	1340	1060	0.39	0.40	1.95	0.93	0.75	0.5
27	1.90	6.00	4.0	1.20	0.80	11	7	3	5.75	1.50	1.95	0.72	1.22	3.15	0.32	5.78	1.91	260.67	1.23	1109	1500	391	0.57	0.40	0.80	0.88	0.75	0.5

CONTINUED.......

	A_3	$(\Sigma L)_3$	L_1	L_2	L_3	$(\Sigma N)_3$	N_1	N_2	P_3	$(Lb)_3$	Br_3	Rc_3	Re_3	D_3	C_3	F_3	T_3	Rh_3	Rn_3	z	Z	H	L_1^-	L_2^-	L_3^-	Rb_1	Rb_2	Rb_3
28	2.03	5.85	4.45	0.6	0.8	11	7	3	6.0	2.05	1.55	0.71	0.93	2.89	0.35	5.43	1.83	439.02	2.6	240	1140	900	0.64	0.20	0.80	0.88	0.75	0.5
29	5.19	18.30	12.1	3	3.25	25	19	5	11.3	4.10	2.60	0.52	0.87	3.52	0.28	4.81	2.22	307.31	4.44	440	1700	1260	0.63	0.80	3.25	0.95	0.83	0.5
30	1.11	5.60	3.6	0.5	1.5	9	6	2	5.75	2.55	0.60	0.42	0.72	5.07	0.20	8.14	1.57	353.94	4.56	700	1600	900	0.60	0.25	1.50	0.86	0.67	0.5
31	1.64	6.60	4.1	1.8	0.7	11	7	3	5.6	2.30	0.95	0.66	0.78	4.02	0.25	6.71	1.96	325.78	2.58	640	1387	747	0.59	0.60	0.70	0.86	0.75	0.5
32	0.93	4.20	2.6	1	0.6	9	6	2	3.95	1.55	1.05	0.75	0.81	4.52	0.22	9.68	2.28	323.58	2.26	640	1140	500	0.43	0.50	0.60	0.86	0.67	0.5
33	2.32	6.90	4.9	1.2	0.8	13	10	2	6.4	2.60	1.40	0.74	0.78	2.98	0.34	5.61	2.03	369.23	2.86	700	1660	960	0.49	0.60	0.80	0.91	0.67	0.5
34	2.60	8.85	6.5	1.4	0.95	13	9	3	7.3	1.95	2.30	0.61	1.19	3.4	0.29	4.99	1.78	338.46	2.24	1180	1840	660	0.72	0.47	0.95	0.90	0.75	0.5
35	3.02	10.45	8	1.2	1.25	12	9	2	8.0	3.20	1.95	0.59	0.80	3.46	0.29	3.98	1.50	269.75	2.98	900	1760	860	0.89	0.60	1.25	0.90	0.67	0.5
36	0.95	5.85	3.4	0.5	1.95	12	9	2	5.7	2.45	0.60	0.37	0.74	6.19	0.16	12.7	2.11	183.27	2.78	900	1349	449	0.38	0.25	1.95	0.90	0.67	0.5
37	0.94	5.30	3	1.5	0.8	9	6	2	5.0	1.75	1.10	0.47	0.91	5.64	0.18	9.57	1.80	389.51	3.83	660	1340	680	0.50	0.75	0.80	0.86	0.67	0.5
38	2.26	11.25	7.2	2.6	1.45	12	8	3	7.9	3.20	1.30	0.46	0.79	4.98	0.20	5.31	1.52	228.44	3.64	800	1531	731	0.90	0.87	1.45	0.89	0.75	0.5
39	2.36	12.20	8.1	2.1	2.00	21	16	4	7.0	2.80	1.45	0.61	0.80	5.17	0.19	8.91	3.00	321.43	4.66	1240	2140	900	0.51	0.53	2.00	0.94	0.80	0.5
40	4.00	16.10	11	3.2	1.90	25	19	5	8.8	3.20	1.45	0.65	0.88	4.03	0.25	6.25	2.84	544.38	7.02	740	2482	1742	0.58	0.64	1.90	0.95	0.83	0.5
41	1.64	6.85	5.2	1.05	0.60	13	10	2	5.75	2.05	1.40	0.62	0.89	4.17	0.24	7.91	2.26	361.98	3.09	1580	2320	740	0.52	0.53	0.60	0.91	0.67	0.5
42	5.73	21.35	14.6	3.5	3.25	36	29	6	10.6	4.00	2.15	0.64	0.84	3.73	0.27	6.29	3.4	119.00	1.78	1940	2416	476	0.50	0.58	3.25	0.97	0.86	0.5
43	10.5	37.60	26.4	7.2	4.00	55	45	9	14.0	4.60	3.95	0.68	0.97	3.57	0.28	5.23	3.93	195.22	3.21	1440	2338	898	0.59	0.80	4.00	0.98	0.9	0.5
44	11.3	33.15	24.1	6	3.05	39	33	5	13.8	5.40	2.60	0.75	0.81	2.94	0.34	3.45	2.84	283.93	4.17	920	2340	1420	0.73	1.20	3.05	0.97	0.83	0.5
45	5.92	18.30	11.9	4.5	1.9	23	17	5	10.4	3.70	3.20	0.69	0.90	3.09	0.32	3.88	2.21	236.49	2.7	1480	2355	875	0.70	0.90	1.90	0.94	0.83	0.5
46	2.17	6.55	5.0	0.95	0.6	8	5	2	6.5	2.50	1.20	0.64	0.83	3.03	0.33	3.7	1.23	240.00	1.82	1420	2020	600	1.00	0.48	0.60	0.83	0.67	0.5
47	1.61	4.40	1.9	1.0	1.5	8	5	2	6.0	2.30	1.25	0.56	0.83	2.74	0.36	4.98	1.33	357.52	2.23	1340	2160	820	0.38	0.50	1.50	0.83	0.67	0.5
48	2.35	8.40	5.5	1.9	1.0	11	8	2	7.25	2.70	1.85	0.56	0.86	3.57	0.28	4.67	1.52	284.89	2.79	1260	2043	783	0.69	0.95	1.00	0.89	0.67	0.5
49	1.65	7.40	4.8	1.0	1.6	10	7	2	7.0	2.75	1.10	0.42	0.83	4.48	0.22	6.05	1.43	335.27	4.13	1080	2002	922	0.69	0.50	1.60	0.88	0.67	0.5
50	2.55	9.35	6.95	1.5	0.9	10	7	2	7.4	2.60	1.65	0.27	0.91	3.67	0.27	3.92	1.35	323.08	3.08	1140	1980	840	0.99	0.75	0.90	0.88	0.67	0.5
51	2.14	10.30	7.3	1.5	1.5	16	11	4	6.4	2.40	1.95	0.21	0.85	4.81	0.21	7.48	2.5	325.00	3.75	940	1720	780	0.86	0.38	1.50	0.92	0.8	0.5
52	2.58	11.00	6.7	1.9	2.4	16	12	3	8.1	3.10	1.10	0.49	0.83	4.27	0.23	6.21	1.98	331.29	4.39	700	1727	1027	0.56	0.63	2.40	0.92	0.75	0.5
53	1.98	6.00	4.1	1.0	0.9	10	7	2	6.0	2.05	1.95	0.69	0.93	3.03	0.33	5.05	1.67	283.93	1.76	1160	1740	580	0.59	0.50	0.90	0.88	0.67	0.5
54	1.08	6.10	3.2	2.2	0.7	9	6	2	5.4	2.30	0.80	0.47	0.75	5.65	0.18	8.33	1.67	304.44	3.95	1080	1788	708	0.53	1.10	0.70	0.86	0.67	0.5
55	1.49	4.80	2.5	1.8	0.5	9	6	2	6.0	1.80	1.30	0.52	1.06	3.22	0.31	6.03	1.50	333.33	1.29	1200	1800	600	0.42	0.90	0.50	0.86	0.67	0.5

3.2.2. Measures of central tendency :

In the present study, the area of the third order basins (A_3), number of streams (ΣN_3), length of the streams $(\Sigma L)_3$, drainage density $(D)_3$, stream frequency (F_3), and basin perimeter (P_3), have been summarized by a frequency distribution table (table 3.3). Here, the range of values observed is sub-divided into classes and the number of observations in each class is recorded. The information of the frequency distribution table have been shown diagrammetrically in figure 3.2. Not only does table 3.3 provide the summary of the data it also allows certain probability of statements to be made. For example, as far as the values of A_3 are concerned the r.c.f. (relative cumulative frequency) column shows that 43.64% of the basins have areas upto 2 sq. km., while the relative frequency in proportion values (r.f.p.) can be divided by 100 in each case to allow a probability statement to be made. Thus, there is a 0.327 probability that a third order basin chosen at random from the area of study will have an area of 2.4 sq. km .

Regarding the length of the streams of the study area, 58.18% of the basin have stream length between 5 to 10 km. The class 5 -10 has the largest probability of 0.436. 64.45% of the basin has number of streams, which lie within the class 8 - 16, which also shows the highest probability of 0.636.

Table 3.3

Frequency, cumulative frequency, relative cumulative frequency and relative frequency in proportion of different morphometric variables

Class boundary (A_3)	Frequency	Cumulative frequency	Relative cumulative frequency (%)	Relative frequency proportion (%)
0-2	24	24	43.64	43.64
2-4	18	42	76.37	32.73
4-6	6	48	87.27	10.91
6-8	3	51	92.73	5.45
8-10	1	52	94.55	1.82
10-12	2	54	98.18	3.64
12-14	1	55	100.00	1.82

(A_3) : Area of third order basins in sq. km..

Class boundary $(\Sigma L)_3$	Frequency	Cumulative frequency	Relative cumulative frequency (%)	Relative frequency proportion (%)
0-5	8	8	14.55	14.55
5-10	24	32	58.18	43.64
10-15	9	41	74.55	16.36
15-20	7	48	87.27	12.73
20-25	3	51	92.73	5.45
25-30	1	52	96.37	1.82
30-35	1	53	98.18	1.82
35-40	1	54	98.18	1.82
40-45	1	55	100	1.82

$(\Sigma L)_3$ Total length of streams of third order basins (km)

Class boundary $(\Sigma N)_3$	Frequency	Cumulative frequency	Relative cumulative frequency (%)	Relative frequency proportion (%)
0-8	1	1	1.82	1.82
8-16	35	36	64.45	63.64
16-24	9	45	81.82	16.37
24-32	4	49	89.09	7.27
32-40	3	52	94.55	5.45
40-48	2	54	98.18	3.64
48-56	1	55	100.00	1.82

$(\Sigma N)_3$ Total number of streams of the third order basins

Class boundary D_3	Frequency	Cumulative frequency	Relative cumulative frequency (%)	Relative frequency proportion (%)
2.5-3.0	7	7	12.73	12.73
3.0-3.5	16	23	41.82	29.09
3.5-4.0	10	33	60.00	18.18
4.0-4.5	11	44	80.00	20.00
4.5-5.0	3	47	85.45	5.45
5.0-5.5	3	50	90.91	5.45
5.5-6.0	4	54	98.18	7.27
6.0-6.5	1	55	100.00	1.82

D_3 Drainage density of the third order basins in km / km^2

Class boundary F_3	Frequency	Cumulative frequency	Relative cumulative frequency (%)	Relative frequency proportion (%)
3-4	8	8	14.55	14.55
4-5	12	20	36.36	21.82
5-6	11	31	56.56	20.00
6-7	7	38	69.09	12.73
7-8	3	41	74.55	5.45
8-9	6	47	85.45	10.90
9-10	4	51	92.75	7.27
10-11	1	52	94.55	1.82
11-12	1	53	96.36	1.82
12-13	2	55	100.00	3.64

F_3 Drainage frequency of the third order basins

Class boundary P_3	Frequency	Cumulative frequency	Relative cumulative frequency (%)	Relative frequency proportion (%)
2-5	6	6	10.91	10.91
5-8	30	36	65.45	54.55
8-11	10	46	83.64	18.18
11-14	5	51	92.73	9.09
14-17	2	53	96.36	3.64
17-20	2	55	100.00	3.64

P_3 Perimeter of the third order basin in km.

Drainage density, within the third order basins ranges within 2.5 - 6.5 with more than 60% of the values lying between 2.5 to 4.0 range. The maximum probability of 0.291 has been found between 3.0 to 3.5 km / km^2 group. Regarding the drainage frequency, it is interesting to note that 56.56% lie between 5 - 6 and only 3.94% lie between 12 - 13. The maximum probability of 0.218 lies between the classes 4-5. Distribution of perimeter of the third order basin are also interesting since, 65.45% of the values lies between 5-8 and have the highest probability of 0.546. The class 17-20 has only 3.64% of the basins and has the lowest probability of 0.036. (table 3.3.)

The various measures of central tendency and dispersion have been represented in tabular form in the table 3.4. There are three measures of central tendency:

FREQUENCY DISTRIBUTION CURVES FOR VARIOUS BASIN MORPHOMETRIC PROPERTIES OF THE THIRD ORDER

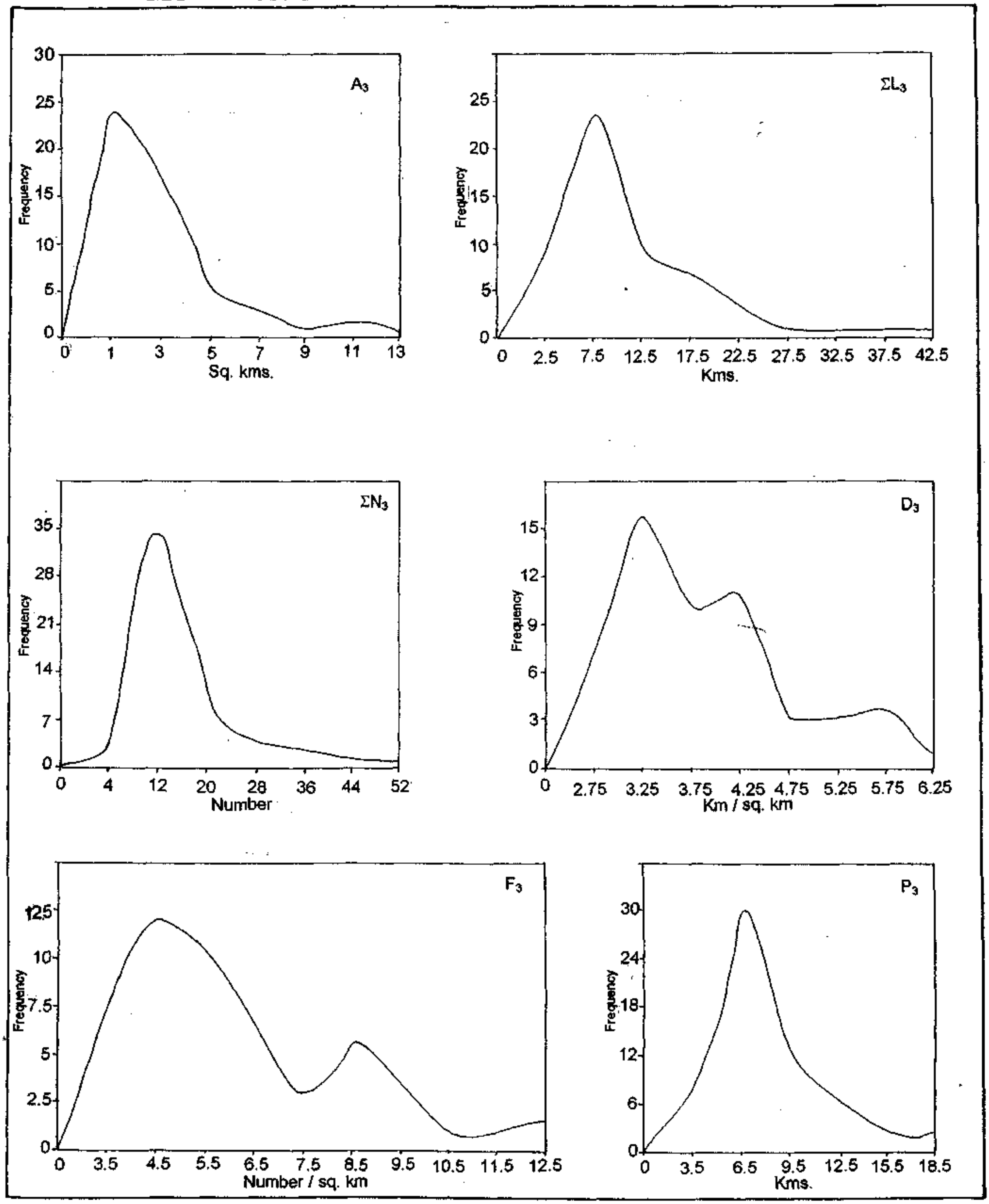

Figure 3.2.

mean, median and mode. The spread of the data has been defined by measuring their dispersion i.e. standard deviation has been represented in table 3.4.

Table 3.4

Measures of central tendency and dispersion*

Sl. No	Variables	Mean	Range	Standard deviation	Variance	Coefficient of variation
1	A_3	3.172	11.98	2.693	7.252	84.899
2	$(\Sigma N)_3$	16.545	48.00	10.749	115.549	64.968
3	N_1	12.509	41.00	9.327	86.995	74.562
4	N_2	3.306	7.00	1.551	2.406	46.945
5	$(\Sigma L)_3$	11.274	38.10	8.417	70.846	74.659
6	L_1	7.619	24.50	5.770	33.288	75.732
7	L_2	1.998	6.74	1.649	2.719	82.533
8	L_3	1.650	8.95	1.494	2.233	90.545
9	Lb_3	2.975	7.20	1.451	2.105	48.773
10	Br_3	1.570	3.35	0.650	0.422	41.401
11	Rb_1	0.899	0.18	0.046	0.002	5.117
12	Rb_2	0.728	0.23	0.071	0.005	9.753
13	D_3	3.651	3.45	0.851	0.725	22.098
14	F_3	6.217	9.43	2.198	4.830	35.355
15	P_3	7.852	16.50	3.504	12.278	44.626
16	Re_3	0.869	0.65	0.133	0.018	15.305
17	Rc_3	0.579	0.66	0.152	0.023	26.252
18	Rh_3	296.287	680.50	121.230	14697.756	40.916
19	Rn_3	3.136	9.52	1.524	2.323	48.597
20	H_3	806.327	1638.00	325.397	105883.34	40.355
21	C_3	0.271	0.20	0.054	0.003	19.926
22	T_3	2.040	2.79	0.596	0.356	23.314

Data compiled from Computer sheets have been preserved by the investigator

3.2.1.2 Normality of morphometric variables:

To have an idea about the nature of distribution of the morphometric properties of the third order basins the author has tried to plot them on arithmetical probability paper (figure 3.3). However, in none of these variables (A_3), $(\Sigma L)_3$, $(\Sigma N)_3$, D_3, F_3 and P_3 do the data points lie on a straight line. This shows, as does the skewed form of the histograms (figure 3.2), that the data are not normally distributed. Normalization has been attempted by plotting the relative cumulative frequency against the logarithm of the class mid-values (figure 3.2). In no case does the log normalization successfully produce a single straight line passing through the plotted points. In all cases, however, the points fall along more than one straight line.

This is typical of those circumstances where the data being analyzed have been drawn from two or more different populations. Thus, in the case of basin area (A_3), the break-point between the two straight lines occur at 4.5 sq. km. on both the

THIRD ORDER BASINS OF THE BALASON BASIN PLOTTED ON ARITHMATIC PROBABILITY PAPER

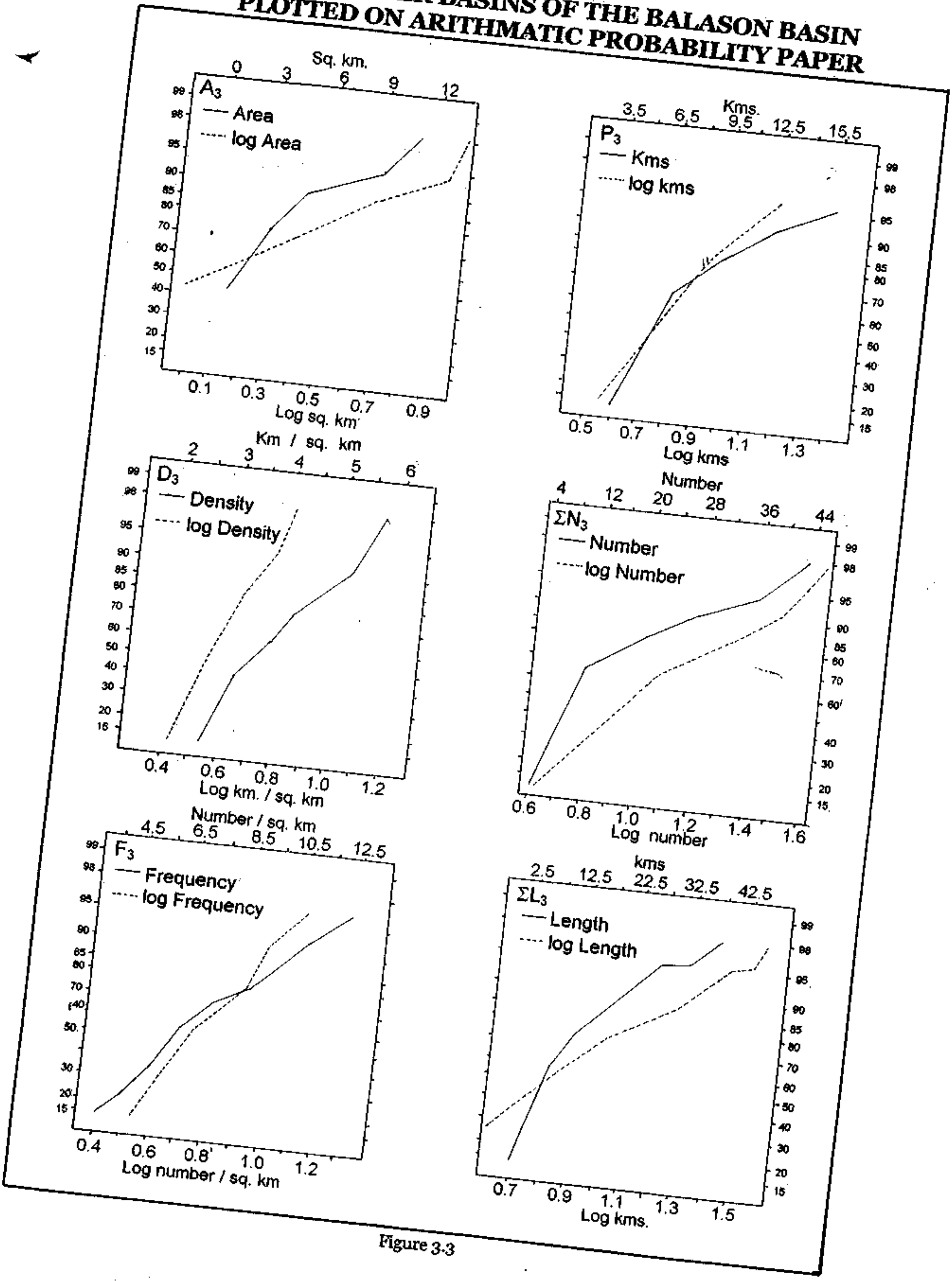

Figure 3.3

absolute and log-normalized data (figure 3.3). As far as $(\Sigma L)_3$ is concerned, the absolute data provide a simpler relationship between the scatter points than does the log transformation, suggesting that the stream numbers are normally distributed on either side of the break-point value of 7.5.

In case of $(\Sigma N)_3$ the absolute data provide a simpler relationship than does the log transformation, suggesting that the total number of streams are normally distributed on either side of the break point value of 12. Drainage density (D_3) provides an almost identical graph whether the data are log transformed or not. However, in either case there is a distinct break point at a value of 3.5, the data relating to basin perimeter (P_3) and drainage frequency (F_3) are not normally distributed and in which log-normalization provide a simpler relationship. However, the break points between the two straight lines occur at 6.5 for both the perimeter and drainage frequency.

3.2.1.3. Regional comparisons

On the basis of the above studies it is possible to understand the regional distribution of morphometric variables. In the analysis of A_3, most of the steep slope hilly sub-basins fall in the category that exceed the break point value of 4.5 sq. km. (figure 3.4). This may be due to lithological and vegetational differences, since the northern hilly tract composed of more resistant gneiss and is generally covered under dense natural vegetation, which normally does not allow the formation of more first order stream and thereby have a larger basin area (A_3). The case is quite different along the central tract where the dominant rocks, the phyllites, schists, sandstones etc. are extensively cultivated leading to more gully erosion (first order streams), leading to smaller area with a value of less than 4.5 sq. km basin size.

The regional distribution of the length of streams $(\Sigma L)_3$ above and below the break point value of 7.5 km shows little in the way of regional concentration (figure 3.4). In all areas, irrespective of relief, slope, geological structure and natural vegetation, have both these groups. It is impossible to select subjectively the

REGIONAL DISPERSION OF MORPHOMETRIC VARIABLES OF THIRD ORDER BASINS

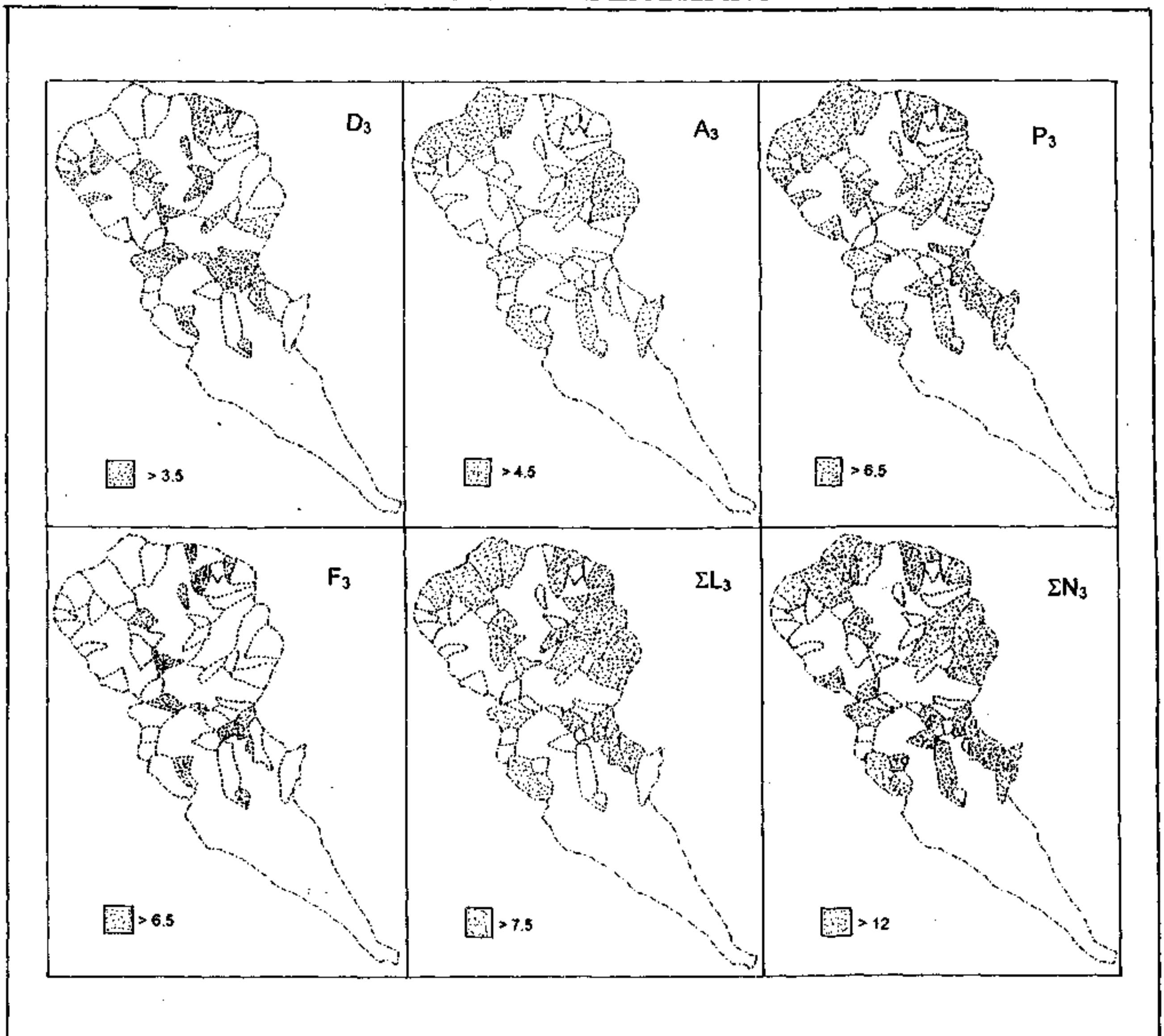

Figure 3.4

determining factor behind this distribution, however, the relationships between the length of streams and other variables are considered in the following sections.

The break-point for the total stream number $(N)_3$ occurs at 12, which again shows little in the way of regional concentration (figure 3.4). However, it may have some sort of relation with the geological outcrops.

The break point for D_3 occurs at 3.5 km/km^2. The regional concentration of D_3 population is most striking, because the sub basins located along the central and northern tract have higher population category, while the sub-basins located along the north western and northern tract and the southern foothill have lower population category. This is due to lithological composition of the central tract, which is composed of highly erodible Damuda and Dalings rocks. These rocks are liable to vicious gully erosion and thereby, form more first order streams and thus higher drainage density value.

The regional distribution of stream frequency (F_3) in the two population groups, above and below 6.5 show more or less similar trend like the D_3.The break point for basin perimeters occur at 6.5 km. Most of the northern hilly and southern foot-hill basins are within the higher population category and the central region is composed entirely of the members of the lower population groups. Both the F_3 and P_3 are frequently dependent on the nature of the bedrock over which they have developed, and the combination of gneiss-schists-phyllite-sandstones within the basin is unique and the relatively high values of these variables within some third order basins may, indicate significant bedrock differences between these sub-basins.

This discussion of the numerical properties of the 55 third order basins, indicate how a large amount of data can be reduced to manageable properties by the use of descriptive statistics. Six morphometric variables, namely the third order basin area (A_3), the total length of streams within the third order basins $(\Sigma L)_3$, the total number of third order streams within third order basins $(\Sigma N)_3$, the drainage density of the third order basins (D_3), stream frequency (F_3) and the basin perimeters (P_3) have been examined and illustrated (table 3.4.) Among the different controls of morphometric parameters within the basin, the lithological, topographical and the vegetational seem to be more prominent. However, a detail discussion along this line has to be carried out in the following sections.

3.2.1.4. Correlation among morphometric variables:

The results of the correlation analysis between morphometric variables drawn from 55 third order basins are presented in matrix form in table 3.5. The correlation coefficients also been checked against the table of significance and an account of these has also been indicated in the correlation coefficient matrix. The correlation matrix shows that there exists high correlation between the various morphometric variables of the basin area (A_3), the stream length (L_1, L_2, L_3 and ΣL_3) and the stream numbers (N_1, N_2, N_3 and ΣN_3). All these relationships bear logical explanations and are consistent with the view that the third order basin tend towards a state of internal order and organization.

The relationships between the density (D_3), the relative relief (H_3), the relief ratio (Rh_3), texture ratio (T_3) are of interest in the analysis of the third order basins. There exists very good relationship among the parameters like bifurcation ratio (Rb_1, Rb_2) perimeter (P_3), length ratio (Lb_3), breadth ratio (Br_3) within the study area.

However, it has been found that there exist an inverse relation between D_3 and H_3 as drainage density is greater where the basin relief is low. This may in itself be a reflection of rock types, such as steep slopes, high altitude regions with a greater Rh_3, Rn_3 and H_3 composed of more resistant rocks (granite and gneiss). Moreover, it has been noticed that the low hills with a moderate slope, composed of highly erodible Dalings, Gondwana and Siwalik rocks, which ultimately gives the formation of a greater number of streams, as well as greater number of third order basin with a relatively small basin area.

Table 3.5

Correlation matrix for 22 morphometric variables for the Balason third order basins.

	A_3	$\sum L_3$	L_1	L_2	L_3	L_1-	L_2-	$\sum N_3$	N_1	N_2	D_3	F_3	P_3	Br_3	Lb_3	C_3	Rc_3	Re_3	T_3	Rn_3	Rh_3	H
A_3		98	97	86	86	14	42	93	93	84			93	72	88	.40			46	16		48
$\sum L_3$			99	87	88	12	40	96	96	86			91	72	87	25			53	23		48
L_1				81	84	18	32	96	96	87			88	75	83	27			56	21		45
L_2					66	6	74	81	80	77			83	60	81	25			37	19		48
L_3							22	85	85	76			86	49	84	15			44	27		43
L_1					4		13						15	20	18	14						
L_2								27	28	17			53	14	58	17				10		36
$\sum N_3$						6			99	93			86	70	79	21			69	20		41
N_1						6				90			87	68	80	21			68	20		41
N_2						3					75		74	75	64	17			70	18		36
D_3	42	28	30	27	16	19	18	24	24	21		P	O	S I	T I	V	E		41	43	5	
F_3	55	47	48	46	30	63	45	32	32	28							10	5	27	19	37	
P_3											38	59		55	96	38			26	18		50
Br_3		N	E	G	A	T	I	V	E		45	50			41	41	24	31	51	2		24
Lb_3											31	56				29			18	20		50
C_3											98	72					29					15
Rc_3	10	15	9	20	29	17	36	7	8	2	29		36		44				35		44	
Re_3	11	14	11	17	20	11	30	7	9		23		21		42				15		46	
T_3						40	17									15				22	11	16
Rn_3						2										42	22	17			11	42
Rh_3	37	38	36	36	35	28	31	33	34	25			47	14	53	6						26
H											20	29					14	19				

Compiled from the Computer Sheets. The numerical values listed = r x 100, N = 55

3.2.1.5. Linear regression analysis

The regression equation among the various morphometric variables are found to be significant in most cases. The calculated 't' values are found significant at 99.9% level in most cases. But the coefficients of determination (R^2) vary from 0.306 to 0.979 but most lie well above 0.701 (table 3.6 & figure 3.5). The problem in statistical analysis of the study of the morphometric data arises when the nature of the 'process-response' relationships cannot be precisely ascertained. Thus, it often becomes extremely difficult to differentiate between the 'response' and the 'process' variable. This stems from the fact that most geomorphological relationships are part of a complex system of interrelationships or in other words, most geomorphological problems require multivariate analysis. A numerically significant correlation between two variables does not necessarily imply, that they are genetically related. Thus, it becomes apparent the process response relations among the morphometric variables are better understood by multivariate statistical method (Doornkamp and King, 1971).

Table 3.6.

Coefficients of linear regression equations between some morphometric properties of 55 third order basins of the river Balason

Variables		Constant of regression equation	Regression coefficient	Standard error		t value		Coefficient of explanation
Dependent Y	Independent X			a	b	a	b	
A_3	ΣN_3	-0.881	0.233	0.250	0.013	-2.728	18.353	0.864
A_3	ΣL_3	-0.373	0.314	0.114	0.008	-3.286	38.808	0.966
A_3	L_1	-0.284	0.454	0.144	0.015	-1.977	30.032	0.944
A_3	L_2	0.363	1.406	0.295	0.114	1.231	12.312	0.741
A_3	L_3	0.629	1.541	0.285	0.128	2.212	11.998	0.731
A_3	Lb_3	-1.666	1.626	0.406	0.123	-4.106	13.243	0.768
A_3	Br_3	-1.519	2.988	0.670	0.395	-2.269	7.571	0.520
ΣL_3	L_1	0.278	1.443	0.279	0.029	0.998	49.304	0.979
ΣL_3	L_2	2.444	4.419	0.906	0.351	2.698	12.593	0.750
ΣL_3	L_3	3.121	4.941	0.823	0.371	3.791	13.305	0.770
ΣL_3	ΣN_3	-1.186	0.753	0.580	0.029	-2.044	25.545	0.925
Br_3	P_3	0.765	0.103	0.182	0.021	4.201	4.830	0.306

LINEAR REGRESSION ANALYSIS OF SOME MORPHOMETRIC VARIABLES OF THE 55 THIRD ORDER BASINS

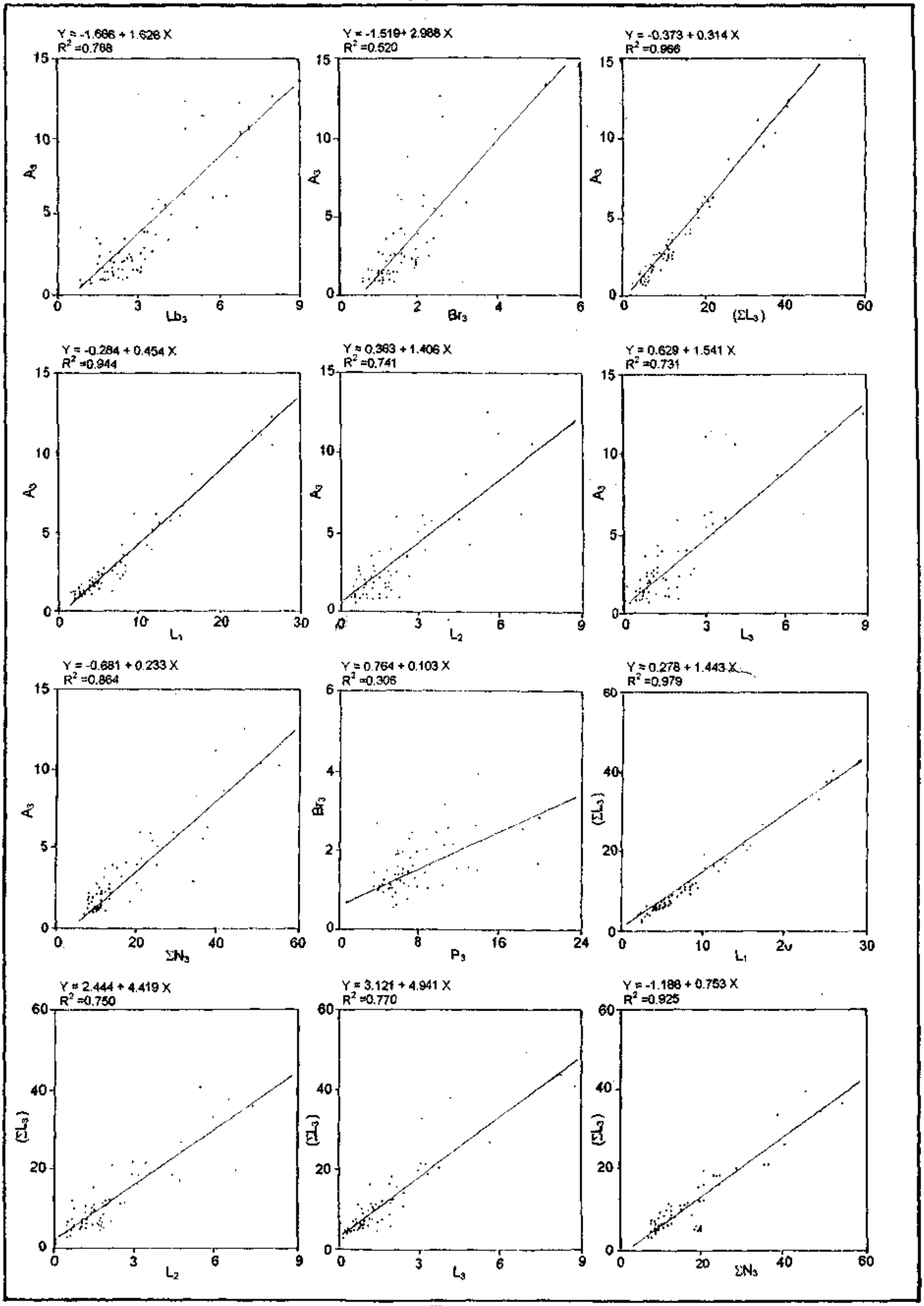

Figure 3.5

3.2.1.6. Sets of inter-correlated variables

Correlation matrix (table 3.5.) has been used to identify the sets of inter-correlated variable. This is done, by resorting the position of the variables around the margin of the table in such a way that the highest positive correlation coefficients fall nearest to the central diagonal line. Here, the coefficients are recorded twice for each pair of variables i.e. one on each side of the central diagonal line. Representing the level of correlation by density shading has makes a greater visual impact. Thus, the numerical information obtained in table 3.5. has been replaced by the figure 3.6. The groups of highly inter-correlated variables can be easily identified and in the present study show the existence of the following groups:

Group I: (A_3), ($\Sigma L)_3$, L_1, L_2, L_3, $(\Sigma N)_3$, N_1, N_2

Group II: (A_3), (P_3), (Lb_3), (Br_3)

Group III: F_3 , (Br_3), (P_3), (Lb_3)

It is relevant to note, therefore, that each of the groups of highly inter-correlated variables are of distinct types. While, group I defines the basin size, stream length, and stream number. Group II defines the area, perimeter, length and breadth and the group III represents basin size, perimeter, stream length and stream frequency.

3.2.1.7. Multiple relations among morphometric variables:

Multiple regression is essentially used for predicting the relationship between one variable to a number of other variables. In this method the genetic relationships between the variables are not given much importance (Carson, 1966).

The present study has shown the existence of some distinct groups of inter-correlated variables found during pair wise relationship study as represented in the matrix in the table 3.5. Multiple regression was undertaken to determine whether the variation in the value of a particular variable is accounted for to a

GROUPS OF HIGHLY INTER-CORRELATED VARIABLES FOUND BY RESORTING THE DATA OF TABLE 3.5

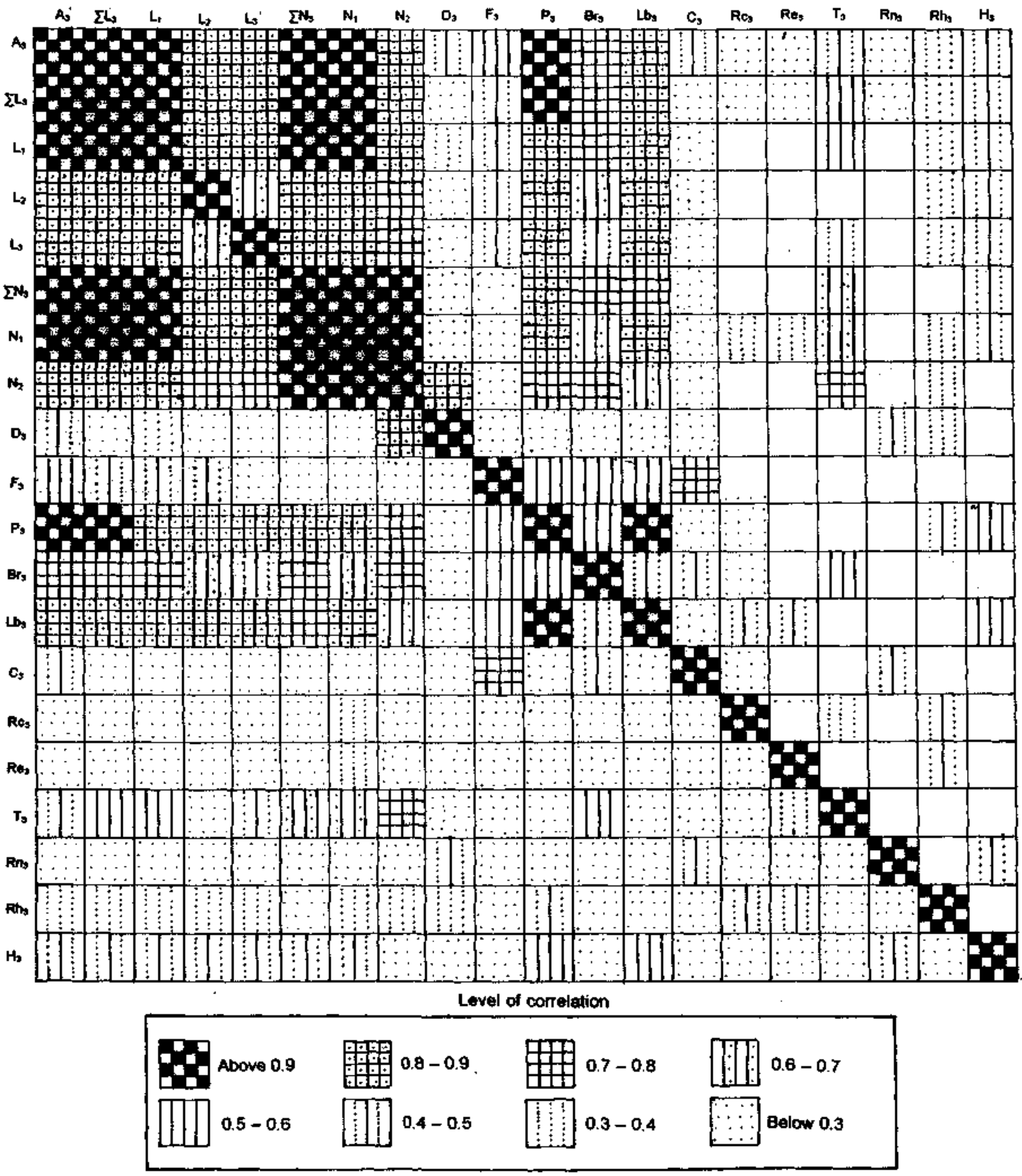

Figure 3.6

greater extent by considering its relationship with variables taken together. The multiple regression of the different groups obtained above are dealt below:

3.2.1.7.1. Area-length and number relationship:

The multiple regression of Y (A_3) on X_1 (ΣN_3), X_2 (N_1), X_3 (N_2), X_4 ($\Sigma L)_3$, X_5 (L_1), X_6 (L_2) and X_7 (L_3) of the 55 third order basins have been represented in the following equation:

$$\begin{array}{lllllllll} A_3 = 17.10 & -17.25.(\Sigma N)_3 & +17.22.N_1 & +17.09.N_2 & -0.05.(\Sigma L)_3 & +0.42\,L_1 & +0.45\,L_2 & +0.37\,L_3 \\ (t = 9.11) & (-9.19) & (9.17) & (9.11) & (-0.09) & (0.80) & (0.86) & (0.70) \\ [SE = 0.41 & [-] & [-] & [-] & [-] & [0.52] & [0.52] & [0.52] \end{array}$$

$$R^2 = 0.9707$$
$$F = 222.606$$

Here the power of independent variables (ΣL_3, L_1, L_2, L_3, ΣN_3, N_1, N_2) on the dependant variable is 97.07% that shows that only 2.93.% of the variation in A_3 can be attributed to be controlled by random factors. The F statistics is very high (222.606) which indicates the overall regression exercise as being highly significant. The correlation matrix has been shown below:

	A_3	$(\Sigma L)_3$	L_1	L_2	L_3	$(\Sigma N)_3$	N_1	N_2
A_3	1							
$(\Sigma L)_3$	0.982934	1						
L_1	0.971887	0.989217	1					
L_2	0.861020	0.865737	0.810043	1				
L_3	0.854733	0.877269	0.836977	0.662375	1			
$(\Sigma N)_3$	0.930001	0.961488	0.957263	0.804751	0.851553	1		
N_1	0.932163	0.962056	0.95677	0.799396	0.855811	0.998101	1	
N_2	0.837856	0.87969	0.869897	0.771416	0.757345	0.927207	0.903647	1

3.2.1.7.2. Basin area and basin geometry

A good statistical relationship between the various parameters of basin geometry and basin area has been established. The multiple regression of Y (A_3) on X_1 (P_3), X_2 (Lb_3), X_3 (Br_3) and X_4 (Rc_3) is given below:

$$\begin{array}{llllll} A_3 = 17.50 & +0.023.P_3 & + -0.02.(Lb_3) & +0.08.Br_3 & +2.25.Rc_3 \\ (t = -1.38) & (2.90) & (-0.08) & (0.43) & (4.76) \\ [SE = [-]\,] & [0.08] & [0.20] & [0.18] & [0.47] \end{array}$$

$$R^2 = 0.9844$$
$$F = 246.81$$

The power of independent variables (P_3, Lb_3, Br_3 and Rc_3) in explaining the variation in A_3 is 98.44% that is only 1.56% variation in A_3 is controlled by random factors. The length, basin perimeter and basin circularity show a positive influence on A_3 while the length of the basin has a negative influence on A_3 . This is most probably due to the elongated nature of the third order basin, to be precise, it may be due to the slope and topographic configuration of the basin. A very high value of F statistics 246.81 indicates that the overall regression exercise is highly significant.

3.2.1.7.3. Stream frequency and basin geometry of the third order basins:

The statistical relationship between the various parameters of basin geometry and basin area has been established below. The multiple regression of Y (F_3) on X_1 (P_3), X_2 (Lb_3) and X_3 (Br_3) can be presented in the following form:

F_3 = 9.85	+ 0.01 . P_3	+ - 0.68 . (Lb_3)	-1.10 . Br_3
(t = 14.4)	(0.04)	(-0.95)	(-2.12)
[SE= 0.68]	[0.32]	[0.71]	[0.52]

$R^2 = 0.398$
F = 11.246

The equation is not a good fit one, as the power of independent variables like P_3 , Lb_3 , and Br_3 , in explaining the variation in F is only 39.81. As much as 60.19% of the total variation remains unexplained. F_3 cannot be explained by the independent variables and are attributed to other random factors. P_3 has a positive influence on F_3 but Lb_3 and Br_3 has a negative influence on F_3 . This is probably due to the fact that the hilly tracts have relatively less number of streams due to lithological control. The F statistics has been calculated to be 11.246, which is statistically significant.

3.3. Conclusion

The data obtained as shown in table 3.5 can be reorganized for arriving at some conclusion about the nature of the major processes operational in the

Balason valley by reducing them to groups of significantly inter-correlated variable. This information can also be utilized to establish a model of the relationship between the morphometric variables and the areas from where they were obtained.

The basin area (A_3) is often highly correlated to many other morphometric variables is very much apparent from the above analysis. It was very often found during the study that there arose the problem of disentangling the influence of area on other apparent relationships. To overcome this problem partially, techniques involving partial correlation was utilized. The strong correlation between the basin area (A_3), the stream lengths (ΣL_3, L_1, L_2 and L_3) and stream numbers (ΣN_3, N_1, and N_2) suggest that local reorganization of drainage basin area would be expected to lead to a reduction in stream length and number. On the contrary, the negative relationship between basin area (A_3) with drainage density (D_3), stream frequency (F_3) and relief ratio (Rh_3) suggest that there are likely to increase as the basin area decreases. These variables (ΣL_3, D_3, F_3 and Rh_3) may change in response to the change in the basin area that result from drainage reorganization following the removal of highly erodible ridge flanks.

It can be concluded that the increase in the efficiency of the drainage network may be responsible for the reduction of first order streams within the third order basins as fewer streams are needed to meet the conditions in the area. As these streams are young and very active, they are still extending their lengths with the consequent increase in the relief ratio, drainage density, elongation ratio and stream gradient to adjust themselves with the existing terrain typified by variation in the lithography, structure, relief, vegetation, land use etc. Thus, the Balason basin which is still young and active is trying to overcome the state of in equilibrium and enter into of state of early maturity in the coming future.

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CHAPTER 4

PEDOGEOMORPHIC RELATIONS WITHIN THE BASIN

4.1. Introduction

Although Robinson (1949) had tried to establish a relationship between soil and landform when he said *"the domain of pedology may come to engross a considerable amount of dynamic geology"* the two have been frequently treated separately with only a token of awareness of one on the other and vice versa. The increasing awareness due to modern research has led to the understanding that soil and landforms are closely dependent upon one other as one influences the other. This has led to the evolution of a new discipline of 'pedo-geomorphology' or soil geomorphology (Conachar & Dalrymple, 1978).

The drainage basin provides a convenient and ideal natural unit for the study of pedo-geomorphic parameters and their interrelationships. Within this unit the constituent parameters of landform, soil and drainage frequently show an organized relationship and without the knowledge of the basin in which they occur many of these events become incomprehensible (Sarkar, 1987, 1994). A realistic correlation can only be drawn if the processes of soil formation are in equilibrium with the surface and sub-surface processes, acting on the slope (Norton & Smith, 1930; Furley, 1968 & 1969; Young, 1968; Jordan, 1974; Gerrad, 1980;). It is often assumed that the meaningful relationship between slope and soil properties becomes the result of any well-organised study.

In the present work pedo-geomorphic study has been carried out to determine and assess the intricate inter-relationship among some of the parameters that include the slope, infiltration and soil properties, in the Balason basin of Darjeeling Himalaya. Collection of the soil samples were made from 50 different sites, randomly selected, within the study area during 1998-2000 (figure 4.1). Slope angle, soil colour, thickness of A horizon were measured at the sample sites. The rate of infiltration was measured with the help of galvanized steel tube (diameter of 20 cm) which was inserted into the soil with a head of water of about 6 mm.

Table 4.1

Pedo-geomorphic parameters obtained from 50 sample sites in the Balason basin

Sl. No.	Locality	Altitude in metre	Slope in Degree	Sand %	Silt %	Clay %	Organic matter %	Hygroscopic moisture %	pH	Thickness A horizon	Total infiltration in 240 minutes	Base exchange capacity	Nitrogen
1	Matigara	121	1	32.51	42.76	24.73	0.89	1.13	6.5	13.2	849	8.43	0.081
2	Fulbari Pump house	190	1	56.25	21.11	22.34	2.05	2.63	6.5	25.3	936	16.46	0.245
3	Khaprail	164	1	27.45	46.03	26.52	1.87	2.18	6.4	19.5	703	12.63	0.301
4	Simulbarie P.O.	213	1.2	53.02	21.93	25.05	1.43	2.01	6.3	15.1	1031	11.91	0.14
5	Panighatta Dispensary	255	1.5	40.03	25.13	34.81	3.3	2.63	5.8	23	831	16.7	0.301
6	Panighatta Bridge	267	11.3	45.1	27	27.9	2.91	2.01	6.1	10.5	992	21.01	0.285
7	Rohini	220	1.6	43.64	20.14	36.22	3.71	3.29	5.3	12.4	879	20.94	0.42
8	Marionbarie T.G.	229	1.3	55.37	25.26	18.37	1.22	1.77	6.4	15	1404	16.7	0.132
9	Garidhura	246	1.7	50.31	31.75	21.75	2.07	2.03	6.5	18.5	1025	10.51	0.201
10	Dudhia Khola	308	1.8	40.9	23.41	35.69	3.36	2.9	5.9	14.2	869	17.7	0.207
11	Pankhabari	540	15.3	65.52	18.31	16.17	2.07	1.73	5.4	12	1703	10.83	0.21
12	Kochigoan	560	13.4	70.91	16.91	12.18	1.93	1.91	5.5	14	1750	12.12	0.25
13	Bungkulung R.H.	640	8	70.31	12.15	17.54	3.62	1.29	5.3	2.5	1476	18.81	0.36
14	Gayabari	768	19.2	46.75	15.09	38.16	3.93	2.93	5.4	8.9	793	15.91	0.48
15	Ambootia	948	18.7	69.09	13.75	17.16	2.41	1.93	5.2	12.9	1585	12.3	0.201
16	Kaphebari	918	13	56.51	8.73	34.76	3.7	2.31	5.3	8.8	782	17.01	0.401
17	Longview T.G.	570	2.5	65.52	18.31	16.17	2.09	1.73	5.4	9.3	1703	10.83	0.21
18	Cedars T.G.	1100	11.1	69.09	13.75	17.16	2.41	1.03	5.1	11.4	1641	7.1	0.12
19	Dooteriah	1260	21.4	60.65	9.56	30.39	4.01	2.92	5.2	6.5	1273	21.29	0.425
20	Mandakoti	1100	17.4	65.73	15.09	19.18	3.83	2.79	5.3	5.1	1491	18.39	0.391
21	Gopaldhara	1340	13.1	58.73	16.93	24.34	2.69	3.29	5.3	7	995	20.13	0.301
22	Nagri	1348	14.2	68.4	16.09	15.51	2.92	2.71	5.6	12.1	1373	21.29	0.401
23	Mane P.O.	1349	7.4	58.4	16.09	25.51	3.41	2.95	5.1	18.5	809	26.12	0.421
24	Sungma Terminus	1340	22	61.73	5.91	12.34	1.81	1.49	5.6	3	642	10	0.19
25	Seeyok	1520	19.5	65.32	17.31	17.37	2.01	1.81	5.5	9.5	1695	11.02	0.195

Continued.......

Sl. No.	Locality	Altitude in metre	Slope in Degree	Sand %	Silt %	Clay %	Organic matter %	Hygroscopic moisture %	pH	Thickness A horizon	Total infiltration	Base exchange	Nitrogen
26	Kalej Valley	1693	22	66.93	14.85	18.22	2.45	3.21	5.4	7.4	1250	19.03	0.363
27	Rungbull	1900	18	64.32	17.31	18.37	2.03	1.86	5.4	10.1	1597	11.75	0.198
28	Mirik P.S.	1600	14	67.2	17.09	25.71	2.4	2.5	5.4	13	1251	18.21	0.31
29	Pokriabong Market	1727	14.4	66.2	16.09	27.71	1.98	1.93	5.3	11.5	1701	10.85	0.201
30	Pubong	1744	17	53.93	10.45	35.62	2.31	2.54	5.6	18	1341	15.61	0.26
31	Tumsong	1833	20	68.95	11.03	20.02	2.41	3.15	5.3	7	1504	16.65	0.319
32	Talkot	1640	14	66.2	16.09	25.71	2.35	2.43	5.4	12.8	1243	16.7	0.295
33	Gorabari	1900	15.4	63.71	12.26	23.99	2.71	1.98	5.2	19.01	1171	12.14	0.214
34	Dilaram	1700	14.4	60.71	15.28	23.97	2.81	2.15	5.4	18.4	1061	11.01	0.24
35	Nayagoan	1547	9.5	60.81	15.2	23.99	3.81	2.51	5.2	28.5	973	21.43	0.35
36	Margaret's Hope	1360	6	50.91	25.1	23.99	3.93	3.12	5.1	29.2	813	26.73	0.421
37	Rington	1302	12.4	59.32	11.78	29.9	2.69	1.92	5.2	20.1	985	19.02	0.201
38	Tung P.O.	1620	19.4	73.91	5.1	20.99	3.74	2.62	5.2	28.2	1203	20.51	0.315
39	Bhotey Busti	1540	15	65.81	10.1	24.09	2.41	2.13	5.3	21.2	973	18.73	0.214
40	Goethal's School	1540	12	58.35	11.75	29.9	2.41	1.98	5.3	20.3	1001	18.75	0.197
41	Kurseong Jail	1380	11	65.3	10.2	24.5	2.91	2.01	5.3	21.2	963	20.1	0.31
42	St. Mary's Seminary	1540	12.4	58.32	11.78	30.9	2.31	1.79	5.2	21	993	19.02	0.199
43	Mane P.O.	1007	21	83.81	5.28	10.91	2.05	2.1	5.2	4.9	1676	10.85	0.201
44	Makaibari	1252	28	66.71	9.09	24	2.31	1.79	5.3	16.9	1093	19.2	0.201
45	2 km from Gayabari	1270	16.2	86.91	4.92	8.75	1.91	1.43	5	5.3	1762	12.9	0.195
46	Simana Busty	2355	13.5	55.75	14.2	29.92	3.41	2.9	5	28.2	870	24.2	0.41
47	Chamong	2100	20	82.91	16.18	10.91	2.1	2.51	5.8	20.6	1444	21.42	0.312
48	Pagoda Forest Dhauki	2106	17.4	64.91	14.12	20.97	2.43	1.98	5.3	19.5	1078	15.93	0.295
49	Sonada P.O.	2000	14.4	60.81	15.18	23.98	2.91	2.43	5.4	18.6	1040	10.74	0.265
50	Lepchajagat	2502	18.9	63.91	15.1	20.99	3.74	3.18	5.5	26.5	978	26.4	0.36

INDEX MAP FOR SAMPLE SITES FOR PEDOGEOMORPHIC STUDIES

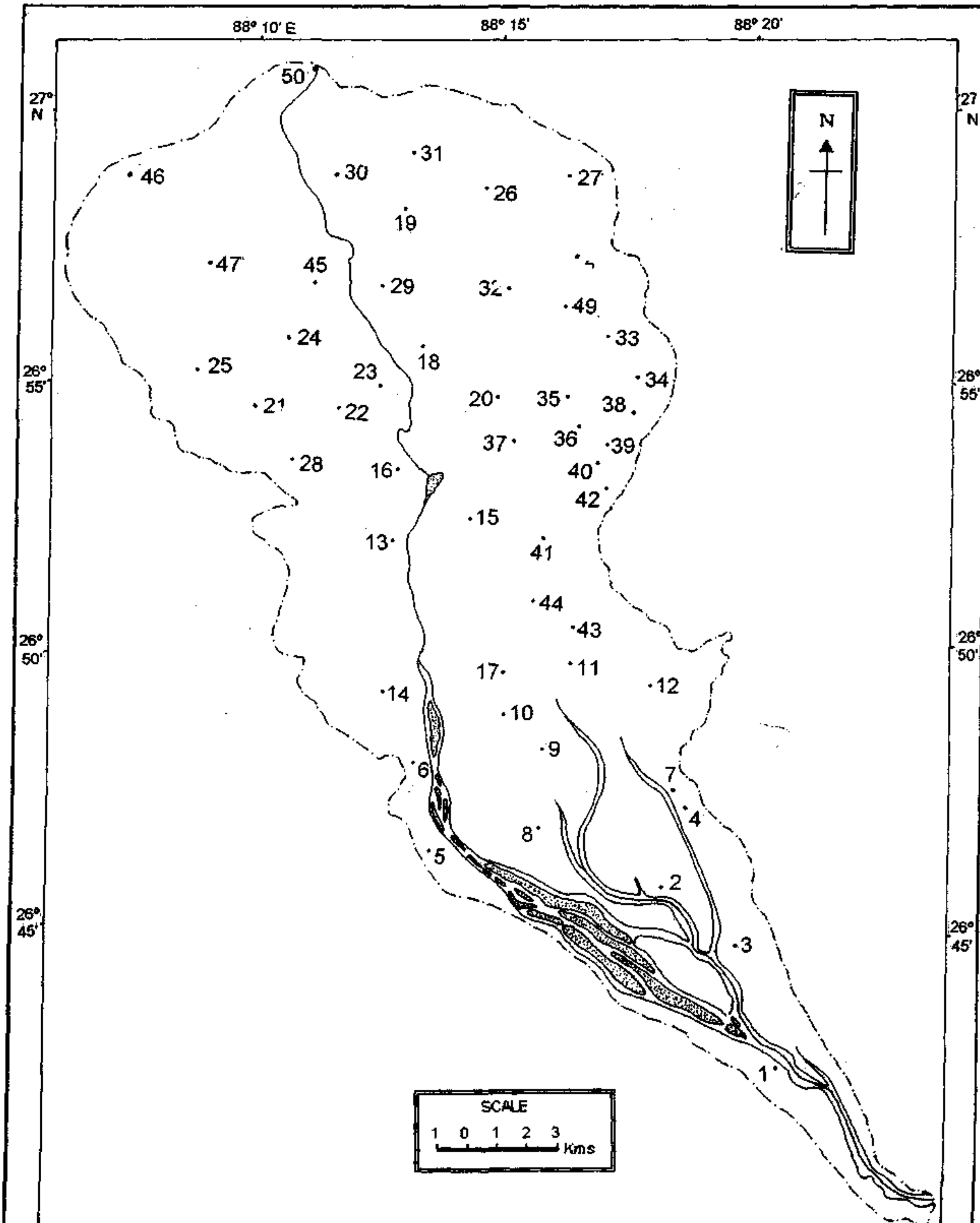

Figure 4.1

The collected soil samples were thus further analysed in the laboratory, for the determination of pH, organic carbon (%), base exchange capacity (m.e.), nitrogen (%), hygroscopic moisture (%) along with the percentage of sand, silt and clay (table 4.1) The data thus obtained were processed and analyzed statistically to find out the exact nature of relationships among them. In order to apprehend the pedogeomorphic relations under different environmental setup, a number of statistical analysis have also been done.

4.2. Pair wise relations

The numerical assessment of the relationships among the different pedo-geomorphic parameters have been conducted based on correlation and regression methods. The data for these study have been obtained from 50 sample sites (figure 4.1) which has been represented in table 4.1.

4.2.1. Correlation among pedogeomorphic parameters :

The results of the correlation analysis have been presented in a matrix form in table 4.2. The correlation coefficients have also been checked against significance table and an account of these have also been indicated in the correlation coefficient matrix (table 4.2).

The correlation coefficients among the various soil properties and slope are consistently significant at the level of 99% in most cases. Significant positive correlations have been found between slope (x) and sand content (y) and between infiltration (y) and sand content (x), while significant negative correlations have been found between slope (x) and silt content (y), pH (y) and slope (x), Infiltration (y) and clay (x). However, most of the remaining pedogeomorphic parameters are found statistically insignificant. .This is due to the fact that these parameters are not dependent on any one parameter but are inter-related and thereby, multiple correlation analysis becomes necessary to apprehend their exact nature of relationships.
The correlation matrix table 4.2) also proves the existence of high correlation

Table 4.2

Correlation* matrix for Pedogeomorphic variables in the Balason basin.

	Slope	A Horizon	Sand	Silt	Clay	Hygroscopic moisture	pH	Organic Carbon	Base Exchange Capacity	Nitrogen	Infiltration
Slope		25		**70**	29		**67**	NEGATIVE			
A Horizon			28								44
Sand	**66**			**77**	**72**	21	**53**	11	7	9	
Silt		16				2		28	15	14	29
Clay		26		18							**62**
Hygroscopic moisture	5	23			39		13				34
pH		7		**75**	4			46	26	34	24
Organic Carbon	11	19			43	**61**					32
Base Exchange Capacity	6	40			30	**66**		**64**			39
Nitrogen	15	8			30	74		**81**	**69**		3
Infiltration	32		**61**					POSITIVE			

Compiled from the Computer Sheets. The numerical values listed * = r x 100, N = 50

(bold) significant at 99.5% level

between the rate of infiltration and the various soil properties. The relationships bear logical explanations and are consistent with the view that the pedo-geomorphic parameters within a drainage basin tend towards a state of internal order and organization.

It is interesting to note that most of the soil properties are inversely related to the infiltration rate, such as the thickness of the A horizon, pH, clay, silt, base exchange capacity, hygroscopic moisture and organic carbon have negative relationships with the rate of infiltration. The positive relations have been noticed between the infiltration rate and sand content and infiltration rate and slope. However, all these relations are found to be highly significant.

4.2.2. Linear regression analysis :

Linear regression analysis has been further employed in order to understand the relations among some of the pedo-geomorphic variables (table 4.1). The results have been tabulated in table 4.3 and digrametrically represented in figure 4.2.

Table 4.3

Linear regression analysis of different pedo-geomorphic parameters

Variables		Constant of regression equation	Regression coefficient	Standard error		't' value		R^2
Dependent Y	Independent X	a	b	a	b	a	b	
Thickness of A horizon	Slope	18.325	-0.253	2.053	0.142	8.928	-1.781	0.062
Sand	Slope	46.606	1.138	2.686	0.186	17.349	6.129	0.439
Silt	Slope	26.812	-0.809	1.738	0.120	15.430	-6.738	0.466
Clay	Slope	26.996	-0.290	2.036	0.141	13.261	-2.063	0.061
pH	Slope	5.920	-0.034	0.101	0.007	58.683	-4.827	0.327
Nitrogen	Slope	0.250	0.002	0.028	0.002	9.061	1.027	0.215
Organic Carbon	Slope	2.488	0.012	0.229	0.016	10.877	0.773	0.012
Base exchange	Slope	16.022	0.040	1.460	0.101	10.973	0.392	0.003
Hygroscopic moisture	Slope	2.221	0.004	0.174	0.012	12.770	0.347	0.003
Infiltration	Slope	992.768	15.027	91.955	6.354	10.796	2.365	0.104
Infiltration	Sand	182.580	16.394	193.665	3.113	0.943	5.267	0.386
Infiltration	Silt	1373.132	-11.455	101.797	5.544	13.490	-2.066	0.062
Infiltration	Clay	1846.398	-28.426	125.904	5.172	14.665	-5.496	0.386
Infiltration	Thickness of A horizon	1492.072	-20.394	98.720	5.927	15.114	-3.441	0.196
Infiltration	Nitrogen	1466.842	-1030.060	139.277	480.705	10.532	-2.143	0.087
Infiltration	Organic Carbon	1543.914	-136.201	158.646	57.675	9.732	-2.362	0.104
Infiltration	Base exchange	1612.229	-25.922	152.023	8.830	10.605	-2.936	0.152
Infiltration	Hygroscopic moisture	1616.601	-190.295	177.573	75.668	9.105	-2.515	0.116

A total of 18 linear regression analysis have been performed and most of them are found highly significant (99.5% level). The coefficient of determination (R^2) shows the percentage of the variation in dependent variable (Y) explained by the respective independent variable (X). It has been shown in table 4.3 and figure 4.2 that in all the cases, the R^2 value lie well below 0.5 i.e., 50 % explanation. This is probably due to the fact that the nature of the process response relations are not precisely known in the present study. In some cases, it is extremely difficult to decide which shall be the 'response' and which will be the 'process' variable,

LINEAR RELATIONSHIPS AMONG THE VARIOUS PEDOGEOMORPHIC PARAMETERS IN THE BALASON BASIN

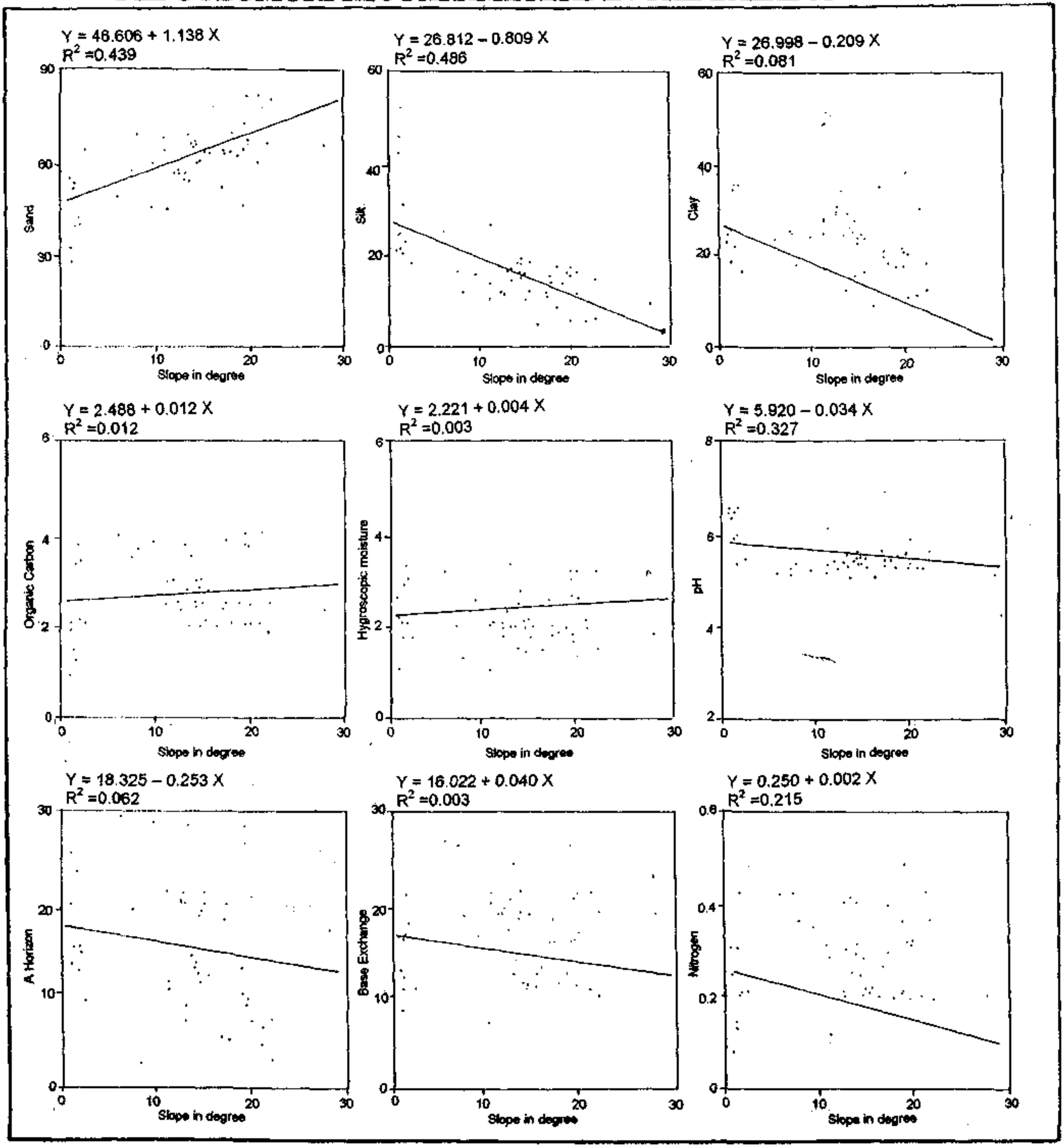

Figure 4.2

LINEAR RELATIONSHIPS AMONG THE VARIOUS PEDOGEOMORPHIC PARAMETERS IN THE BALASON BASIN

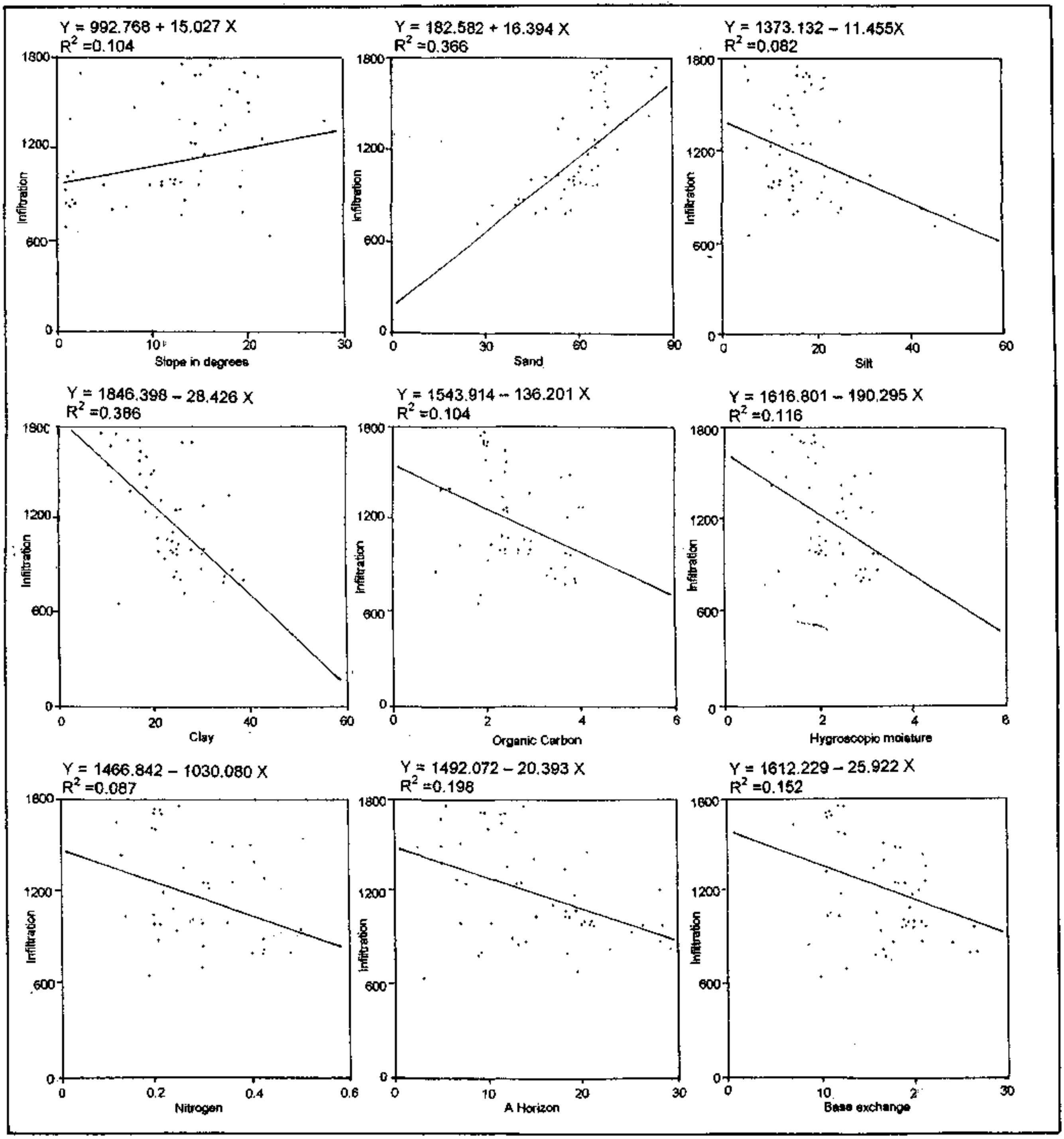

Figure 4.2.

GROUPS OF HIGHLY INTER-CORRELATED VARIABLES FOUND BY RESORTING THE DATA OF TABLE 4.2

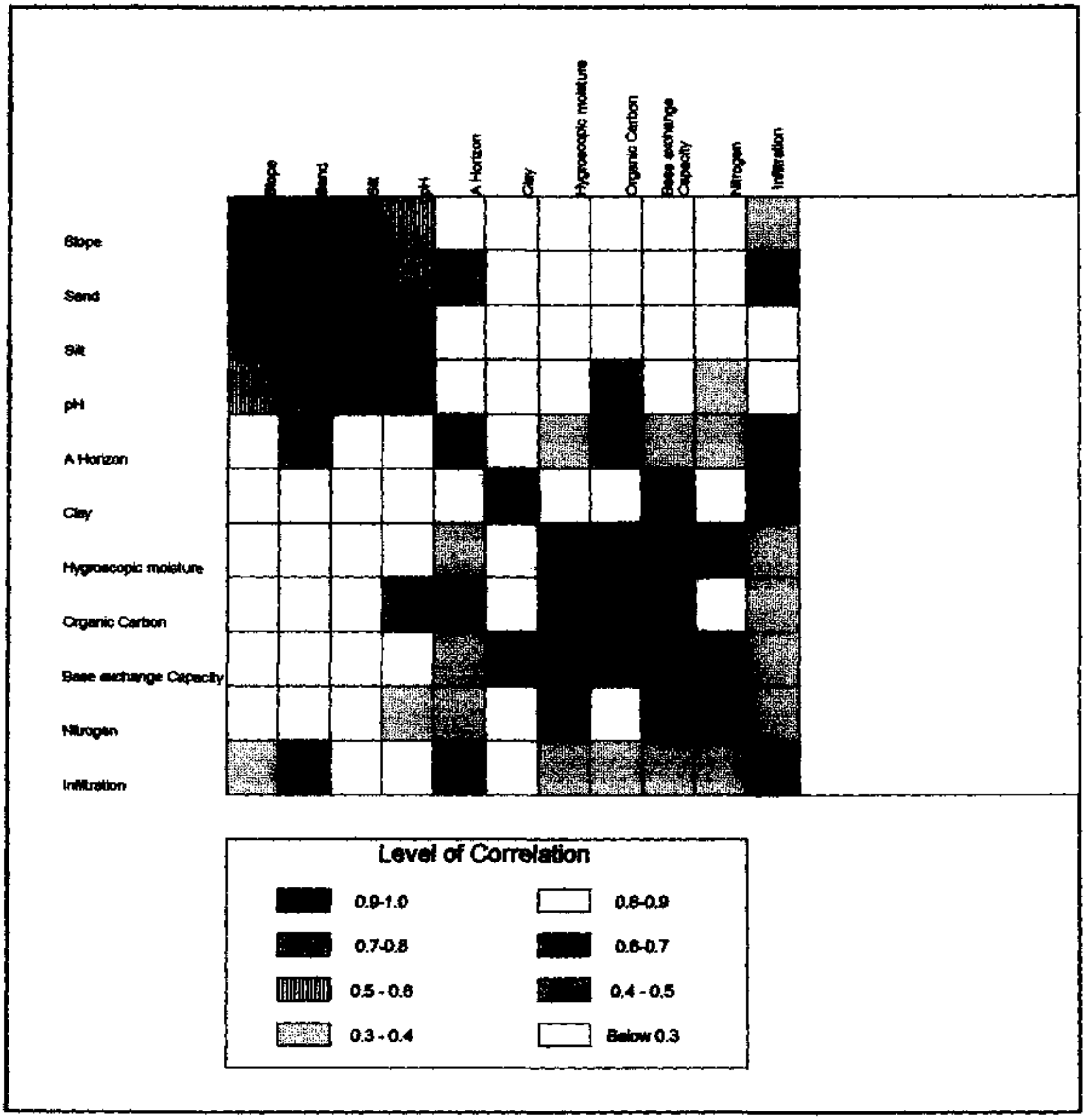

Figure 4.3

because, most of the pedo-geomorphic relationships are parts of a complex system of inter-relationship among their constituent parameters.

Thus, the process-response relations need not be thought of only in the sense of pair-wise analysis. Indeed, the multivariate nature of pedo-geomorphological problems demand that their analysis should involve multivariate statistical methods.

4.3. Multiple Relations

It has already been mentioned that there are some distinct groups of inter-correlated pedo-geomorphic variable found in pair-wise study in the Balason basin. For the comprehensive understanding of this 'process-response' system, more than two variables should be considered simultaneously. The purpose of this study is to discover the variation in a particular variable by considering its relationship to other variables taken together.

4.3.1. Sets of inter correlated variables

The correlation matrix (table 4.2) can be used to assess the presence of inter-correlated variables by resorting the position of the variable around the margin of the table in such a manner that the higher positive correlation coefficients fall nearer to the central diagonal line.

The coefficients are recorded twice for each pair of variable i.e., one in each side of the central diagonal line. A greater visual impact has been made by representing the level of correlation by density shading. Thus, the groups of highly inter-correlated variables can easily be observed and in the present study the following groups have identified (figure 4.4).

Group I : Slope, sand, silt and pH
Group II : Clay, hygroscopic moisture, organic carbon, base exchange, nitrogen and Infiltration.

4.3.1.1. Slope, soil properties and infiltration rate :

In order to apprehend the relationship among the gradient, infiltration rate and some soil properties, the following multiple regression equation has been performed:

$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 + b_8x_8 + b_9x_9 + b_{10}x_{10}$

where Y = slope, x_1 = thickness of A horizon (cm); x_2 = sand (%); x_3 = silt (%); x_4 = clay (%); x_5 + hygroscopic moisture (%); x_6 = pH; x_7 = organic carbon; x_8 = base exchange (meq); x_9 = nitrogen (%) and x_{10} = infiltration rate upto 240 minutes (cm). The regression equation has been represented:

Y=	24.72	$-0.06.x_1$	$0.21.x_2$	$-0.29.x_3$	$0.05.x_4$	$1.56.x_5$	$-3.36.x_6$	$-3.33.x_7$	$-0.13.x_8$	$15.99.x_9$	$-0.001.x_{10}$
SE =	34.63	0.13	0.29	0.32	0.29	2.06	3.16	2.10	0.25	18.59	0.003
t =	0.71	-	0.72	-0.09	0.18	0.75	-1.06	-1.11	-0.52	0.86	-0.31

$R^2 = 0.5766$
F= 5.312

The regression equation is a good-fit one. However only 57.66 % of the total variation in Y have been explained by the independent variable, leaving 42.34% controlled by random factors. Sand, clay, hygroscopic moisture and nitrogen have positive influence on slope, while the other variables have negative influence. This is probably due to the fact that the steep slope regions of the basin have a dense cover of natural vegetation which helps the soil to enrich in nitrogen, base exchange and increases the hygroscopic moisture content, while the negative relationship between the infiltration rate and slope gradient is due to the fact that the lower slopes of the *terai* region contain fine textured soil which may interrupt infiltration. The 'F' statistic has been calculated to be 5.312 which is greater than the tabulated value at 99% level of significance, which indicates the overall regression exercise is significant. But, if we consider the 't' values of individual cases at the level of significance (95%) and compare it with the calculated values, we may then predict that only x_1, x_2, x_3, x_4, and x_6 to be significant.

4.4. Pedo-geomorphic Relations in Different Environmental setup

In order to apprehend the nature of interactions between some of the pedo-geomorphic parameters in different lithological, altitudinal and slope environments, the following multiple regressions have been performed.

4.4.1. Pedo-geomorphic relations in different lithological setup:

To apprehend the influence of parent materials on pedo-geomorphic properties, the following two multiple regression analysis have been performed: a) for the samples obtained from the area having consolidated bed-rocks (N= 33), and b) for the samples obtained from the area having unconsolidated parent materials (N=17).

4.4.1.1 Relations in areas having consolidated bed rock as parent materials

The regression equation for various pedo-geomorphic properties, can be presented in the following form:

$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 + b_8x_8 + b_9x_9 + b_{10}x_{10}$

where Y = slope, x_1 = thickness of A horizon (cm); x_2 = sand (%); x_3 = silt (%); x_4 = clay (%); x_5 + hygroscopic moisture (%); x_6 = pH; x_7 = organic carbon; x_8 = base exchange (meq); x_9 = nitrogen (%) and x_{10} = infiltration rate upto 240 minutes (cm). The regression equation has been represented:

Y=	-30.63	$-0.11 . x_1$	$-0.09 . x_2$	$0.64 . x_3$	$-0.15 . x_4$	$2.20 . x_5$	$10.86 . x_6$	$0.16 . x_7$	$0.07 . x_8$	$-9.13 . x_9$	$0.003 . x_{10}$
SE =	31.55	0.13	0.25	0.27	0.25	2.44	4.40	2.11	0.26	21.86	0.003
t =	-0.97	-0.81	-0.34	-2.41	-0.56	0.90	2.47	0.08	0.28	-0.42	0.97

$$R^2 = 0.5719$$
$$F = 2.939$$

The equation shows the power of independent variables on Y is 57.18% i.e. only 42.82% of variation is controlled by random factors. The hygroscopic moisture, pH, base exchange, organic carbon, and the infiltration rate have positive influence while, thickness of the A horizon, sand, silt, clay and nitrogen have negative influence on slope.

It is interesting to note that the infiltration rate have positive influence on the slope, in areas having resistant parent materials which may be due to the fact that the steep slope of the hilly regions contain more porous, coarse textured soil and the bed rock are highly jointed that may invite uninterrupted infiltration. The calculated 'F' statistic (2.939) is greater than the tabulated value which indicates the overall regression exercise to be significant. But if we consider the 't' value at the level of 95% significance we can predict that only x_3 and x_6 are found to be significant.

4.4.1.2. Relations in areas having unconsolidated parent materials :

This study includes 17 samples obtained from the southern rolling to gently undulating areas (figure 4.1). Here the regression equation for various pedo-geomorphic properties can be presented in the following form:

Y= 46.04	$0.06.x_1$	$-0.37.x_2$	$-0.60.x_3$	$-0.04.x_4$	$-4.04.x_5$	$-0.99.x_6$	$-0.16.x_7$	$-0.58.x_8$	$34.12.x_9$	$0.007.x_{10}$
SE=307.79	0.89	3.19	3.16	3.87	11.26	14.73	9.40	1.27	49.36	0.03
t= 0.15	0.07	-0.11	-0.19	-0.01	-0.36	-0.07	-0.02	-0.46	0.69	0.26

$$R^2 = 0.5445$$
$$F = 0.717$$

The equation shows the power of independent variables on Y is 54.45% i.e. only 45.55% of variation is controlled by random factors. The A horizon, and nitrogen and infiltration rate have positive influence while, hygroscopic moisture, pH, base exchange, organic carbon, sand silt clay percentage and base exchange have negative influence on slope. The 'F' statistic has been calculated to be 0.717 which proves that the overall regression equation is insignificant.

Thus, it reveals that the pedo-geomorphic relations are more meaningful in the northern hilly tracts composed of consolidated parent materials. The process-response relations are also found to be more prominent in these areas. While, the pedogenic processes have been found to be frequently interrupted in the southern unconsolidated areas due to continuous deposition of sediments brought down by the fluvial agents. Thereby, soil properties show inconsistent relations with geomorphic parameters.

4.4.2. Pedogeomorphic relations in different slope zones :

The investigator of the present study has also tried to assess the pedo-geomorphic relations under different slope zones. The total sample data has been divided into two broad groups: a) data obtained from the areas having gradient of more than 15° and b) data obtained form the area having gradient of less than 15°. The former consists of 31 observations and the latter composed of 19 observations. The multiple regression for pedogeomorphic variables obtained from areas having slope more than 15° is presented in the following form:

Y= 7.06	$-0.27.x_1$	$-0.04, x_2$	$-0.16, x_3$	$0.001. x_4$	$-0.39. x_5$	$+3.49. x_6$	$-0.22. x_7$	$+0.56x_8$	$-13.94. x_9$	$-0.002. x_{10}$
SE = 54.42	0.19	0.67	0.80	0.75	3,64	8.01	2.78	0.39	35.88	0.004
t = 0.13	-1.41	-0.06	-0.21	-0.001	-0.11	0.44	-0.08	1.44	-0.39	-0.40

$$R^2 = 0.3742$$
$$F = 0.538$$

While, the multiple regression for pedo-geomorphic variables obtained from the areas having slope less than 15° is represented in the following equation:

Y= 10.72	$-0.08. x_1$	$0.56. x_2$	$0.26. x_3$	$0.31. x_4$	$-0.91. x_5$	$-5.68. x_6$	$-1.82. x_7$	$-0.11. x_8$	$10.39. x_9$	$-0.01. x_{10}$
SE = 36.37	0.14	0.31	0.33	0.28	2.01	2.91	2.18	0.24	18.58	0.01
t = 0.29	-0.52	1.81	0.80	1.13	-0.45	-1.95	-0.83	-0.48	0.56	-1.29

$$R^2 = 0.6542$$
$$F = 3.594$$

The above analysis reveals that the relations among the pedo-geomorphic parameters are more consistent in areas having gentle to moderately gentle slope (15º). Only 37.42 % of total variation are found to be explained among the pedo-geomorphic parameters in areas having slope more than 15º. In fact, the calculated F statistic of 0.538 also fails to prove its significance at an acceptable level. In contrast, the multiple relations among the pedo-geomorphic parameters in areas having slope less than 15º are found more consistent where 65.42 % of the total variations are found to be explained. The calculated F statistic also proves such a contention. Thus, it is apparent that the youthful and active hill-slope process in the northern hilly tracts (>10º), prevent pedo-geomorphic process to reach a certain stage of stability. While, the pedo-geomorphic process in the southern undulating and summit plains have achieved some sort of stability to produce meaningful relations among themselves.

4.4.3. Pedogemorphic relations in different topographic setup :

The investigator has also tried to assess the level of multiple relations among the pedogeomorphic properties and infiltration rate under different topographic forms, which are thus divided into two broad groups: a) data obtained from erosion surface and b) data obtained from the deposition surface. The former consists of 22 observations and the latter consists of 28 observations.

The multiple relations among the pedogeomorphic properties obtained from the erosion surface may be represented in the following form:

Y= -32.83	-0.12. x_1	-0.10. x_2	-0.66. x_3	-0.11. x_4	1.54. x_5	11.54. x_6	0.18. x_7	-0.01. x_8	0.07. x_9	0.002. x_{10}
SE = 32.31	0.13	0.27	0.29	0.28	2.34	4.41	2.10	0.25	19.67	0.003
t = -1.02	-0.97	-0.36	-2.27	-0.38	0.66	2.62	0.08	-0.04	0.003	0.88

R^2 = 0.5593
F = 2.919

And the multiple relations among the pedo-geomorphic properties obtained from the depositional surface may be expressed in the following form:

Y= 36.16	0.43. x_1	1.93. x_2	1.86. x_3	0.72. x_4	-3.95. x_5	-26.41. x_6	-3.24. x_7	1.56. x_8	-50.85. x_9	-0.03. x_{10}
SE ≈ 88.46	0.65	1.38	1.46	0.68	7.60	15.79	5.21	1.21	53.44	0.03
t ≈ 0.41	0.65	1.40	1.27	1.04	-0.52	-1.67	-0.62	1.29	-0.95	-1.22

R^2 = 0.6966
F = 1.148

It is interesting to note that the multiple relations among the pedo-geomorphic parameters are found to be significant in both erosion and deposition surfaces. However, it is found more consistent among the samples obtained from the depositional surface, where 69.66% of the total variation in the slope have been explained by the respective independent variables.

4.4. Conclusion

The soil of Balason basin, is erosion prone and extremely precarious along the northern hilly tracts. Very high slope gradient (30°-40°), along with high and concentrated rainfall (2500–4500 mm) aggravates the erosional hazards. Field observations reveal that soil is active in the study area. Solum mixing, truncation and the presence of coluvial stone horizons have been identified in many cases, due to excessive soil erosion.

Several statistical relationships have been observed among many soil properties, infiltration rate and their respective slope in the study area. These relationships seem to be prominent and statistically significant and coincide with that of the established relationships found in other places. Most of the soil properties are inversely related to the slope, while the rate of infiltration is positively related to the slope. This is most probably due to complex interactions among a number of variables like soil texture, organic matter, thickness of A horizon etc. the multiple correlation studies also show some striking results.

Moreover, to understand the spatial distribution of these relationships and their interactions in different lithological, altitudinal and slope environment, the total samples have been suitable divided and analysed statistically. Significant relationships have been found around the broad summits in the northern hilly part, i.e. the gneissic area, with higher elevation (>1000 m), and southern undulating plains having a gradient of less than l5º. But the pedo-geomorphic parameters obtained from areas having unconsolidated parent materials with moderate altitude (300 –1000 m), steep gradient (>15º) fail to achieve statistically significant relationships. This is most probably due to the fact that the northern summit and the southern undulating plains of the Balason basin have achieved pedo-geomorphically more stable state where the pedogenic and geomorphological processes have achieved some sort of equilibrium as a process response system. The northern non-gneissic terrain and the southern piedmont areas experience heedless deforestation, mass movements and the streams draining through the region are in the habit of depositing enormous amount of fresh silts during rains each year.

Thus, the continuous depletion of the slope materials in the northern hilly terrain and continuous increment of highland refuges in the southern piedmont areas have detrimental effect towards achieving the stability of the pedo-geomorphic parameters.

The four major pedo-geomorphic units have been recognizes as : (a). the northern moderately sloping summit composed of gneissic rocks which is characterized as erosion surface; (b). the extreme southern undulating plains; (c) the north central non-gneissic hilly areas with slopes more than 15º and (d) the active depositional surface of piedmont zone. The former two (a & b) exhibits some sort of equilibrium as a process-response system between the pedogenic and geomorphic process. Equilibrium between the pedogenic and geomorphic processes has not been achieved in the latter areas (c &d).

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CHAPTER 5

SOIL EROSION: ASSESSMENT AND STRATEGIES FOR CONSERVATION

5.1. Introduction

The extremely dynamic nature of the geological, geomorphologic and fluvial processes operating in the Balason basin provides unrivalled possibilities for the study of soil erosion in the region. Mass movement and gullying are rampant on most slopes and soil loss is widespread over the basin, which is of increasing concern to the inhabitants (Photo 5.1 & 5.2).

This chapter aims at making a quantitative assessment of the soil erosion hazard by apprehending a number of diagnostic criteria, culminating, in the proposal of a soil conservation plan, to protect the extremely vulnerable region against extensive soil loss.

5.2. Assessment of Soil Erosion Hazard

The assessment of soil erosion hazard is a specialized extension of land resource evaluation, whereby areas of land are identified where the maximum sustained productivity from the given landuse is threatened by excessive soil loss. The assessment aims at classifying the area into regions with similar intensity of erosion hazard, as a basis for planning soil conservation work (Requier, 1980). Such an assessment of soil erosion is concerned with measuring and comparing the variables that determine forces like soil erosivity and soil erodibility in order to predict the likelihood of erosion and soil loss.

5.2.1 Diagnostic criteria

Soil erosion is controlled by a number of factors (figure 5.1), some of which can be easily quantified while it becomes more difficult to make a quantitative

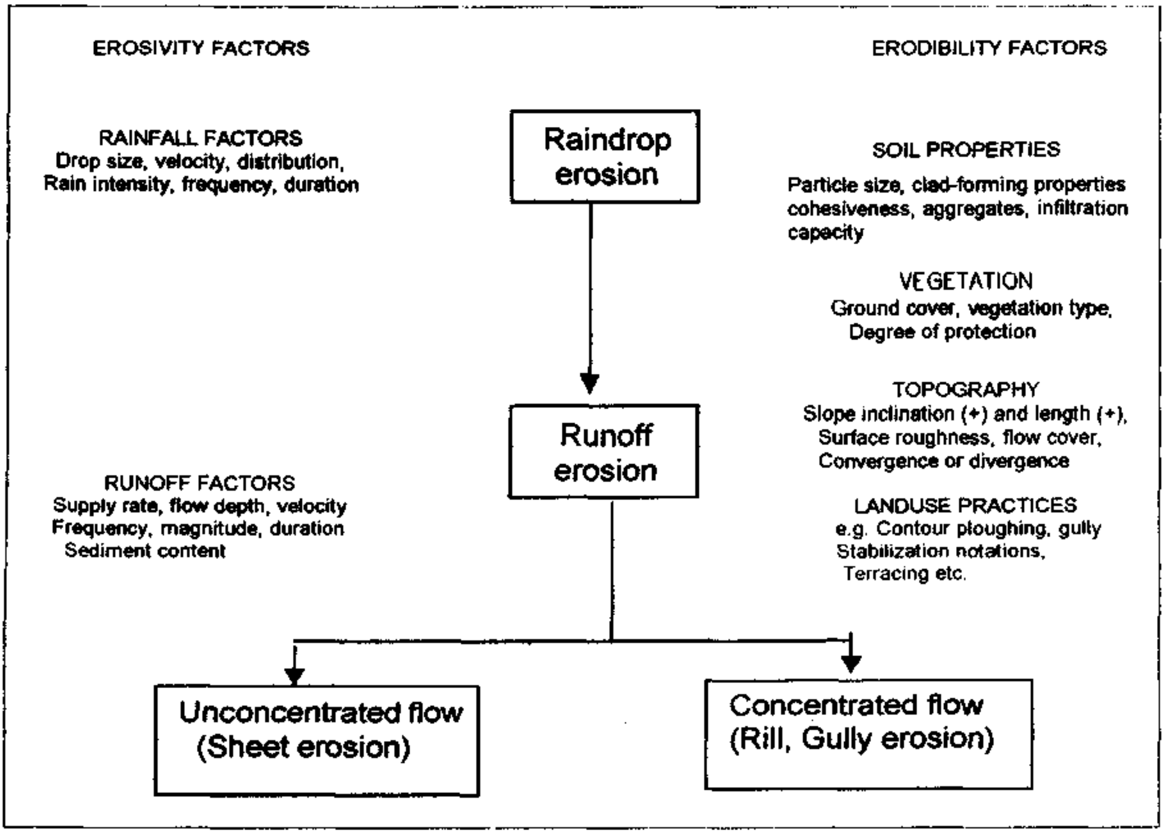
Photo 5.1 Top soil removal in the Northern hilly part : note the indigenous conservation measures

Photo 5.2 Bank erosion - rampant in the Southern piedmont zone

assessment in the case of other factors. In the present study, the following diagnostic criteria have been assessed quantitatively:

1. Climatic / Rain erosivity (R)
2. Soil factor/ erodibility (K)
3. Topographic factor / erosivity (LS)
4. Biological factor (CP)

FACTORS IN SOIL EROSION BY WATER



Based on Cooke and Doornkamp.1990

Fig.5.1

5.2.2. Methodology :

A detailed soil erosion hazard assessment of the Balason basin has been attempted based on the diagnostic criteria mentioned above with necessary modification using the existing standard literature and rating tables (Wischmier and Smith 1978; Fournier 1972; FAO/UNEP, 1978; Arnoldus 1980; Requier, 1978 and Sarkar 1987, 1989 a, 1989 b, 1991 & 1997). A rating value is assigned to each group of the factors in such a way that each group can influence the final result according to its own importance (FAO/UNEP, 1978). The index value of all the above criteria have been calculated on the basis of field data collected from various stations at regular intervals within the basin area. Details of assessment of soil erosion has been put forward as an example of "unit area". The site near Makaibari tea garden has been chosen for this purpose and the following diagnostic criteria have been employed for the assessment:

1. Climatic / Rainfall erosivity or R

$$R = \sum_{1}^{n} Pr_{10mm}^{2} / P \qquad \text{..........5.1}$$

where Pr_{10mm} is the average monthly rainfall of months having >10 mm rain in a single rainfall event i.e. 463.8 mm and P is the annual rainfall in mm i.e. 4030.72 mm and hence R = 426.94.

2. Soil erodibility (K) has been calculated, based on the USLE Nomograph (figure 5.2); where sand (0.10 – 2.0 mm) content is 66.71%, silt and very fine sand (0.002 – 0.10 mm) content is 9.09%. organic matter content is 2.31%; soil structure has been identified as coarse granular to crumby; soil permeability is moderate to moderately rapid and hence, the K value is calculated to be 0.34

3. Topographic erosivity (LS) has been estimated based on USLE model such as:

$$LS = \sqrt{L/100}\ (0.136 + 0.0097.S + 0.0139.S^2) \qquad \text{..........5.2}$$

where L is the length of the dominant slope in metre, i.e. 450 metre, S is the slope gradient in percentage i.e. 47% and L.S is the topographic erosivity i.e. 66.39.

4. Biological factor (C.P) has been estimated, based on the parametric rating value (modified FAO/UNEP, 1978) i.e. 0.08.

SOIL ERODIBILITY NOMOGRAPH

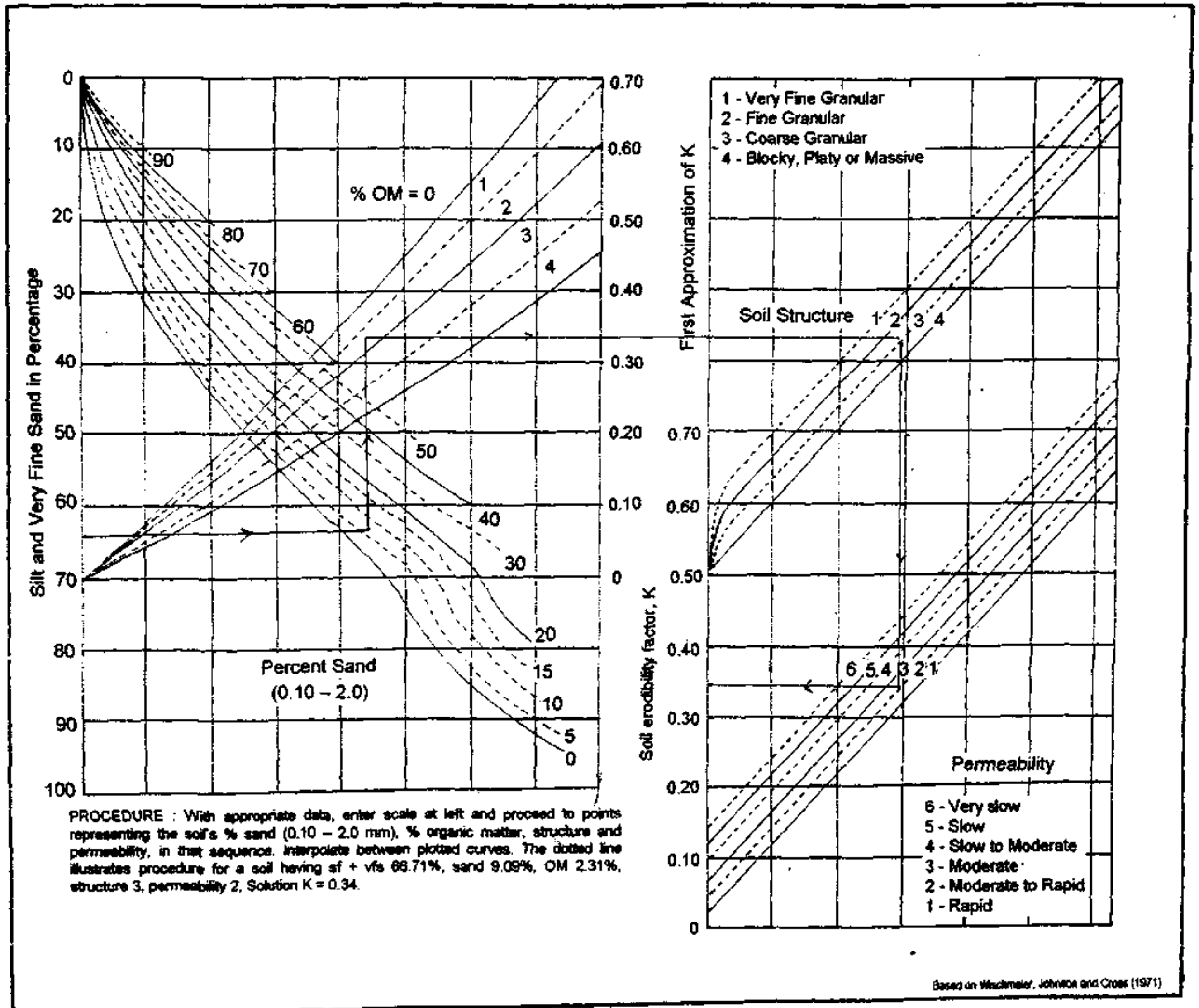


Figure 5.2

The potential (natural vulnerability) soil loss and predicted or actual soil loss have been assessed from the following empirical formula:

a). The Potential soil loss by the water erosion has been assessed from:

$$Pe = R.K.L.S. \quad\quad (5.3)$$
$$= 9637.15 \text{ tons} / h^{-1} / y^{-1}$$

b). The Predicted or Actual soil loss has been estimated based on the following equation:

$$E = R.K.L.S.CP \quad\quad (5.4)$$
$$= 770.97 \text{ tons} / h^{-1} / y^{-1}$$

5.2.3. Climatic / Rain Erosivity :

It has been increasingly realized that the amount of soil in runoff increases rapidly with the increase of raindrop energy, and it has also been noted that erosion can be greatly reduced by preventing raindrop impact (Morgan, 1986). Thus, climatic erosivity is essentially a function of the intensity of rainfall, its duration, the mass diameter and the impact of raindrops. Based on the works of Laws and Pearsons (1943), Wischemeier and Smith (1958) obtained the equation:

$$KE = 13.12 + 8.78 \log. 10^{I} \quad\quad (5.5)$$

where, I is the rainfall intensity (mm / h^{-1}) *and K.E is the Kinetic energy* (Jm^{-2} / mm^{-1}).

For tropical rainfall, Hudson (1965), gives the equation:

$$K.E = 29.8 - 127 / I \quad\quad (5.6)$$

Based on measurements of rainfall properties in Zimbabwe, Zanchi and Torri (1980) carried out similar research in Italy and obtained :

$$K.E = 9.81 + 11.25 \log^{I} \quad\quad (5.7)$$

But all the methods require a continuous rainfall data, which is not generally available from the present recording stations of the study area. However, the

Fournier's Index (1972):

$$R = Pm^2/P \quad \text{.......... 5.8}$$

where *Pm is monthly rainfall having highest rainfall and P is the mean rainfall in mm*, can easily be calculated within the limitations of insufficient rainfall records.

This index is very popular due to its simplicity, but correlation studies between it and equation nos. 5.5, 5.6 and 5.7 show that the Fournier's Index can hardly be used to approximate the R factor (Arnoldus, 1980). Thus, the FAO/UNEP experts (1978) have tried to modify the Fournier's equation (Eq.5.8) in such a way, that not only the month that receives the highest rainfall but also the average monthly rainfall can affect the evaluation of the R factor:

$$R = \Sigma p^2 / P \quad \text{.......... 5.9}$$

where p is the average monthly rainfall and P is the annual rainfall in mm.

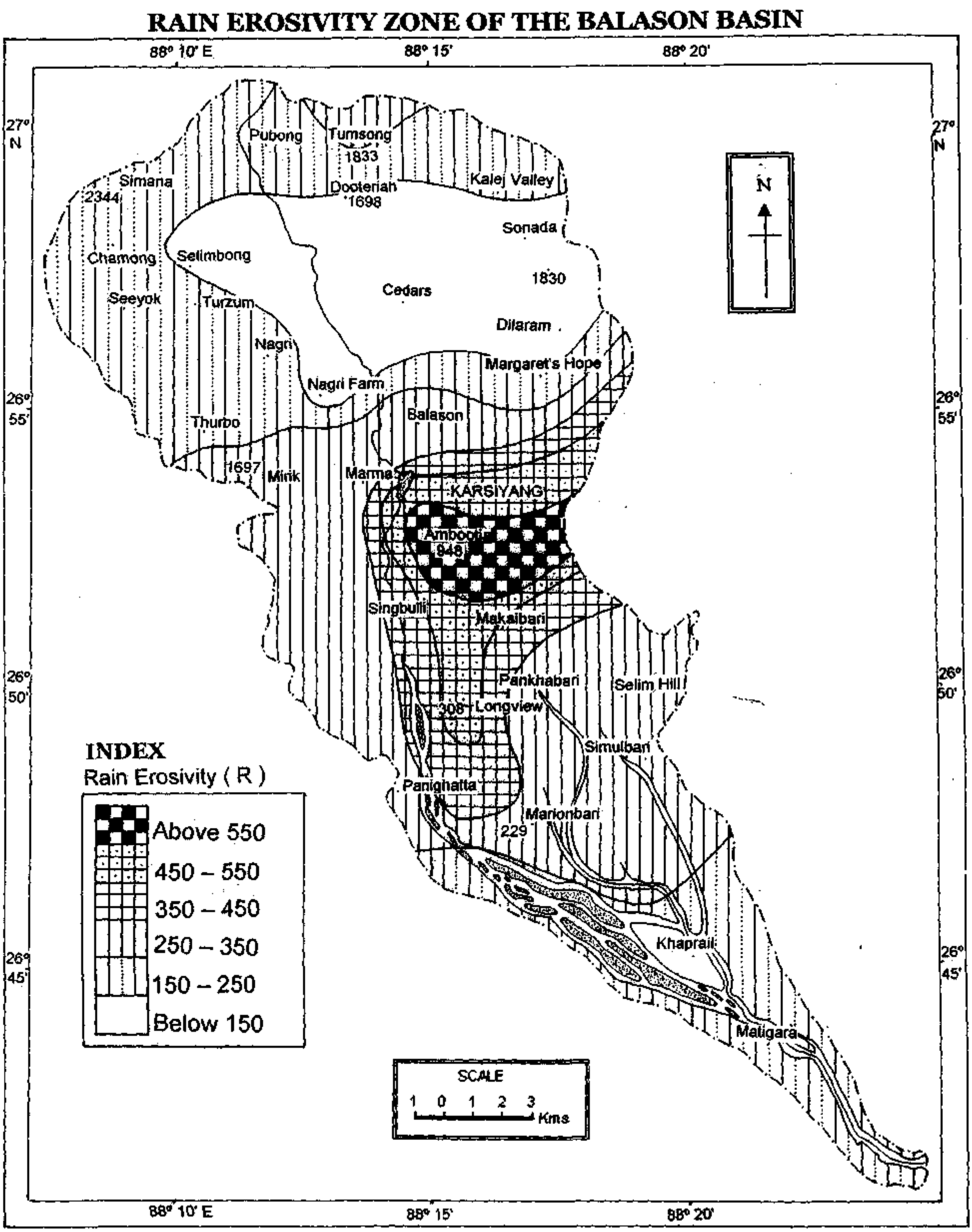
The result again has not been found satisfactory, probably because in the FAO/UNEP model, the average monthly rainfall is the only criteria and the intensity of the rainstorm is left untouched. Sarkar (1989 b) in his study of rainfall erosivity of Darjeeling Himalaya has modified the FAO/UNEP model in the following manner:

$$R = \sum_{1}^{n} Pr^2 \, 10 \, mm / P \quad \text{.......... 5.10}$$

The present investigator has found that the above equation suits best as an effective alternative to the existing standard index for the evaluation of rain erosivity (R) for the study area. An iso-erodent map of the study area has been prepared based on interpolation method. Classes have been recognized for a better understanding of the geographical distribution of rain erosivity. (figure 5.3)

Class I: Very high rain erosivitiy (R = >550) : has been recognized along a narrow wedge extending in the center of the Balason basin, starting at Ambootia and moving in a narrow strip to the eastern extremity of the basin.

Class II : High rain erosivity (R = 450 – 550): zones are found bordering the



RAIN EROSIVITY ZONE OF THE BALASON BASIN
88° 10' E
88° 15'
88° 20'
27° N
26° 55'
26° 50'
26° 45'
N
Pubong
Tumsong
1833
Simana
2344
Dooteriah
1698
Kalej Valley
Sonada
Chamong
Selimbong
1830
Seeyok
Turzum
Cedars
Dilaram
Nagri
Margaret's Hope
Nagri Farm
Balason
Thurbo
1697
Mirik
Marma
KARSIYANG
Ambootia
848
Singbulli
Makaibari
Pankhabari
Selim Hill
308
Longview
Simulbari
Panighatta
Marionbari
229
Khaprail
Matigara
INDEX
Rain Erosivity (R)
Above 550
450 – 550
350 – 450
250 – 350
150 – 250
Below 150
SCALE
1 0 1 2 3
Kms

Figure 5.3.

class I zone on all sides and forms a broader wedge engulfing the former.

Class III: Moderately high rain erosivity (R = 350-450): forms the outer boundary, engulfing the former zones on all sides, with a marked extension towards the Panighata and Longview in the south.

Class IV: Moderate rain erosivity (R = 250-350): zones are observed towards the northwestern and southern parts of the basin.

Class V : Moderately low rain erosivity (R = 150-250) : zones are found in the north western, northern and extreme southern part of the basin, engulfing Chamong, Thorbu, Mirik, Soureni, Seyok in the north western part, Pubong, Tumsong, Takdah in the extreme north and Matigara and Khaprail in the south.

Class VI : Low rain erosivity (R = <150) : is centered around the north eastern part of the basin around Kalej Valley, Doteriah, Selimbong, Cedars and Dilaram tea gardens.

The Longview tea estate records very high rainfall (5116.50 mm), the erosivity remains moderately high in the order of class III, whereas Ambootia that falls in the very high erosivity zone (class I) records a lesser annual rainfall of 3922.51 mm. The high steep slopes of Ambootia along with the high intensity of rainfall in the region within a short period probably accounts for this observation.

5.2.3. Soil Erodibility :

Erodibility defines the resistance of soil to both detachment and transport. Soil properties are the more important determinants of erodibility, although topographic position, slope steepness and nature of disturbances created by man also have decisive role Soil erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic and chemical properties. The dynamic field oriented methods of Wischemeier and Mannering (1969), seems to be the best available method in this regard. The assessment of soil erodibility (K) of the

Balason basin has been calculated from the soil erodibility Nomograph (figure 5.2) of the USLE (Wischemeier, Johnson and Cross, 1971) based on the following:

i). the percentage of sand, silt and very fine sand (USDA, 1951),

ii). the organic matter content in %,

iii). the structure and

iii). the profile permeability.

It has been found from the analysis that the K value varies from 0.1 to 0.5 in the study area. A soil erodibility map has been prepared based on the available K value (figure5.4). The following erodibility classes have been identified:

Class I. High soil erodibility (K = >0.5): has been identified along a narrow elongated tract running almost longitudinally between the central and northern hilly part of the basin, extending through the major valleys and cliff surface, from Simripani to south of Dooteriah enclosing Ambootia en route. The high erodibility of this belt can be attributed to the coarseness of texture and less organic matter content in the soil of the region.

Class II. Moderately high soil erodibility (K = 0.4 – 0.5): has been identified in an area engulfing the former zone on all side, surrounding Balason, Singbuli, Marma and Nagri Farm.

Class III. Moderate soil erodibility (K = 0.3 - 0.4): are found on the fringe areas belonging to class II, which includes Tumsong, Pubung, Dooteriah in the northern side, Cedars, Margaret's Hope, Karsiyang on the eastern side, Nagri, Turzum, Selimbong on the western side, and Makaibari, Rington, Dhajia on the southern side. A small pocket is found centered around Matigara.

Class IV. Moderately low soil erodibillity (K = 0.2- 0.3): occur in the north western region around Chamong, Seeyok and Thurbo, around the north eastern extremity in Kalej Valley, Sonada and Dilaram. A small section is found in the southern side of the basin around Khaprail.

Class V. Low soil erodibility (K = 0.1- 0.2): has been identified in a small tract

SOIL ERODIBILITY ZONES OF THE BALASON BASIN

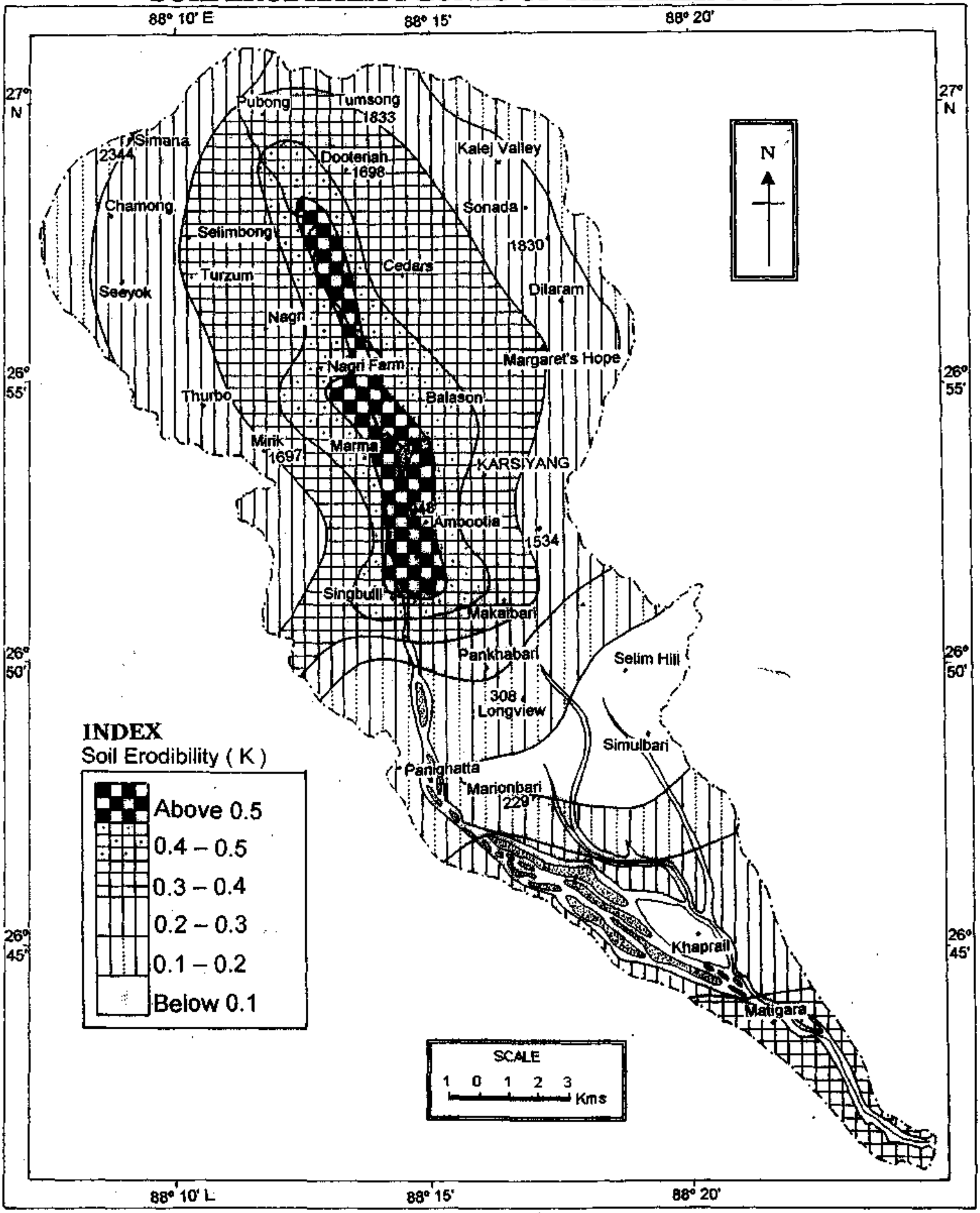


Figure 5.4.

around Simulbari, Marionbari, Panighatta and Longview area.

Class VI. Very low erodibility (K = <0.1): lies around the foothill and forested tract. The low to very low soil erodibility can be attributed to the vegetation cover that account for a very high organic matter content.

5.2.4. Topographic Erosivity:

The topographic erosivity L.S of the Balason basin has been determined with the help of the following equation which is based on USLE model:

$$LS = \sqrt{L/100}\ (0.136 + 0.0097.S + 0.0139.S^2) \qquad 5.2$$

where S is the slope gradient in % and L is the slope length in metre.

The highest topographic erosivity (>120) remains confined in a narrow V shaped wedge in the center of the region around Ambootia, and in small pockets on the north eastern part of the study area. High topographic erosivity of 80 and above extends in a similar wedge around Nagri farm, Marma, as well as in the northwestern part of the study area around Simana, Chamong, Seeyok and Thurbo. Moderate topographic erosivity with values extending from 20 to 80 encircles the high topographic erosivity class from all sides. The low topographic erosivity with values less than 20 is confined to the southern and southeastern tip of the Balason basin in the region lying south of Marionbari.

It is evident from the above analysis that topographic erosivity is directly related to the nature of the terrain. The higher topographic erosivity values indicate hilly terrain as opposed to the low values, which indicate the gently undulating *terai* plain. Thus, the lower LS values (figure 5.5) are confined to the southern and south eastern part of the basin while the rugged hilly areas of the northern, north western, north eastern central and east central parts of the study area exhibit high to very high L.S values. In the remaining area moderate topographic erosivity occurs, where the slope steepness is less. LS factor, thus provides an inventory of computation for both the potential and predicted soil loss of an area, but does not play any critical role in soil erosion mechanism (Hudson, 1971).

TOPOGRAPHIC EROSIVITY ZONES OF THE BALASON BASIN

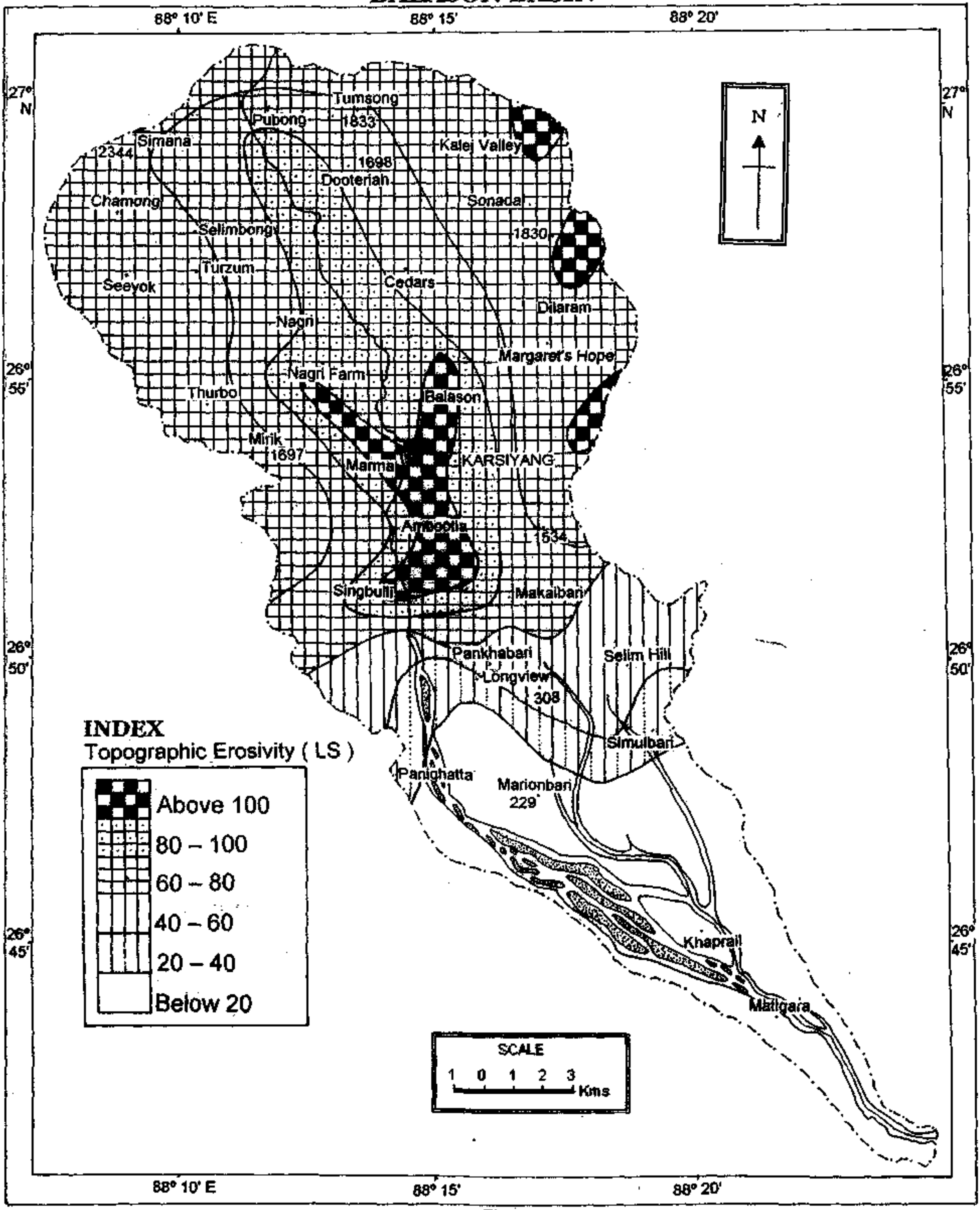


Figure 5.5.

5.2.5. Biological Erosivity :

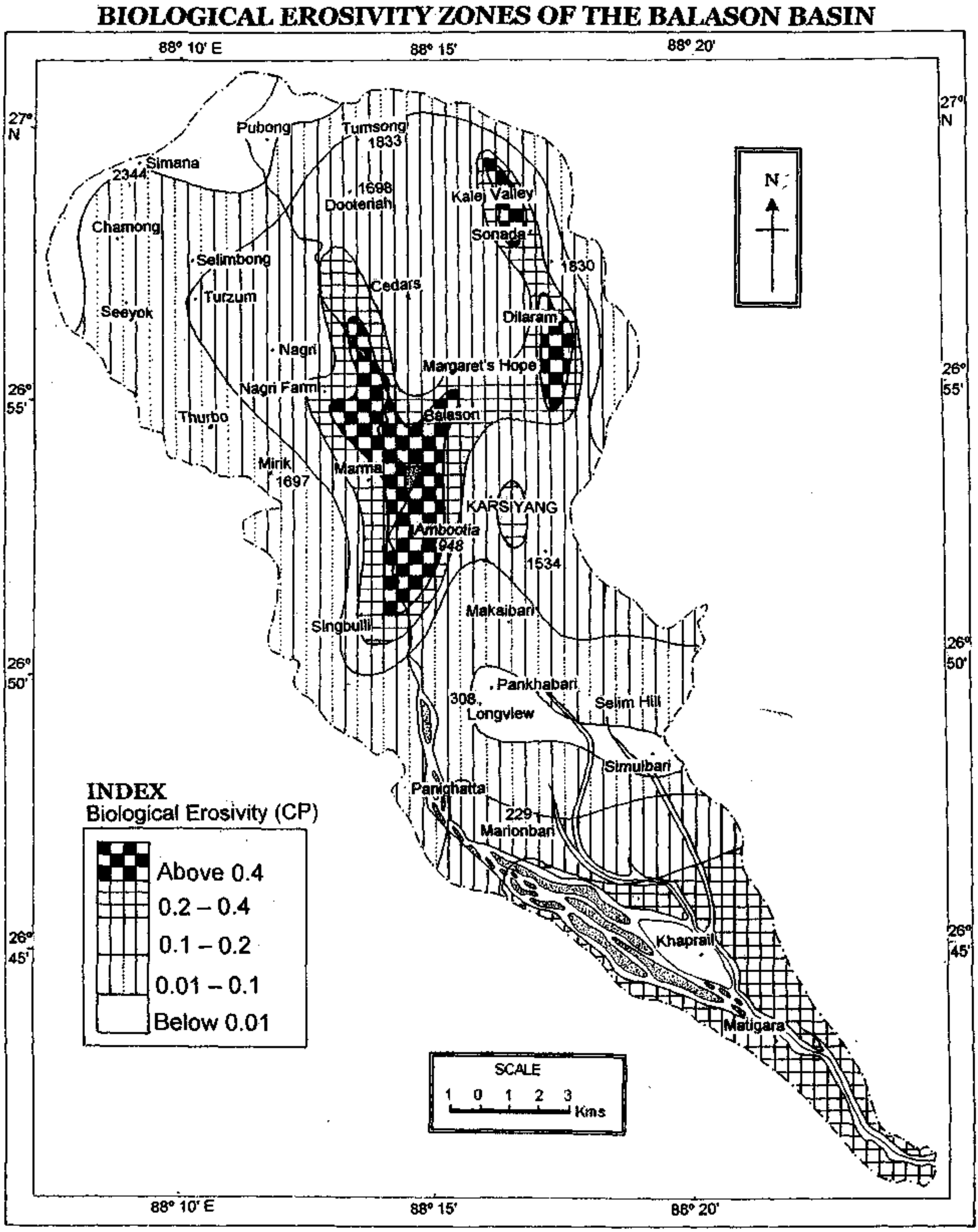
The combined effects of land cover, land productivity, various landuse, over a particular area contribute to the biological erosivity (C.P) of the basin.The biological erosivity (C.P) in the study area has been assessed based on the parametric rating value as shown in table 5.1 which has been prepared based on FAO/UNEP, 1978 model with necessary modifications (Sarkar, 1989 a). A biological erosivity map has been prepared (figure 5.6) from the available C.P values which also includes C and P co-efficient of the USLE. The following biological erosivity classes have been identified:

Class I. Very high biological erosivity (C.P = >0.4) : occurs in three distinct places of the study area; a). in a narrow central wedge around Ambootia, b). around Dilaram, and c). around the Kalej Valley. Heedless deforestation, unscientific slope cultivation and other extensive human interferences make the region highly vulnerable to soil erosion.

Class II. High biological erosivity (C.P = 0.2 - 0.4) : encircles the very high biological erosivity area along the western fringe with a marked increase as one progresses towards the eastern section of the basin and a small strip in the southern section around Khaprail and Matigara.

Class III. Moderate biological erosivity (C.P = 0.1-0.2) : follows more or less the same pattern fringing the class II area but there is a broad extension of this zone towards the northern and eastern section extending from Takdah to Dajia and Phulbari and in the southern section running parallel to the southern strip of the previous class between Simulbari and Marionbari. This extension can be broadly attributed to moderate zones in and around the tea gardens.

Class IV. Low biological erosivity (C.P = 0.01 - 0.1) : almost forms a complete arc around the previous zones extending across the western, central northern and a narrow strip along the southern margin of the study area.



BIOLOGICAL EROSIVITY ZONES OF THE BALASON BASIN
88° 10' E
88° 15'
88° 20'
27° N
26° 55'
26° 50'
26° 45'
Pubong
Tumsong 1833
Simana
2344
1698
Dooteriah
Kalej Valley
Chamong
Sonada
Selimbong
1830
Cedars
Turzum
Seeyok
Dilaram
Nagri
Margaret's Hope
Nagri Farm
Balason
Thurbo
Mirik 1697
Marma
KARSIYANG
Ambootia
948
1534
Makaibari
Singbulli
Pankhabari
308
Longview
Selim Hill
Simulbari
Panighatta
229
Marionbari
Khaprail
Matigara
N
INDEX
Biological Erosivity (CP)
Above 0.4
0.2 – 0.4
0.1 – 0.2
0.01 – 0.1
Below 0.01
SCALE
1 0 1 2 3
Kms

Figure 5.6.

Class V. Very low biological erosivity (C.P = <0.01) : is confined to a small central wedge around Pankhabari and a very narrow arc extending across the western and northern part of the basin around Sukhia Pokhri-Simana busty and Pubong. This is primarily due to the dense vegetative cover. Biological erosivity is considered to be the most important parameter in quantitative assessment of predicted or actual soil erosion in a given area over a given period, because a highly vulnerable potential erosion hazard may have insignificant amount of predicted or actual soil loss if the region is under the cover of dense natural forests.

Table 5.1

Parametric rating value for different landuse patterns

Sl No.	Major land use type	Percentage coverage	Rating value
1.	Virgin forest with a thick vegetal matter in the forest floor	100%	0.0005
2.	Natural vegetative cover, i.e. forest, bush, permanent grasslands	100%	0.001-0.0005
3.	Natural vegetative cover i.e. forest, bushes, permanent grasslands	50-100%	0.05-0.001
4	Tea garden (well stocked)	100%	0.05-0.1
5.	Degraded forests, rough permanent grasslands and other perennial cover	25-50%	0.05-0.1
6	Degraded to semi-degraded tea garden	25-50%	0.1-0.2
7.	Row crops, inter tilled crops	20-80%	0.2-0.8
8.	Terraced cultivated field	10-50%	0.2-0.8
9.	Root crops such as ginger, potato, cardamom	50%	0.8
10.	Bare soils, cultivated fallow cover	0	1.0

Based on FAO/UNEP, 1978 & Sarkar, 1987, 1993.

5.2.7. Assessment of soil erosion:

The assessment of soil erosion has been based on the quantitative estimation of the physical factors like the climatic erosivity (R), the soil erodibility (K), the topographic erosivity (L.S) and the biological factors (C.P). two kinds of assessment have made: i). potential soil erosion based on the equation 5.3 and ii). Predicted soil loss based on equation 5.4.

5.2.7.1. The potential soil erosion

The potential soil loss is the natural vulnerability of land to erosion, which results from the action of physical factors without the intervention of biological factors Requier, 1980). A potential iso-erodent for the Balason basin has been prepared based on equation no. 5.3.

The highest potential soil loss is confined to the central hilly tract around Ambootia where the potential soil loss has been estimated to be above 10,000 tons h^{-1} y^{-1}. This excessively high potential erosivity is due to factors, including very high gradient, large slope length, high rainfall, low organic matter content and coarse texture of the soil. As one moves away from the Ambootia region the potential soil loss diminishes very rapidly on all sides attaining a moderate potential soil loss ranging from 500 to 8000 tons/h^{-1}/y^{-1}. However there is a marked decrease towards the southern plains as one moves away from the foothills around Simulbari and Longview. The main factors for the low potential soil loss (< 1000 tons/h^{-1}/y^{-1}) are the very gentle gradient over the part of this basin, very fine textured soil and a comparatively high organic matter content (figure 5.7).

5.2.7.2. The predicted or actual soil erosion hazard assessment

The predicted or actual soil loss has been assessed, based on the potential erosivity and the biological erosivity by using the equation no. 5.4. An isoerodent map has been prepared by interpolating the soil loss values of different sites (figure 5.8). The east central part of the basin have experienced an exceptionally high rate of erosion (> 1000 tons/h^{-1}/y^{-1}), while, the extreme northern and south central parts of the study area have experienced low predicted soil loss (< 250 tons/h^{-1}/y^{-1}). However, for the better understanding of spatial distribution of soil erosion, the following classes of erosion susceptibility have been put forward.

Class I. Exceptionally high susceptibility zone (>1000 tons/h^{1}/y^{1}) : is centered around Ambootia with a slight extension towards the north. This exceptionally high value of predicted soil loss can be attributed to a large number

POTENTIAL SOIL LOSS OF THE BALASON BASIN

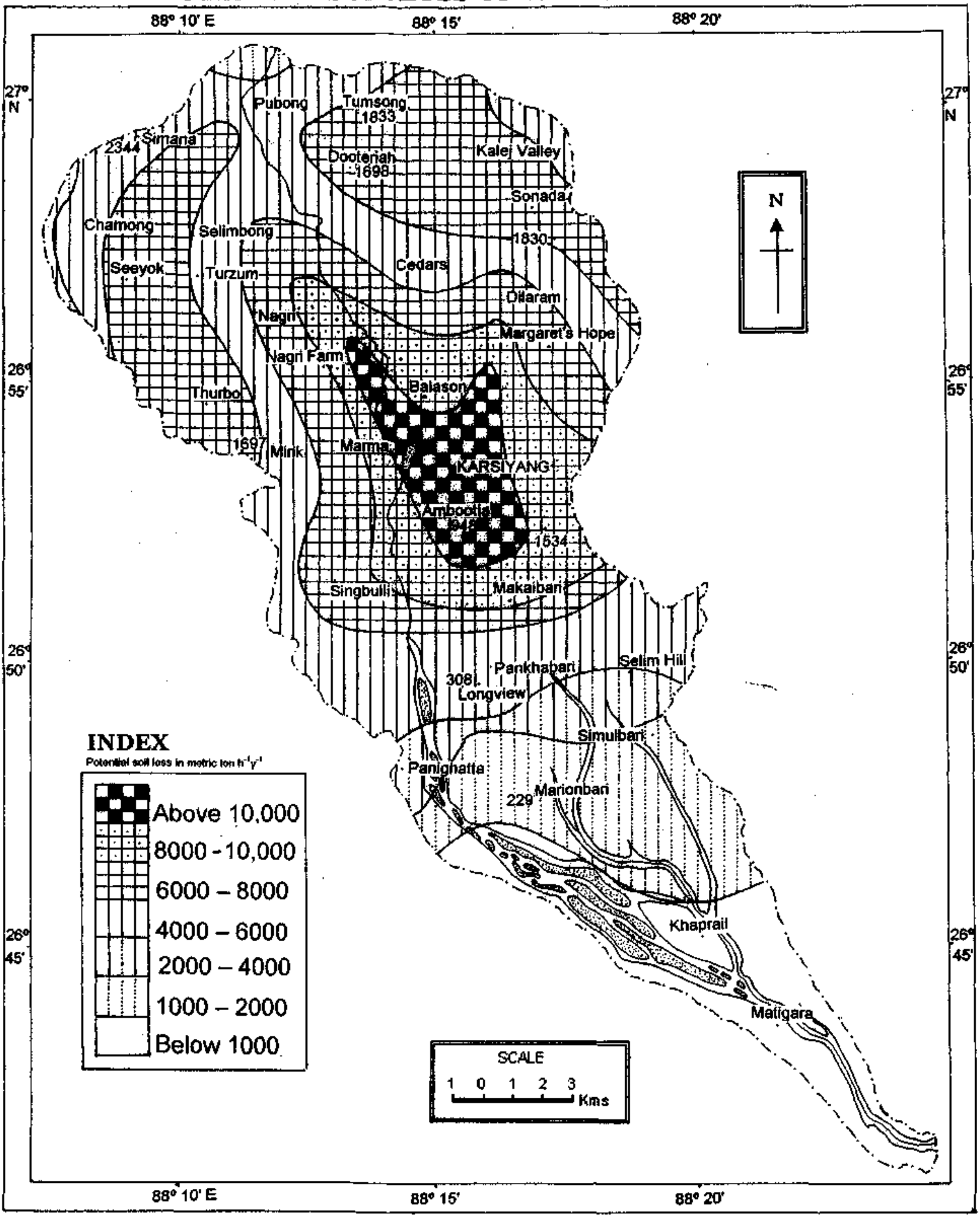


Figure 5.7.

PREDICTED SOIL EROSION OF THE BALASON BASIN

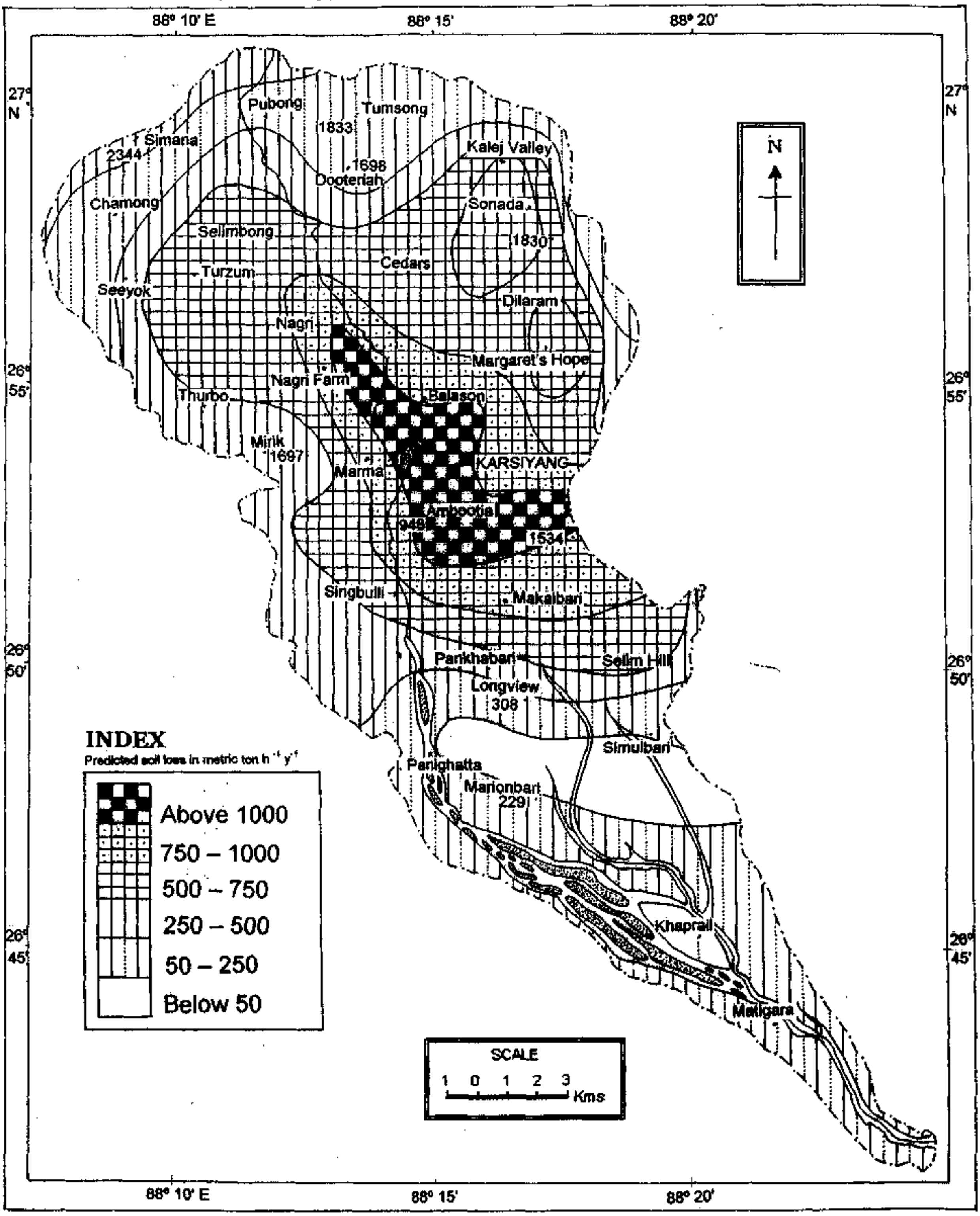


Figure 5.8.

of landslides, prevalent in the area of which the Ambootia landslide has earned the notoriety of being one of the largest in India, covering an area of about 2.06 sq.km. This problem has been further aggravated by the unscientific landuse, accelerated deforestation and coarse textured soil with less organic matter content.

Class II. Very high soil loss zone (750 – 1000 tons/h^{-1}/y^{-1}) : surrounds class I on all sides extending from Nagri farm in the north to Makaibari in the south.

Class III. High soil loss zone (500 - 750 tons/h^{-1}/y^{-1}) : surrounds class II areas on all sides with a broad extension towards the eastern and western fringe of the basin. The northern projection goes beyond Turzum, Selimbong, Rungmook, Cedars and in the south it extends till Singubulli.

Class IV. Moderate soil loss zone (250 - 500 tons/h^{-1}/y^{-1}) : forms a narrow strip around class III on the southern, eastern and western side.

Class V. Low susceptibility zone (50 – 250 tons/h^{-1}/y^{-1}) : forms an arc in the western, northern and a very narrow strip in eastern section of the region, that is from Chamong, Pubong, through Takdah and beyond Dilaram. A narrow band also occurs in the southern section running in a west to east alignment through Panighatta to Khaprail and Matigara.

Class VI. Very low soil loss zone (< 50 tons/h^{-1}/y^{-1}) : has been identified along a broad wedge in the south eastern section of the basin around Longview and Simulbari, covering the foothills. The soil loss is less due to gentle undulating slopes with a dense vegetation cover.

5.3 Strategies for Soil Erosion Control

Soil conservation aims at obtaining the maximum sustained level of production from a given area of land while maintaining soil loss below a threshold level

(Morgan 1979 &1986).The maximum acceptable rate of erosion is known as the soil loss tolerance, which has been estimated by various scientists as ranging between 0.01 in semi desert environments to as high as 1.0 mm / y^{-1} in certain areas of humid tropics and humid temperate environments. (Douglas, 1976; Holeman, 1968; Zacher, 1982). Sarkar (1991) has estimated 0.3 mm/y^{-1} soil loss as the uppermost limit for permissible soil erosion in the Darjeeling Himalaya.

Table 5.2

Impact of conservation measures in soil erosion mechanism

Conservation measures	Rainsplash		Runoff	
	D	T	D	T
A. Agronomic measures				
i). Covering soil surface	o	o	o	o
ii). Increasing surface roughness	*	*	o	o
iii) Increasing surface depression storage	+	+	o	o
iv). Increasing infiltration	*	*	+	o
B. Soil management				
i). Fertilizer application	+	+	+	o
ii). Manuring	o	o	o	o
iii). Drainage	+	+	o	o
C. Mechanical measures				
i). Contouring	*	+	+	o
ii). Terraces	*	+	+	o
iii). Shelterbelts	*	*	*	o
iv). Waterways	*	*	*	o

** = no control; + = moderate control; o = strong control; D = Detachment; T= transport.*

Modified from Voetberg, 1970, Morgan, 1986.

The strategies for soil conservation must be based on covering the soil to protect it from raindrop impact, increasing the infiltration capacity and increasing surface roughness to reduce the velocity of transport phases of erosion (table 5.2).

Soil conservation schemes must be well designed if they are to reduce erosion effectively. Their ultimate success depends on how well the nature of erosion problem has been identified and suitable conservation method selected. The various soil conservative measures effective for the present purpose may be sub-divided into three major groups: i) agronomic measures, ii) soil management and iii) mechanical methods.

5.3.1 Agronomic measures :

Plants differ in their effectiveness in protecting soil from erosion because of differences in their density and morphology. Generally, row crops are least effective and give rise to the more serious erosion hazards. In designing a conservation strategy based on agronomic measures, row crops must be combined with protection effective cover crops in a logical cropping pattern. Of the various agronomic measures, cover crops, strip cropping and mulching are important and are recommended as protective measures against soil erosion in the Balason basin.

5.3.2. Soil management :

The aims of soil management are to maintain the fertility and structure of the soil because fertile soil results in high crops yield, good plant cover and therefore, in conditions which minimize the erosive effects of raindrop and runoff. In the study area, good soil fertility can be achieved by applying organic matter because it improves the cohesiveness of soil, increases water retention capacity and also promotes a stable aggregate structure.

5.3.3. Mechanical methods :

The mechanical methods are used widely to control the movement of water and the decision which is to be adopted, depending on whether the objectives is to reduce the velocity of run-off and increase surface water storage capacity or safely dispose off excess water. All mechanical should be employed in conjunction with agronomic measures. Of the various mechanical methods, contouring, contour bunds, terraces and waterways are recommended in the study area.

5.3.4. Proposed conservation scheme

The assessment of soil erosion in the Balason basin reveals that the soil is highly erodible and when environmental factors are conducive, very high rates of soil

PROPOSED SOIL CONSERVATION SCHEME FOR THE BALASON BASIN

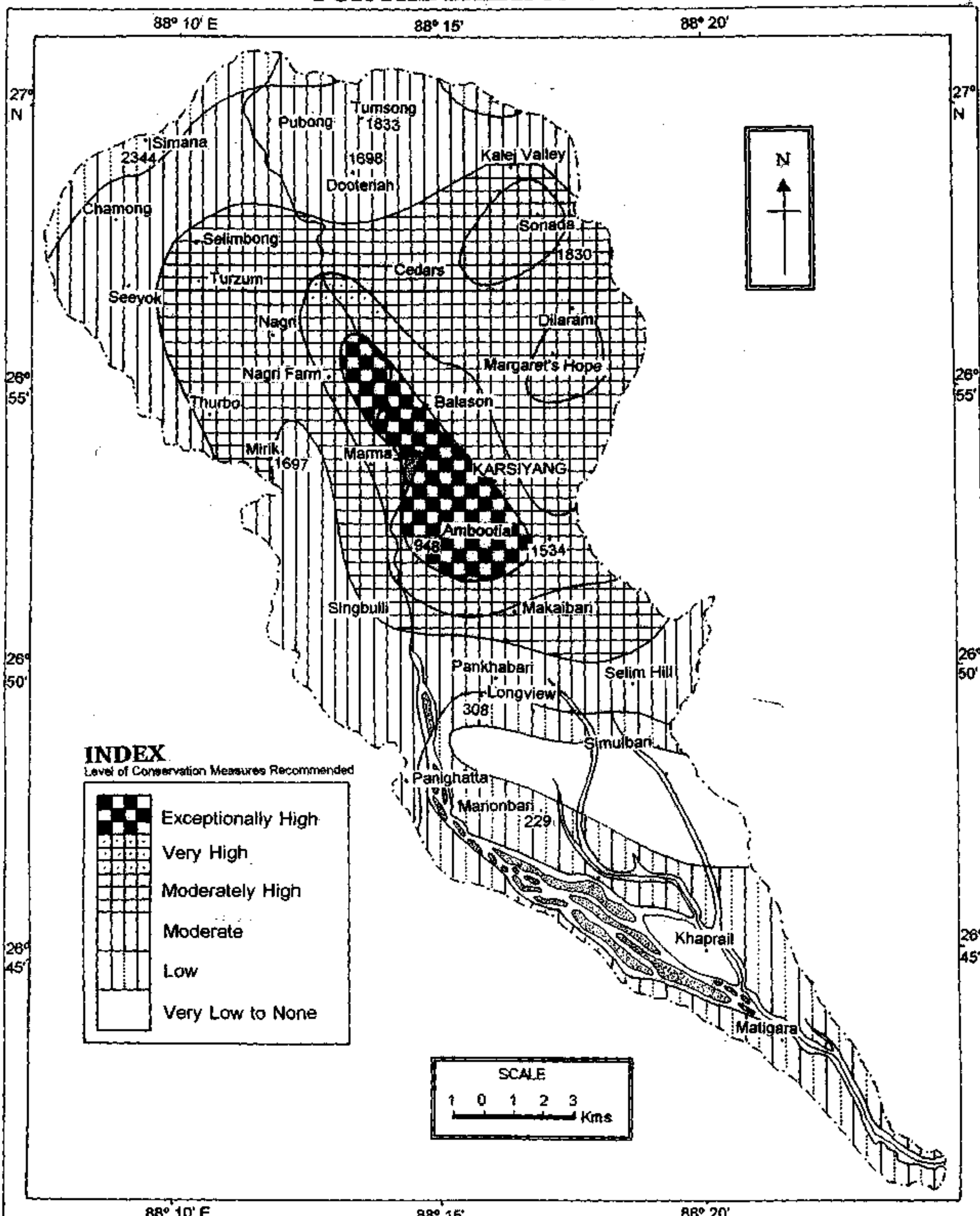


Figure 5.9.

erosion occur. Moreover, the climatic conditions of the region is such, that a rapid decomposition of parent material has taken place which also accelerate soil formation. Keeping these two factors in mind, the present investigator has proposed a target of 0.5 $kg/m^{-2}/y^{-1}$ or 5 ton / h^{-1}/y^{-1} or 0.3 mm/y^{-1} of soil loss be accepted as the permissible limit (table 5.3).

Table 5.3

Conservation measures proposed for different soil erosion classes

Major erosion classes	Rate of soil loss in tons / h^{-1}/y^{-1}	Level of conservation	Recommended conservation measures to be taken
VI	Below 5	None to negligible	No immediate conservational measure is needed except careful crop management.
V	5 to 50	Low	Cover crops, crop rotation, strip cropping, contour bunds along with suitable waterways
IV	50 to 250	Moderate	Cover crops, mulching organic matter application, retention and bench terracing; diversion channel and cross waterways are required
III	250 to 1250	High	Cover crops, mulching, ladder and bench terraces, waterways, storm water disposal systems along with slope stabilization
II	1250 to 2500	Very high	Here all possible agronomic, mechanical and soil management methods should be adopted simultaneously. Plantation of quick growing plants and intensive root spreading grasses, mulching, bench terraces, application of geo-wire , suitable waterways along with slope stabilization works should be applied
I	Above 2500	Exceptionally high	Agriculture should not be allowed in such areas. They should be kept under natural cover i.e. permanent grass or forest.

5.4. Conclusion

The Balason basin, surrounded by forest-clad hills attracted human settlements. As these settlements grew, the acute human interference through the heedless destruction of the forest cover has had its toll on the natural landscape. The degradation of the forest cover with increasing population pressure has elevated the natural soil erosion manifold. The complete severance of the fertile topsoil has gradually led to the loss of fertility and the natural regeneration of the forest cover has dwindled. Thus, the compactness of the soil of the study area has been lost and this has led to various environmental hazards.

The worst affected area lie in the central parts of the Balason basin. This area is deforested and characterized by skeletal soil and very steep slope (>30°); and needs immediate conservation measures recommended in table 4.4. Special attention must be given to areas along the roads, railways, tea gardens, agricultural terraces and existing settlements. Large-scale afforestation, with suitable tree species, along with terracing and drainage facilities is necessary to check massive soil loss. The southern parts have shown very low to negligible soil loss, below 5 tons/ h^{-1}/y^{-1}. This amount is below the upper limit of the permissible soil erosion, thereby, no immediate conservation measures are required.

Agronomic measures should be given a priority over all other measures, as it is less expensive and deals directly with reducing raindrop impact, increasing infiltration, reducing run-off volume and decreasing water velocity. Other measures, mentioned above, should then be implemented without further delay, to save the basin from massive destruction.

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CHAPTER 6

LANDSLIDE : PROBLEM AND STRATEGIES FOR ITS CONTROL.

6.1. Introduction

Landslide is the most pervasive of natural problems that undermine the economic and cultural development of Darjeeling Himalaya in general, and the Balason basin in particular. Chronological studies reveal that there has been a sharp increase in the rate of devastating landslide since 1849, leading to great loss of life and heavy damage to land and property. The situation has further deteriorated in recent years, the last two decades having witnessed as many as 42 devastating landslides in the Balason basin.

Extensive heedless deforestation, tea plantation, haphazard construction and inadequate drainage have led to the establishment of a vicious cycle of degradation. Heavy and concentrated rainfall aggravates the problem further. At present, therefore, suggestion of remedial measures and their active implementation is of vital concern, both for the region and the nation as a whole, for the preservation of delicate ecological balance and geo-political stability of this extremely sensitive region.

A number of case studies on landslide and associated problems of the Darjeeling Himalaya have been carried out at both personal and Government levels from time to time (Griesbach, 1899-1900, Ghosh, 1950; Nautiyal, 1951 and 1966; Dutta, 1966; Sondhi, 1966; Ray & Sensharma 1967; Basu, 1969-1970; Paul, 1973; Sinha *et al* 1975; Verma, 1978; Basu and Sarkar, 1985 and 1987, Froehlich, et al, 1991, Sarkar, 1999). The present investigator has attempted to identify the landslide prone areas, to provide corrective measures and to ensure an all round protection against the menace. Suitable case studies have also been undertaken.

The methodology employed in this study comprises of the quantitative determination of instability factors of slope, analysis of slope materials, geological structure and geomorphological processes, together with the study of human interference. Survey of India topographical maps (1:50,000), have been used for preparing the detailed groundwork for the present study. Detailed geological maps published by the Geological Survey of India, have been consulted to collect the relevant information about the lithology and structure. The identification of the landslide prone areas has been done with the help of a checklist. After studying the location of the landslide prone area, the investigator has selected a few landslides for detailed analysis.

6.2. The Occurrences of Landslides

With rapid modernization, the Balason basin at present is experiencing a phenomenal growth in population (456% during the last hundred years in the Darjeeling hills). To cater to such an overwhelming population increase, pressure on the land is ever increasing. Forests have gradually been eliminated, steep slopes generally unsuitable for human habitations and arable use, have already been occupied. As a result, the study area has, of late, turned into a highly vulnerable region, without paying any heed to its ecological imbalance.

From the available records (Griesbach, 1899-90), it may be said that the first recorded disastrous landslide occurred on September 24th.1899, following unprecedented rainfall and caused the loss of 72 human lives within Darjeeling town and many unconfirmed deaths and widespread destruction of property, in the surrounding areas. Many episodes of disastrous landslides occurred during the following years (Ghosh, 1950; Nautiyal, 1951,1966; Paul, 1973; Roy & Sen Sharma, 1986; Sarkar, 1999).

Since 1980 onwards, it has been found that almost every year, some parts of the basin have been suffering from major or minor landslides. Landslides have become an integral part of the life of the hill people (Sarkar, 1999). Table 6.1 and figure 6.1 show the major incidences of landslides and their impact in the Balason basin.

LANDSLIDE SCARS IN THE BALASON BASIN

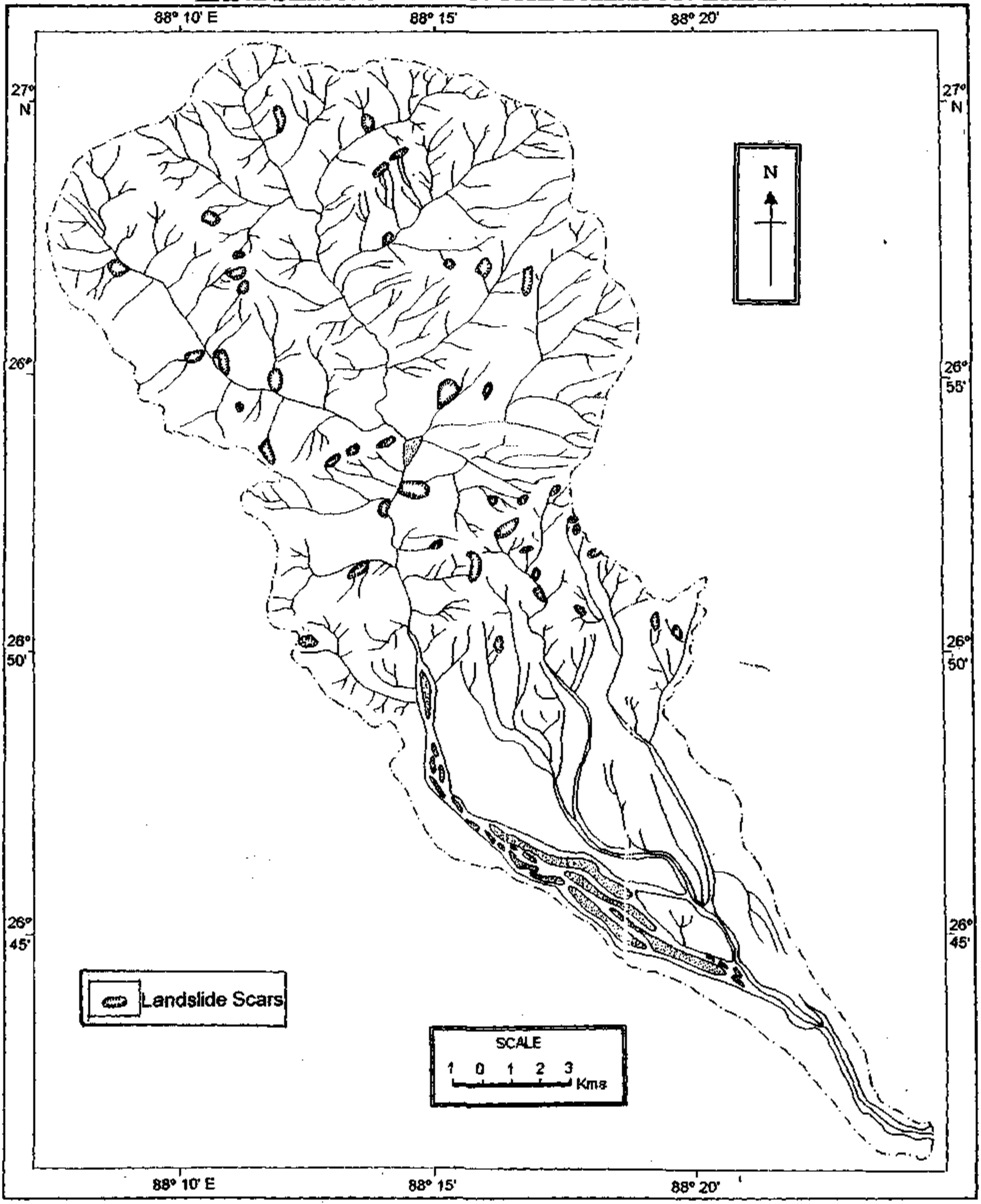

Figure 6.1

Table 6.1.
Occurrences of major landslides in the Balason basin

Major events and rainfall	Affected area	Remarks
September 24th –25th, 1899 Rainfall: 1065.5 mm. From September 22nd to 25th	Karsiyang, Ghoom, Tindharia.	72 lives lost in Darjeeling town. Houses along the eastern slopes and along the Observatory hill were mostly destroyed.
January 15th, 1934. Bihar-Bengal earthquake.	Sonada, Sukhiapokhri, Karsiyang.	Few destruction were reported
June 11th and 12th, 1950 Rainfall: 820.0 mm. From June 11th –13th.	Tindharia, Karsiyang etc, and the hill remain cut-off from the rest of the country for five days	127 lives lost, thousands of people were rendered homeless: slides breached many arterial roads.
October 3rd to 5th, 1968. Rainfall: 1121.4 mm., From October 2nd to 5th.	Ambootia.	Hill Cart road and N.H. 31 were completely wiped out, heavy loss of life and property especially in Ambootia.
September 3rd to 4th, 1980, Rainfall: 299.1 mm., From September 3rd to 5th	Sukhiapokhri, Sonada, Tindharia, Ambootia	Over 215 lives lost, property amounting to Rs.100 million destroyed.
September 16th, 1991. Rainfall: 462.5 mm. From September 15th to 16th	Tindharia	2 people killed. Rail connection between Siliguri and Darjeeling was snapped for five months
July 13th, 1993. Rainfall: 211.3 mm., From July 11th to 13th	Rangtong, Tindharia, Pankhabari, Ambootia, Gayabari etc.	15 lives lost at Mongpu.
August 10th, 1993 Rainfall:115mm., August 8th –10th	Kalimati Landslide, Tindharia, 26.5 km from Siliguri, left hand side of Tenzing Norgay Road	Darjeeling Himalayan Railway line and T.N. Road disrupted for a couple of days. (This was the reactivation of the landslide that began in Sept. 9 1984.
August 26th, 1994 Rainfall: 56.3 mm. in 1 hour 35 minutes	Hill slope on the right side of Tenzing Norgay Road, 4.2 km from Karsiyang towards Darjeeling	Traffic between Karsiyang and Darjeeling disrupted.
July 15th, 1995 Rainfall: 25.5 mm in 48 hours July 13th to 15th, 1995	Hill slope, 1.5 km north of Mirik by the right side of the Siliguri Mirik road.	Road link between Mirik and the hospital was disrupted.
14th July, 1998 Rainfall: 76.4 mm in 24 hours July 13th –15th, 1998	Hill slope and crest at Pankhabari approximately 3.6 kms from Karsiyang	Communication between Karsiyang and Darjeeling was disrupted.
2nd. September, 2000. Rainfall : 54 cm. 30th Aug. – 2nd Sept., 2000	Neezgoan and Payundara Division in Oaks Tea Estate, Sonada	About 3000 matured bushed were washed away, 31 labour houses were completely demolished at Neezgoan and Payundara.
15th September, 2000. *Continuous rainfall on 14th and 15th. September, 2000.*	Bangsghari landslide at Margaret's Hope	The Bangsghari labour village was cut off from the rest of the garden. 15 families were shifted to nearest rescue shelter. This landslide was dormant for past years.

6.3. Nature and Processes:

An intensive survey of major landslides in the study area revealed certain topographic, geological and landuse influences. Table 6.2 and figure 6.1 shows the intrinsic influences exerted by these factors.

Table 6.2.

Landslides registered in different geological, topographical and land-use types

Rocks types	Number of slides	Slope angle and length	Number of slides	Land-use types	Number of slides	Relief types	Number of slides
Sandstone	3	>50° & > 500 m	8	Barren & rocky	0	Ridge	0
Shale	2	>50° & < 500 m	4	Barren & talus	2	Spur (upper)	6
Phyllites	12	40° - 50° & > 500 m	11	Degraded	5	Spur (middle)	5
Schists	10	40° - 50° & < 500 m	7	Grazing	1	Spur (lower)	1
Slate	1	30° - 40° & > 500 m	7	Tea garden	7	Valley (upper)	3
Felspathic rocks	1	30° - 40° & < 500 m	2	Arable land	6	Valley (middle)	4
Granite & gneiss	6	20° - 30° & > 500 m	1	Urban areas	1	Valley (lower)	6
Complex	5	20° - 30° & < 500 m	1	Semi-urban	2	Along streams	12
Not known	2	10° - 20° & > 500 m	1	Rural	3	Complex	5
		10° - 20° & < 500 m	0	Construction Sites	13		
		Below 10°	0	Dense natural forest	2		

Generally, deforested tracts, tea gardens, urban and other settled areas are more susceptible than the natural forested tracts. Geologically, the Daling rocks (phyllite, slates, schists, feldspar etc.) and Damuda rocks (sandstones, shales, etc) are more susceptible to landslide.

Landslides occur on almost all types of slopes, which are composed of various rocks in the Balason basin (table 6.2) Composite slides also take place, involving soil or talus and underlying rocks. Slope failure is caused by shearing, where the plane of shears, taking the form of an arc of a circle in section leaving a parabolic outline of the slipped portion (Dutta, 1966). The most common occurrence of landslide is found along the spring (locally known as Jhora), where rock debris gets detached from their parent body along the slope and form channel. Such channels, later, 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 exhibit scars from a distance.

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 angle below 30° were not generally affected by slides. The talus materials are formed due to the weathering and loosening of rocks along the joints and foliation planes of the parent rocks. Such materials when dry or in permanently drained state, are stable at an angle of even 45° and the stability are not necessarily impaired by occasional wet spells. 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 thin soil cover. Most of the slides have affected the materials, but at some places, slides along the joints of 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 25 metre or so, but they are further widened by subsequent erosion. Thus, once landslide occurred, it generally remains a permanent feature and increases in dimension.

6.4. Major Types of Slope Failure

The Balason basin exhibits a great variety of landslides from small terracettes, indicating soil creep, to large landslide i.e. the Ambootia landslide – the largest in India. It has been observed that each landslide is peculiar in itself, therefore it is important to organize these various types of slope failures into few major types for better understanding. The following are the important types of landslide and related slope instability that has been recognized in the study area:

6.4.1. **Creep** may develop on the slope formed of unconsolidated materials such as residual soil or rock debris. Creeping is found to occur most frequently in areas composed of former landslide debris. The study area posses many types of field evidence to show the existence of creep including outcrop curvature, tree curvature, tilting of structures and cracks. Creeps are found near Rongtong, Toong and Tindharia (photo 6.1).

6.4.2. **Sheet slides** are denoted by the displacement of shallow slope debris, and weathered materials on the surface of the bedrock (Zaruba, 1982). This type of slide can be of large areal extent, but they are generally of small thickness, not more than a metre. The disturbed slopes can exhibit several stages of instability, ranging from the initial fissuring of the surface layer to advanced forms, with several generations piled one on top of another. Sheet slides generally occur after a heavy shower. A typical example of such sheet slide is found at Gourigaon Railway Colony at Tindharia.

6.4.3. **Soil slips** occur in small magnitude mainly along the lower slopes. Such slips are very common and are found almost everywhere within the study area, particularly in Bamonpokhri along the Rakti river, which is an important tributary of the Balason.

6.4.4. **Debris slides** are more extensive and occur on a large scale. These slides are quite common and devastating as well. Debris slides occur along the weak plane, even when they have gentler inclination than the angle of sliding frictions due to the reduction of cohesion and the rise of piezometric head. Most of the slides found in the study area are of this type. Ambootia landslide, Mirik landslide etc. are the examples. The materials involved in

Photo 6.1
.Soil creep along the Hill Cart Road near Rangbull

Photo 6.2.
Mud-Rock flow along Rinchintong khola

Photo 6.3.
Debris flow caused by Toe-erosion along the Balason valley

Photo 6.4.
Pankhabari Landslide

debris slides are a mixture of soils and rock fragments. The debris collects at the foothill or the base of the valleys and forms tongue- like talus cones.

6.4.5. **Slump** generally has curved failure planes, and involves rotational movements of soil and rock materials. Slumping along many roads within the study area may be either due to the removal of basal support by water action or by overloading. Another potent cause of such slumping in the urban centre is due to human carelessness i.e. leakage of water pipe line etc. Perhaps, the best example of slumping is found near Karsiyang town along the Hill-Cart Road.

6.4.6. **Mud-rock flows** found in the study area, are confined to the slopes, formed of talus material and where the slope angle is more than 30° due to seepage pressure of percolating water as a result of heavy rainstorm. After a slip starts, the saturated material rushes down, transporting big blocks of rock and, eroding its own channel. These are known as mud rock flows. This type of landslide is very common in and around the Lower Balason Basin, particularly along the natural and artificial waterways (photo 6.2).

6.4.7. **Debris flow** is another common form of landslide, found in the Balason basin. During heavy and incessant rainstorm, over-saturation of slope materials causes liquefaction. The slope materials i.e., debris rush down-slope very rapidly under the influence of gravitational pull. Debris flow often causes heavy loss to human life and property. Landslides around Tindharia and Marma valley are typical examples (photo 6.3).

6.5. Identification of Landslide Prone Areas

In order to identify landslip-prone areas, it is relevant to distinguish between the environs and the site. Those environs where landslips may be expected to occur have been identified from 1:50,000, Survey of India topographical maps (Sheet Nos.: 78A/4, 78A/8, 78A/1, 78A/5 and 78B/6).), along with the Geological Survey of India maps and from the past incidences. Site on the other hand, refers to the exact location of a particular landslip along a specific slope. The present investigator has attempted site analysis using checklists that enables a systematic consideration to be given to the main factors associated with landslides, at each site under investigation.

In the present study, however, the excavation position and depth, drainage diversion across the hills, loading of the upper slopes and valleys, cutting up of basal support, unscientific construction, terracing, deforestation, legacies from the past slope movements, relief, drainage, materials etc, have been accounted for in the "check-list" (appendix 6.1). Data for such investigation has been collected from the direct field observations as well as from other secondary sources and a map of the landslide prone areas has been prepared (figure 6.2), in which the following zones have been identified:

Class I: Exceptionally high landslide prone area:

This zone extends in a narrow elongated patch in a north-south direction over the middle part of the hill tract and extends towards the eastern boundary of the basin towards Tindharia. The area is mostly composed of Dalings and Gondwana group of rocks. In these areas landslides are very common, and almost every year, after every torrential rain, these tracts experience slips. Ambootia – one of the biggest landslides of the country, is situated within this belt. The other important slides of this belt are located in and around Makaibari-Singell area. Occurrences of landslide in these area are of greater concern, because, not only do they cause heavy damage to land, property and human life, but they also disrupt the communication link between the surrounding villages and the NH - 51 - the life line of the entire Darjeeling Hills. In this zone, there exist 32 active landslides, covering an area of about 1.021 sq. km.

Class II: High landslide prone area:

The zone of high susceptibility surrounds the previous zone. Much of the settled areas, tea gardens, most of the hill slopes, valleys with moderate forest cover are categorized as the high slide prone area. These are areas where slips occur for more than 2-10 times in ten years. Steep slope, high rainfall and unscientific use

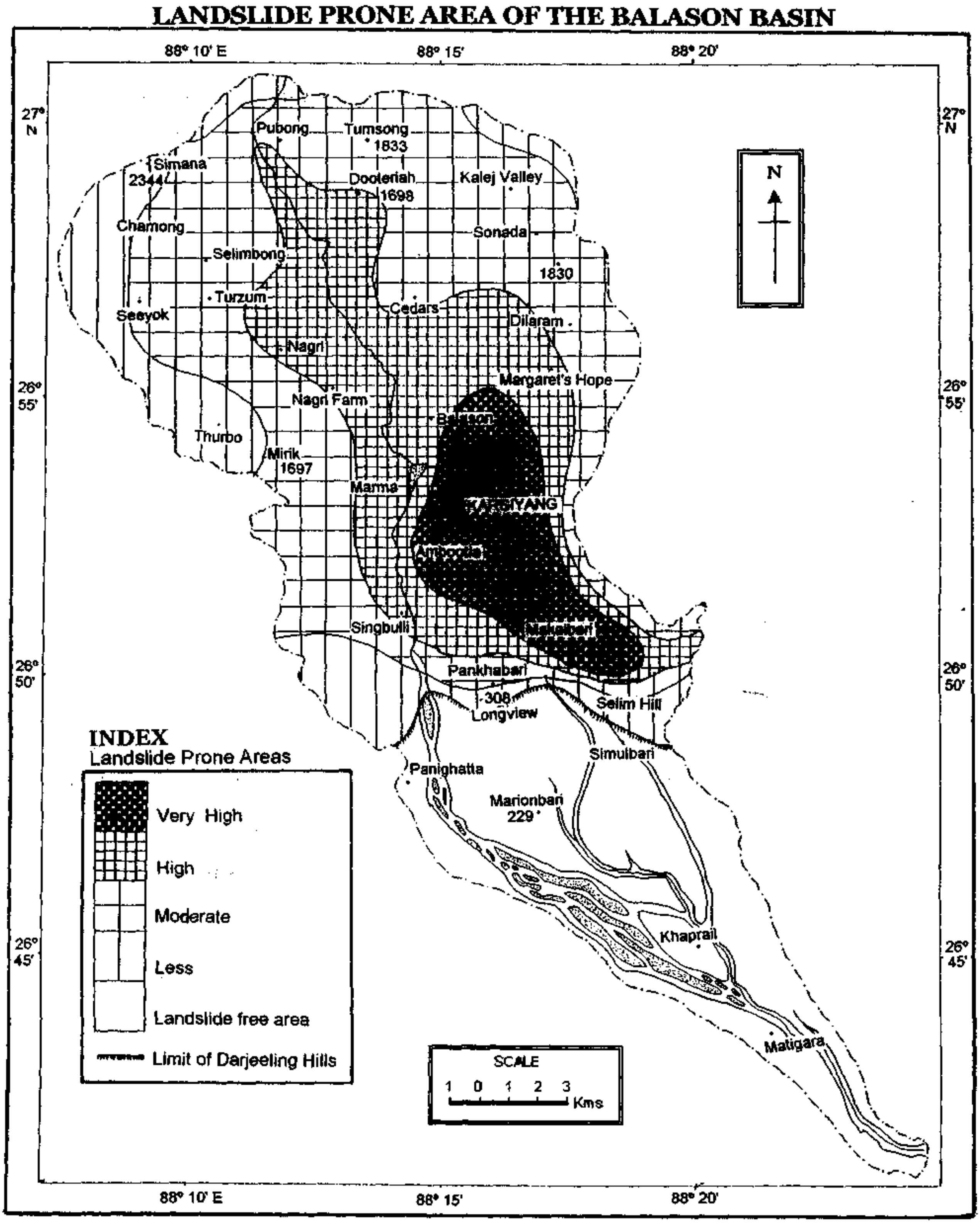
LANDSLIDE PRONE AREA OF THE BALASON BASIN
88° 10' E
88° 15'
88° 20'
27° N
26° 55'
26° 50'
26° 45'
N
Pubong
Tumsong
1833
Simana
2344
Dooteriah
1698
Kalej Valley
Chamong
Sonada
Selimbong
1830
Turzum
Seeyok
Cedars
Dilaram
Nagri
Margaret's Hope
Nagri Farm
Balason
Thurbo
Mirik
1697
Marma
KURSIYANG
Ambootia
Singbulli
Makaibari
Pankhabari
308
Longview
Selim Hill
Simulbari
Panighatta
Marionbari
229
Khaprail
Matigara
INDEX
Landslide Prone Areas
Very High
High
Moderate
Less
Landslide free area
Limit of Darjeeling Hills
SCALE
1 0 1 2 3
Kms

Figure 6.2

of the slope which are composed of highly weathered rock, often make this region highly susceptible to slope failure. Occurrence of slide is common in these areas due to severe deforestation and this often causes heavy damage to tea gardens, settlements and arable lands. Gayabari tea estate falling within this zone exemplifies such a case.

Class III: Moderate landslide prone area:

This zone extends in a north-south direction, in the eastern and western parts of the hilly area. Bare rocky slope surfaces in some places, along with the severe human interferences through unscientific terrace cultivation, and improper construction activities are the main factors for moderate slope failure in this region.

Class IV Low to negligible landslide prone area:

The entire southern part of the basin has gently sloping to rolling topography and the extreme northwestern corners with dense vegetative cover are categorized as the low to negligible slide susceptible zone. These areas may be treated as stable and/or safe zones.

6.6. Case study of Pankhabari landslide

From the foregoing analysis, it is apparent that many parts of the Balason basin have been experiencing devastating landslides. To apprehend the exact nature of this menace and to understand the mechanism of such failures, the investigator has tried to undertake two case studies, selected from different environmental set-up. The study, though having a few unique features, may yet seem to be representative of the landslide of the study area, nearly everywhere, as human need and greed accelerated slope failures.

On the 14th of July 1998, the hill slope and crest at Pankhabari, approximately 3.6 kms from Karsiyang along the Pankhabari Road (leading from Siliguri to Karsiyang), witnessed a massive landslide that crippled communication for several days (figure 6.3). An intensive survey and field investigation was initiated

MAP OF CONTOUR, ROCK UNITS AND STRUCTURAL ELEMENTS OF THE PANKHABARI LANDSLIDE

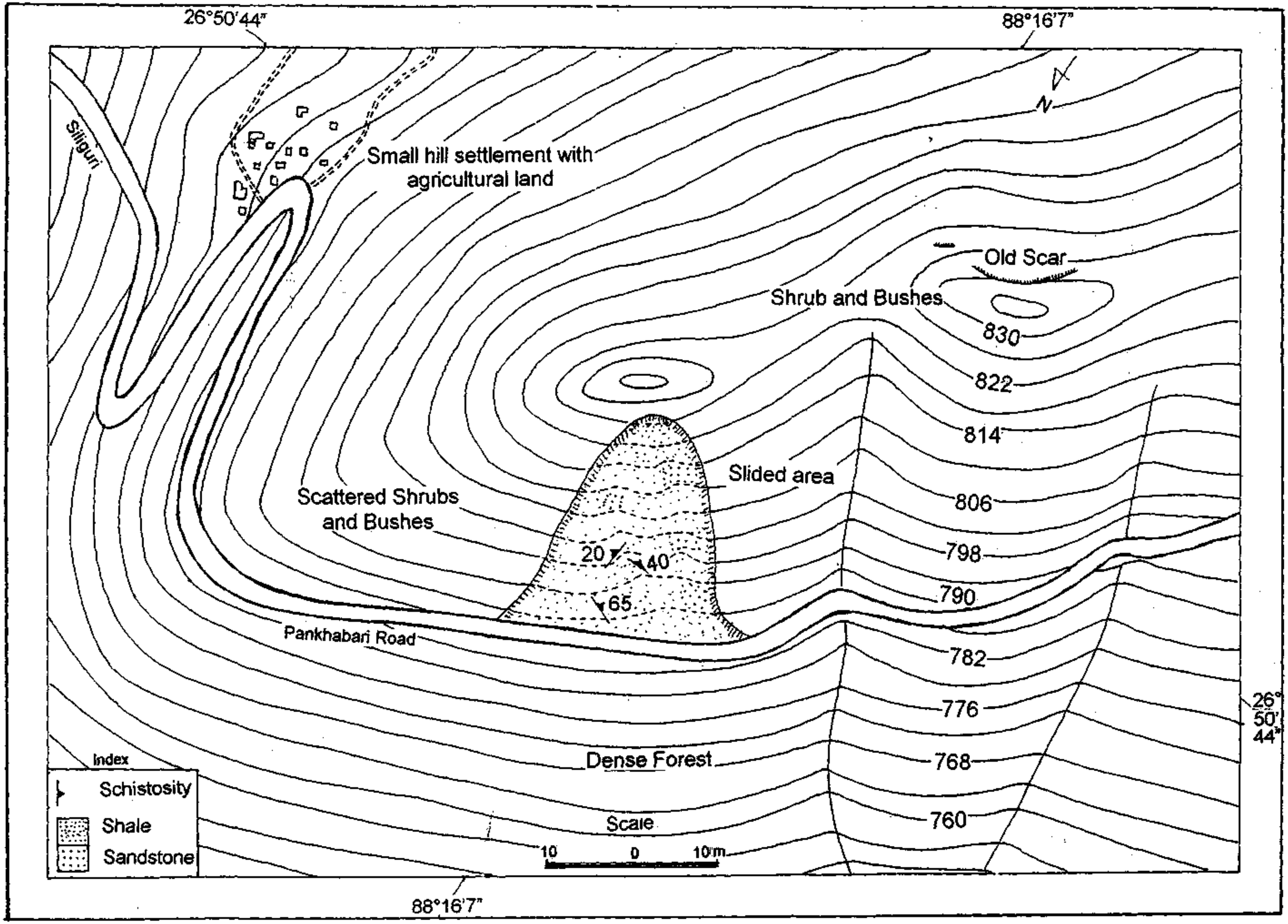

Figure 6.3

by the investigator to apprehend the exact nature of the menace and to understand the mechanism behind the massive slope failure (photo 6.4).

6.6.1. Factors of Instability

6.6.1.1. Geological factors:

The area taken up for the case study is chiefly composed of slightly altered sedimentary rocks of Gondowana formation (Damuda Series), in which sandstone and shale are noteworthy, showing varying depths. Above the sandstone, altered metamorphic rocks of the Daling formation, notable among which are quartzite, philites, slate and mica schist are found. In the study area, it was found that the slightly recrystallised, coarse-grained sandstone is characterized by deformation that destroyed the clastic texture and the intense granulation along the ramifying narrow zones of fractures. The rocks show an inclination that is generally steep towards the roadside and the effect of weathering is conspicuous on the local rock.

Vertical cracks within the rocks result due to both diurnal and seasonal ranges of temperature, that leads to alternate expansion and contraction. The vertical cracks are conspicuous especially along zones of weakness. Thus, solid masses of horizontal beds of rocks disintegrate into blocks. Added to this, the high amount of rainfall leads to large amount of water seeping through the pore spaces of the coarse textured sandstone, which in turn help to decompose feldspar to form kaolin, that acts as lubricant for further sliding down of rock materials.

6.6.1.2. Pedological Factors:

To comprehend the nature of the topsoil as a factor of slope instability in the slide areas, a number of soil samples were analysed. The analysis reveal that the physical characteristics of the soil of the study area is interesting in the sense that at the apex of the slided zone, vulnerable conditions have naturally developed at a depth of 30–40 cm, below the surface, where clay predominates with a good amount of organic matter, high water holding capacity and volume expansion.

6.6.1.3. Changes in the vegetation cover

The local inhabitants have converted the apex area, into terraces for cultivation, after clearing down the forest cover. These terraces are unscientific, being seldom laid along the contours and are not reinforced by protective retaining walls. The cultivation of root crops like potato, ginger, radish carrots etc. that are uprooted during harvesting leads to the disturbances of the cohesiveness of the soil, thus making it vulnerable to erosion. The exposed slopes, stripped of proper vegetative cover when subjected to heavy and continuous rain becomes susceptible to both sheet and gully erosion; thereby becoming easy prey to catastrophic slope wash.

6.6.1.4. Effects of rainfall and infiltration

Rainwater percolation through the joints, cracks and pore spaces of the soil and the regolith, leads to the increase in the hydrostatic pressure within the soil and thus changes the consistency of the soil. The internal friction thus develops, leads to the loss of cohesion in between the particles. With the onset of the heavy monsoons, rill cutting as well as gully erosion begins, and soon, the run-off concentration, through these denuded portions, becomes the dominant agent of soil erosion.

6.6.2. Morphology of the Pankhabari landslide

A detailed morphological account of the pre and post slide conditions of the study area is tabulated in table 6.3.

6.6.3. Summary

The increase in human population in the later part of the last century, led to unscientific and heedless deforestation, to make room for tea plantations, settlements and terrace cultivation, roads etc. The establishment of a new metallic road between Siliguri and Darjeeling led to large scale slope cutting.

Table 6.3.

Morphological features of the Pankhabari landslide

Pre-slide conditions	Post-slide Conditions	Remarks
a). Rocks: Moderately to highly decomposed jointed phyllites, inter-bedded with very thin mica layers, dipping at 20°NNW **b). Altitude:** 820m. **c). Slope:** Convex 60° **d). Rainfall:** 386.98 mm **e). Natural Vegetation:** Scattered bushes, shrubs, bamboo groves and dense forest. **f). Landuse:** Intensively cultivated terrace at the apex of the slide zone, lower slopes unutilized. **g). Soil Colour:** Top : 7.5 yr 3/2 Middle: 7.5 yr 3/4 Base : 5.0 yr 4/3 **h).** Soil is temporarily saturated with water.	**a). Length:** 47.3m **b). Width :** *Maximum* 22.1m Minimum 12.6 m Average 17.35m **c). Depth:** Maximum: 1.5m Minimum : 0.5m Average : 0.9m **d). Shape:** Rectangular **e). Total Area:** 799 sq m. **f). Total Volume of displaced materials:** 1118.6m^3 **g). Processes primarily responsible for the slide:** • Removal of the basal material by toe erosion • Spontaneous liquefaction due to heavy rainfall provide the so called 'trigger mechanism'. **h). Modified Slope**:Concave 55°- 60° **i). Type of slide:** Debris slide and certain soil slip. **j). Special features:** A very prominent stream has developed on the slopes being sided by the dip direction of the country rocks.	The displaced materials temporarily disrupted the road connection between Siliguri and Karsiyang (along the Pankhabari road). It endangered the terraces used for cultivation at and near the top of the slide area. It is recommended that the construction of a protective wall with adequate drainage should be carried out immediately. Further vegetation cover should be erected.

Compiled by the investigator during field survey on 28th Nov. 2000

The construction further led to the increase of the steepness of the slope. The cutting of basal support for the construction of road, settlements, and arable terraces without proper drainage may be treated as causative factors of the Pankhabari landslide. Adding further heavy vehicular movement through this metallic road may add to the disturbance of the underlying rocks.

Thus, the area of the case study, that has been over-steepened by both natural and human interferences, has reduced its inherent stability significantly. During the monsoons heavy rainfall increase the pore water, and the pressure thus developed leads to upward movement of pizometric head and this ultimately has led to the occurrence of the slide.

6.7. Case Study : Ambootia Landslide

The incessant and torrential downpours of 3rd to 5th October 1968, left behind a legacy and a landmark in the Balason basin, a gaping scar in the form of the Ambootia landslide, one of the biggest in the country. Located on the left side of the Balason river, only 4.5 km from the Himalayan margin, the landslide was initially only a shallow khola (channel), along the southern margin of the Ambootia tea garden, very close to Karsiyang town. The landslide itself starts about 200 m below the ridge, rising 1350 m a.s.l. and runs 625 m down the Balason valley. The specific feature of this landslide valley is its form and close co-operation of gravitational processes and linear down cutting, which are continuously active, in contrast to other stabilized smaller landslides (Froehlich, Starkel, Kasza 1992).

6.7.1. Morphology

The Ambootia landslide valley extends for 1300 m in length. At an elevation of 1065 m.a.s.l, the upper niche begins, while at an elevation of 480 m. below cascading waterfalls, the fan zone begins. (figure 6.4).The maximum width of the landslide reaches 625 m across the central portion and the total area occupied by the landslide is approximately 56.5 hectare. The scar depth increases from 10-20 m in the upper part to 200-270 m in the middle and drops to below 100 m in the lower part. The form of the landslide has acquired the shape of a gully-canyon cut in bedrock with a perennial creek. It is characterized by high gradients and water falls with a drop of 15m. Mass movements are continuously modeling and remodeling the unstable slopes. The side valleys are filled with debris flow masses. This continuously growing form has engulfed an area of about 2.5 km in 1999.

According to Froehlich & Starkel (1992), the Ambootia landslide valley has a very complex character and shape. The uppermost part is worked by slumping and sliding upto 10-20m deep. Frequent and active cracks often accompany niches. Dip slopes, inclined at 25-45° at the left have straight or convex profiles. Bare rocks are exposed on the upper sections of the landslide, while the lower sections exhibit inactive revegetated fragments between creeping block fields.

It may be pertinent, at this point to note that the floor of the main gully is changing every year. The colluvial fan, 100m wide and 15-20 m high, that was created by the October 1968 rains has often been transformed by the frequent debris flows and rock avalanches and by the landslides of 1983, 1988, and 1989 (Starkel et al, 2000).

6.7.2. Factors of Slope failure

There is no doubt that the Ambootia landslide is a big complex form, accentuated by long lasting mass-movements, differentiated in space as well as in time. Its continuity and extension can be contributed to a number of factors like: i). geology, ii). hydrology, iii). climate and iv). anthropogenic interruptions.

6.7.2.1. Geology

The Ambootia region is built of gneisses , mica schist, chloritic schists etc. belonging to the Darjeeling group (Heim & Gansser, 1939). These rocks exhibit changeable bedding with inclinations of 30°-50° towards N - NNW, with a high density of deeply weathered joints. The pre-landslide slope consisted of 3 parts. The upper portion inclined at 15° - 25° was dismembered by shallow depressions and one deeper hollow (to the north). The middle flat part elevated at 900 to 950 m a.s.l. was occupied by colluvial fan inclined at l3° - 6°, towards W and NW built of 30 m thick silty-sandy deposits with gravel and stony layers. The lower portion formed steep valley sides dissected by a shallow side valley 30-100 m deep. The existing landslide is bare or covered by pioneer vegetation with several trees.

The region around the landslide zone is composed of thick silty and sandy regolith with depths varying between 1 - 5 m. The lower sections of the colluvial fan have loose deposits upto 30 m, including gravel and stony layers as well as silty-clay impermeable horizons.

6.7.2.2. Climatic factor

It has been observed that the most catastrophic landslide in the Darjeeling Himalaya, have been initiated by continuous, torrential downpours lasting 2 to 3 days, usually in the monsoon season. Between the 2nd and 5th day of October 1968, Ambootia recorded a rainfall of 890 mm, while the corresponding rainfall recorded in Darjeeling for the same time period was 600 mm. These heavy rains, continuously feeding the ground water reservoir, coupled with the positioning of Ambootia at an elevation of 900 m, in the valley crossing the first marginal ridges of the Himalaya, directly on the path of the incoming humid air masses from the Bay of Bengal, increased the susceptibility of the region and led to the initiation of the landslide.

6.7.2.3. Hydrological Factor

The Ambootia valley has a number of springs and perennial streams, with discharges varying from 0.2- 0.9 litre/sec. Various seepage points can be detected in the region. In 1991, Froelich and Starkel estimated that the regolith (mainly sandy silts with 10% clay content overlying deeply jointed rocks) could absorb 100 mm of rain in 3025 minutes. The daily rainfall exceeding 300 mm is a threshold value for the hydrologic capacity, leading to and intensifying the mass movements.

Hence, the intensive rainfall along the seepage points in the porous soils, underlain by weathered and deeply jointed rocks accelerate the process of saturating the slope materials faster. This leads to the low shearing strength, that results in the cohesion of the intervening sandy strata, thereby, providing an ideal environment for the sliding activities.

6.7.2.4. Edaphic factor

The edaphic factor plays a significant role in the development of the Ambootia landslide, since the infiltration rate varies remarkably on the basis of granulometric composition. In this region, the soil composition varies with the slope. At and around the landslide apex, the 50 cm thick layer of sandy silty soil includes 4 % of clay fraction. In the flat, lower areas, the percentage of clay rises to 12 %. The clay lenses diminish the infiltration rates remarkably (upto about 60%) in the lower sections of the landslide valley.

6.7.2.5. Anthropogenic interferences

Prior to 1968, the lower slope was covered with shrubby jungle and bamboo groves, while the middle and the upper slopes were occupied by the villages, orange orchards and tea gardens (Froehlich & Starkel, 1991). At present, the increasing population pressure has disturbed the previous landuse pattern by way of haphazard constructions, shifting cultivations and extensive deforestation, establishing a vicious cycle of degradation, torrential downpours, aggravate soil-erosion and landslides.

6.7.3. Evolution of the Ambootia landslide

The present day relief and variety of processes reflected in the changeable geomorphic features indicate a complex history of various parts of the landslide area and to various stages of evolution (Starkel,2000).

From the old topographic map (1930) of Survey of India, it can be deduced that the region was a shallow 'V' shaped valley. The continuous torrential downpour between the 2nd and 5th of October 1968, triggered off the massive debris flow and the entire mass in the order of 10-15 million m^3 was partially deposited on the Balason valley floor. A big debris-tongue, slumping over the former valley-head carved out a channel at least 30-60 m deep. Big rock falls on the right side and consequent slips on the left side resulted from the undercutting of the gully sides.

SEQUENTIAL CHANGE IN THE AMBOOTIA LANDSLIDE

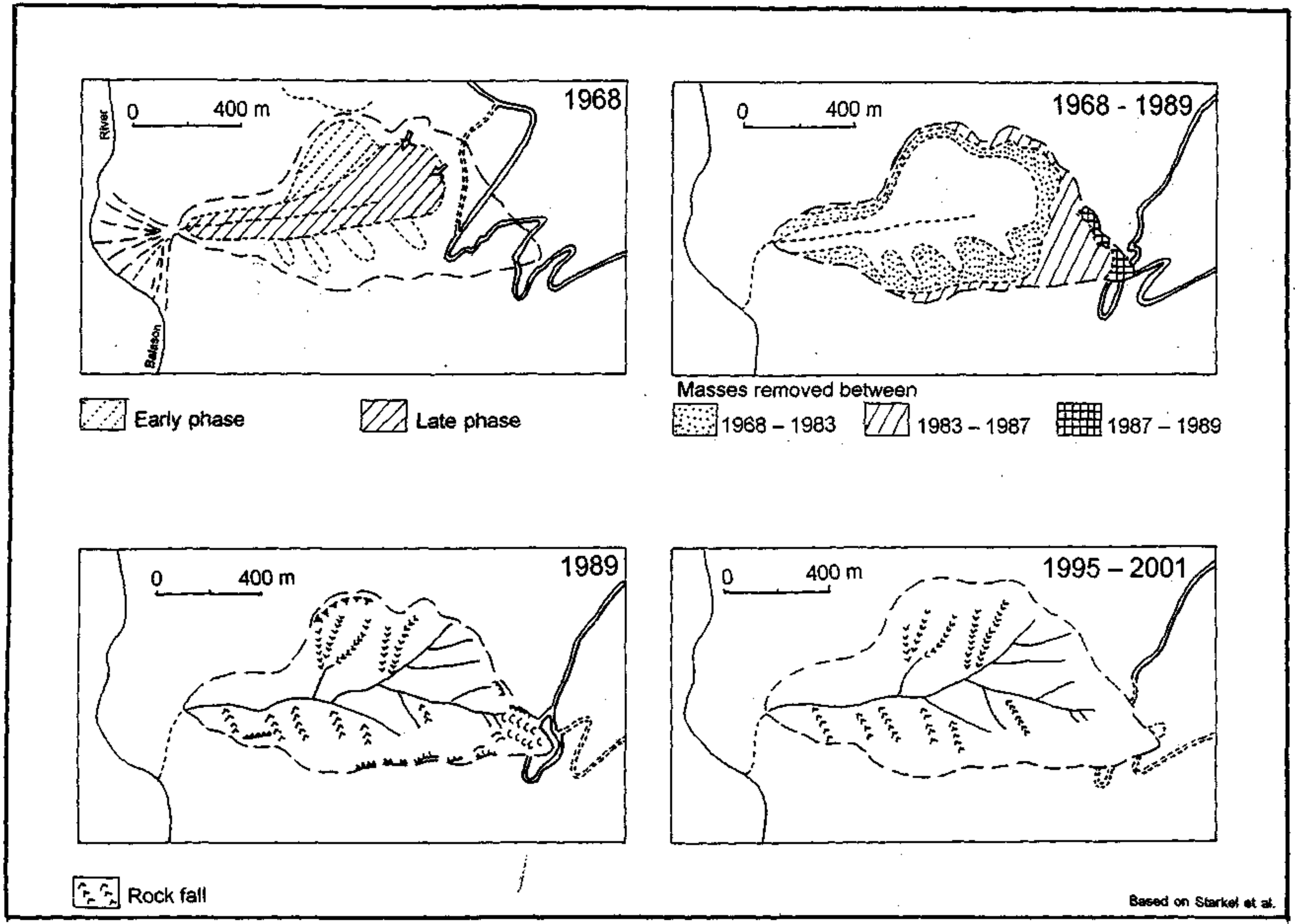

Figure 6.4

In the following years, the landslide expanded, owing to the deepening of the main channel and the retreat of the niches fed by the ground water.

Between 25th – 30th June 1983, many houses and roads were damaged due to acceleration in mass movement and deepening of the main channel, by the continuously lashing high rains, recording 400 mm. The colluvial fan in the Balason valley was built up again (figure 6.4).

Froehlich and Starkel (1991) established that the undermining of the upper part by chutes continued between 1983 and 1989, resulting in permanent damage to houses and to the main road leading up to Ambootia. Slumping and falling on the right side and sliding on the left side followed. A simultaneous modification of chutes and main canyon by the flowing water continued for at least 6 months, along with episodic debris flows.

For the period from 1990 to 1995, the rainfall characteristic however, does not show any distinct events. Hence, during this period, only a slight reactivation of the upper niche was registered, with slow sliding on the left consequent slope. However, in the summer of 1995, big rock falls on the right vertical wall were registered. Since 1995, the Ambootia landslide remain more or less in a dormant state. Observation made by the investigator in 2001 fails to identify any significant change in the landslide from that of 1995 as surveyed by Starkel et all. However, the lower and middle part shows significant revegetation.

6.7.4. Precautionary measures to be adopted

The existing landslide valley in Ambootia is the effect of specific combination of processes acting since 1968. The over saturation of the high elevated water reservoir in the thick colluvial and the high gradient that includes the linear erosion are the major factors that have created the Ambootia landslide. At present the geomorphic parameters of slopes have reached the stage of an unstable equilibrium. Each extreme rainfall may however cause some change in their morphology.

Between 1989 and 1996, about 80-90% of the landslide area was covered by relatively dense vegetation. Overgrazing and denudation practices among locals are being checked. Infiltration into the ground can be checked, by rebuilding the old canal into an impermeable one. The hydraulic parameters of such canal should take into account the overflow and bed load during heavy rains. Its steep gradient should be armored in some correctional dams to reduce the energy of the flowing water (Sastry & Viswananthan, 1982).

The very unstable equilibrium of slopes around the landslide zones are indicated by the cracks and grabens, the crushed buildings and the curved trunks of orange trees. Hence, all houses should be removed from this section and construction of new houses and roads in the zone should be forbidden. Any changes in the water mañagement should be made only after a careful study of the water flow, both on the surface and in the ground.

6.8. Preventive Measures for Stabilization of Landslides and Landslide Prone Areas

Examination of the geological set-up, process of slope evalution, precipitation, slope cover, landuse, soil characteristics and hydro-geomorphologic history shows that the study area has a high potential for landslide hazard. In the Balason basin, increases in pore water pressure and/or rise in piezometric head have often contributed to the so-called trigger mechanism for initiating a landslide. Potentially, most unstable hill slopes are also sensitive, either to the increase in the load, which they bear at the top, or to the decrease of support at the toe. To recognize which of the causative factors is in operation, can, in itself suggest the cure. Though the absolute prevention of such landslide is nearly impossible, good engineering practices can certainly minimize the hazards.

The methods for prevention and control should include:

- Slope regradation and removal of unstable slope materials,
- Excavation followed by maintenance of proper drainage,
- Construction of retaining walls and similar structures,
- Stabilization by sheets and sheet piles;

- Grouting and hardening of soil;
- Rock bolts and rock anchors;
- Jhora (rivulet) management
- Restriction of settlements and
- Afforestation.

The demarcation of stable areas and the differentiation of them from the unstable parts of the study area may be done on the basis of slope zone, which indirectly depicts the stability (table 6.4).

Table 6.4.

Slope, stability and recommended landuse for Balason basin

Slope	Stability class	Recommended landuse
>40°	Unstable area	Should be kept under nature's domain
30° – 40°	Less stable area	Very restricted use.
20° – 30°	Marginally stable area.	Restricted use with careful slope–water management.
10° – 20°	Considerably stable area.	Intensive use may be permitted with conservative measures
<10°	Stable area	Intensive use of considerable dimension.

6.9. Conclusion

In view of the ever-increasing problem of landslides in the study area, man must be made aware of the possible dangers that his is inviting, due to his careless dealing with the 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.

At the same time it is important to create a general awareness among the ever growing population, for a proper understanding of their environment. They should realize that its protection and maintenance, will, in the long run play a role in their own survival. Proper evaluation of the present land-use, afforestation programmes along with the use of alternative source of energy through mini-hydel projects by tapping perennial springs may prevent cutting down of more trees. The construction of high rises should be immediately stopped, along with the banning of polythene carry bags, which are being dumped along with garbage, choking drains and restricting free drainage of water which eventually cause the landslides. It is also necessary that a scientific garbage collection method be evolved, so that the bio-degradable and non-degradable wastes are separated, with the later being sent for recycling. Dumping the wastes into the jhoras is a major cause of concern in many areas. It is only through proper awareness and proper implementation of remedial measures that both property and life can be saved in the coming future.

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CHAPTER 7

FORMS AND PROCESSES OF THE RIVER BALASON

7.1. Introduction

The river Balason, a tributary of the mighty river Ganga, originates from the Lepchajagat, near Sukhiapokhri (Latitude 27°3'55" N, Longitude 88°14'12" E) at an elevation of 2416 meter and meanders conspicuously through the lower Darjeeling Himalaya and the North Bengal Plain, for a distance of about 46.6 km and joins the river Mahananda near Siliguri (Latitude 26°48'37" N, Longitude 88°18'30" E) at an elevation of 116 metre. The river is noteworthy for its erosional and depositional havocs.

The upper part of the Balason catchment has mostly been deforested and the clearings of the steep slopes have been used for the extension of settlements, agriculture, tea plantation and communication, disrupting the overall ecological balance. As a result, during heavy and concentrated rainfall, innumerable landslides are caused transporting huge amount of sediments to the river. Most of these slides have never been treated scientifically with proper protective measures and as such these are in habit of expanding their territories during monsoon, adding more and more silt to the parent river, the Balason which is incapable of transporting the loads efficiently under the existing hydrological conditions, specially along its lower reaches (Sarkar 1989 & 1997).

During summer, the observed increment of the size of bars and shoals downstream to Matigara proves such a contention. In order to avoid such numerous islands in midst of the channel, the river in its lower reaches thus, attains the significant physical characteristics of braiding, which may be attributed to both incompetence and incapacity of the river (photo 7.1). The river, thus, can transport neither the total amount of debris not the size of debris that is supplied to it as bed load (photo 7.2 & 7.3). As a result, the bed of the river is rising at some sections in the plain, resulting in the lessening of cross sectional areas. The

Photo 7.1. River Balason at Dudhia

Photo 7.2. Bed materials in River Balason

Photo 7.3. Bed materials in River Balason

INDEX MAP FOR HYDROLOGICAL STUDY OF THE RIVER

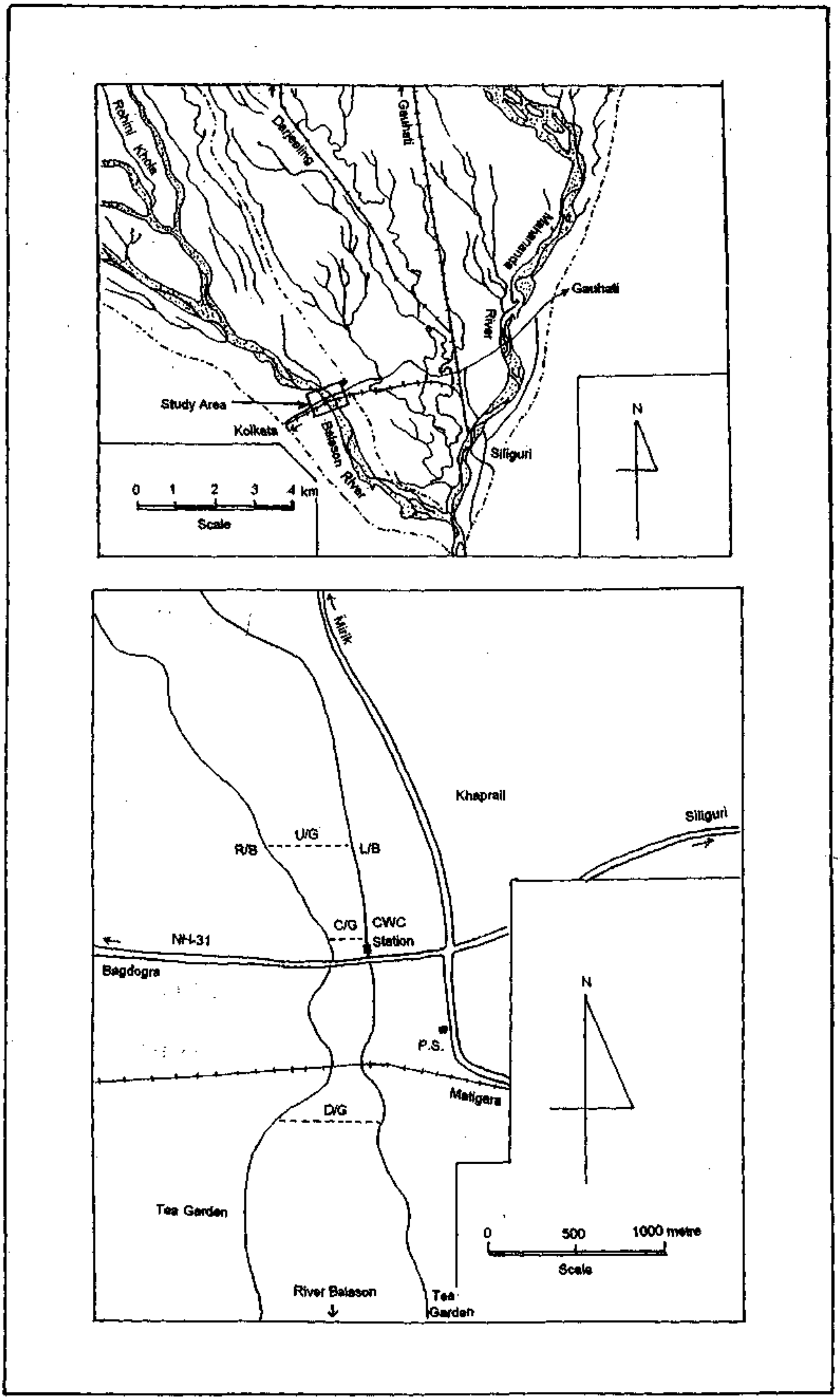

Figure 7.1.

shrinking river channel often fails to contain unusual monsoon discharge and thereby, allow water to spill, causing devastating flood and bank erosion.

Being alive to the commanding role of the river Balason in regulating the overall economy of the region, the present investigator has outlined the results of this hydrological investigations along the lower course of the river Balason, near Matigara (figure 7.1). The ultimate aim is to depict the sequential changes of the river channel in combating with the increasing loads supplied form the upper course of the river.

7.2. Study of the Cross Section:

The shape of the cross section of a river channel at any location is a function of the flow, the quantity and character of the sediment in movement through the section, and the character of composition of the materials making up the bed and banks of the channel (Leopold, Wolman & Miller, 1964). Detailed survey of cross-sections during both monsoon and non-monsoon periods for the four consecutive years from 1998 to 2001 was carried out by the investigator to study the changing nature of the channel bed with special reference to the impact of huge flood water on the channel form. Three different sites in the lower course of the river Balason were chosen:

a) the central station gauge (C/G) located 100 metre north of NH 31 bridge across the river Balason, near Matigara
b) the up-stream gauge (U/G) 500 m. north of the central station gauge and
c) the down-stream gauge (D/G) 700 m south of the central station gauge.

The study has been carried out twice a year (pre-monsoon and post-monsoon) from 1998 to 2001. The data thus, collected have been analyzed and diagrammatically represented in (figure 7.2).

7.2.1. Characterisitcs of the cross profiles along the studied sections for the years 1998 -2001:

The cross profiles along the lower course of the river Balason is typical braiding type (figures 7.2.a., 7.2.b., and 7.2.c). It is characterized by a number of water-covered channels that are separated by sand bars, mud-flats or timbered

CROSS SECTIONS ACROSS THE RIVER BALASON AT U/G (1998 – 2001)

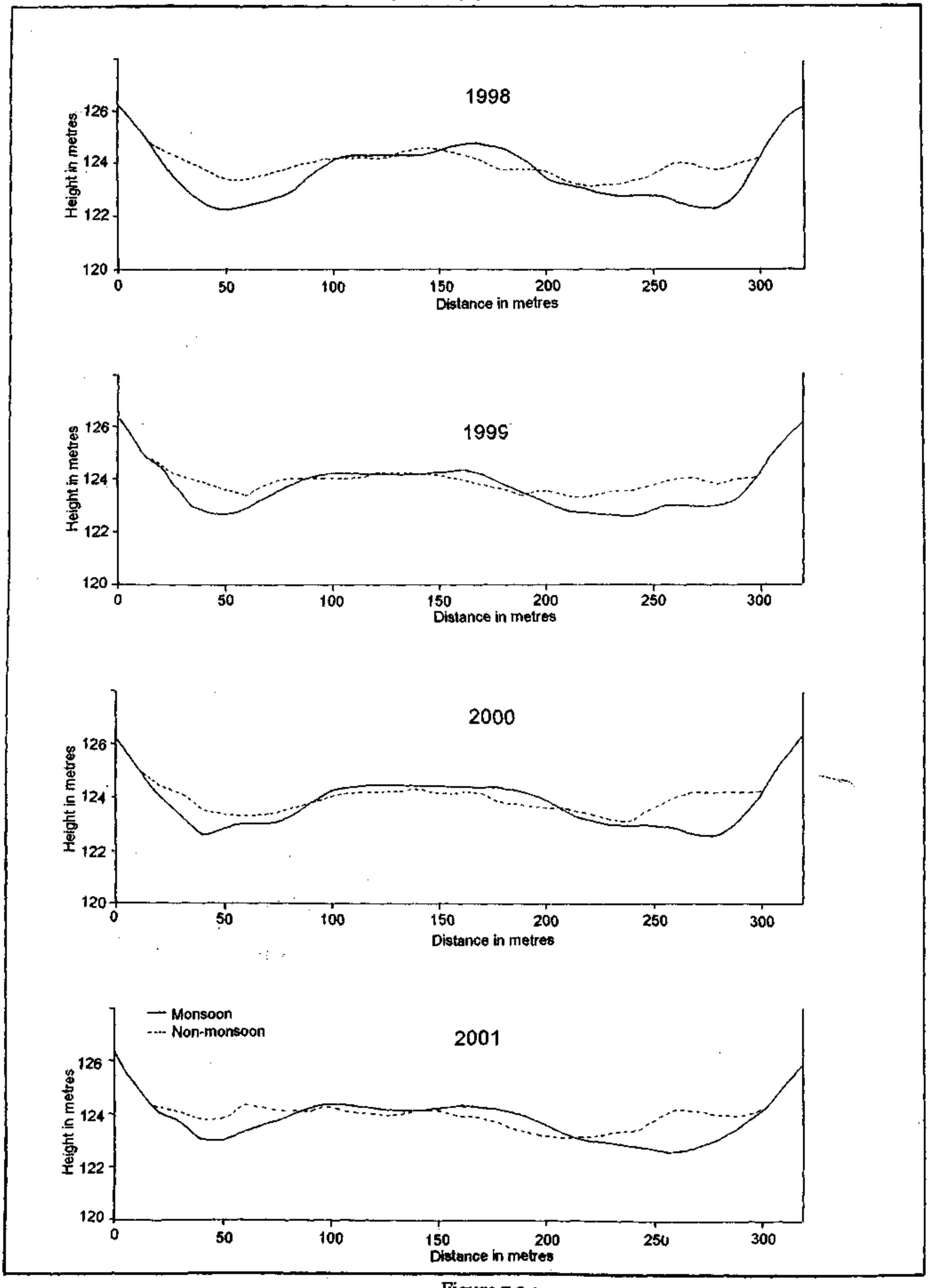

Figure 7.2.a.

CROSS SECTIONS ACROSS THE RIVER BALASON AT C/G (1998 – 2001)

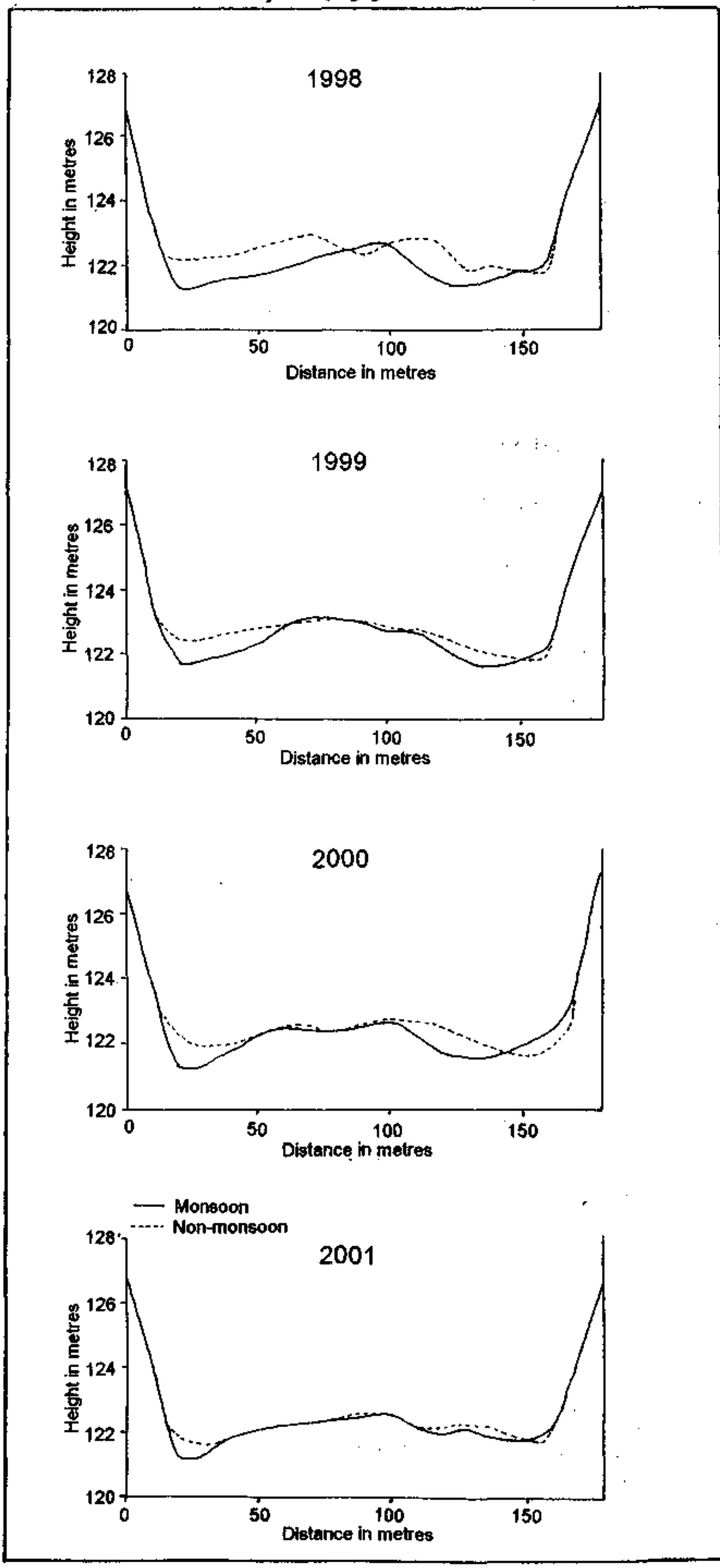

Figure 7.2.b.

CROSS SECTIONS ACROSS THE RIVER BALASON AT D/G (1998 – 2001)

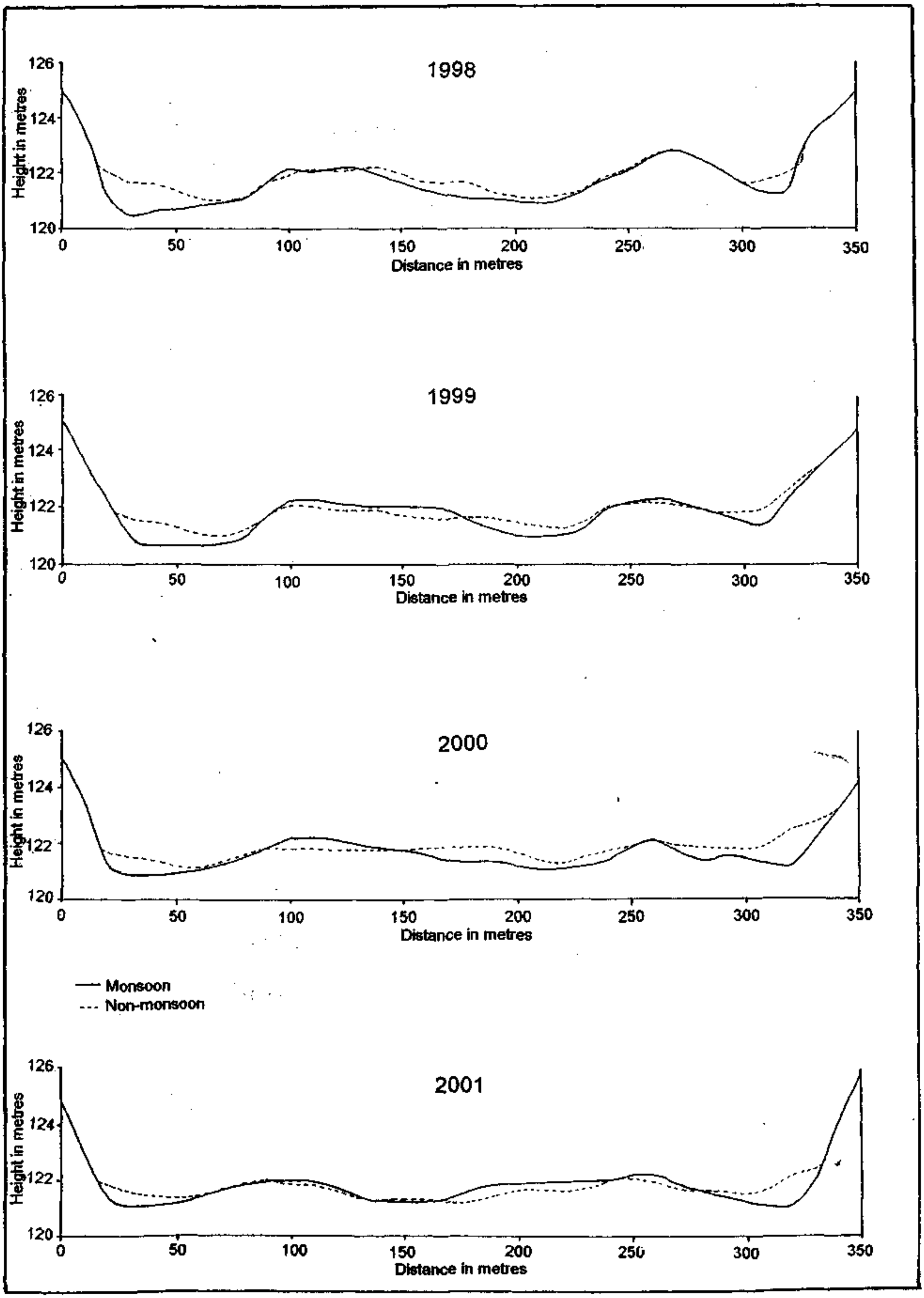

Figure 7.2.c.

islands. These deflect the water currents against the side walls of the channels leading to erosion. The erosional effects can be seen in the form of the bank wall caving, eliminating the possibility of a convex slip-off slope side often present in meandering channel. The widths of the cross profiles (maximum 263.21 and minimum 15.99) meter are quite conspicuous and these increase away from the hills as the water spreads with the fall of gradient of the stream as it passes from upland to the lowland (table 7.1). A different scenario is observed in the cross section at *central station gauge where artificial bank protection to protect the* bridge across the river has obstructed the natural process of channel formation. The depth of the channel is also conspicuous.

Table 7.1.

Hydrological parameters of the different cross section from 1998 – 2001 of the river Balason near Matigara.

Date	Cross sectional area (sq. metre)	Wetted perimeter (in metre)	Hydraulic radii (in metre)
05.09.1998	447.921	263.209	1.792
01.12.1998	12.764	38.916	0.418
11.08.1999	173.975	211.875	0.768
15.12.1999	10.946	26.977	0.326
13.09.2000	199.207	211.954	0.941
27.12.2000	17.631	44.105	0.351
05.08.2001	119.065	204.923	0.601
30.12.2001	9.663	28.761	0.263

Up Stream Gauge (U/G)

Date	Cross sectional area (sq. metre)	Wetted perimeter (in metre)	Hydraulic radii (in metre)
05.09.1998	358.420	167.853	2.387
01.12.1998	11.896	45.678	0.260
11.08.1999	113.587	155.431	0.799
15.12.1999	8.956	29.451	0.306
13.09.2000	163.739	150.623	1.033
27.12.2000	12.169	33.942	0.321
05.08.2001	83.462	148.005	0.667
30.12.2001	7.823	15.993	0.401

Central Station Gauge (C/G)

Date	Cross sectional area (sq. metre)	Wetted perimeter (in metre)	Hydraulic radii (in metre)
05.09.1998	498.256	254.998	1.890
01.12.1998	12.763	51.121	0.251
11.08.1999	186.662	224.978	0.791
15.12.1999	10.986	37.661	0.273
13.09.2000	204.831	219.542	0.912
27.12.2000	18.963	47.991	0.409
05.08.2001	127.305	211.945	0.576
30.12.2001	9.998	32.967	0.270

Down Stream Gauge (D/G) Based on field survey.

(maximum 2.387and minimum 0.263 meter) and that often changes due to the instability of the channel way and bars under condition of highly variable discharge of the river. The deposition of the bars increases the velocity as it narrows the channel and acts as an effective hydraulic device. Furthermore, the deposition serves to decrease the depth of flow increasing roughness and turbulence until the bar is built up above the water level (Ghatwar, 1986, Sarkar, 1989). As the bed materials are not only too coarse but also too much to be moved, the river channel under study is naturally attributed with both incompetence and incapacity.

7.3. Progressive Changes of Hydrological Parameters:

It is evident that sequential changes of cross sections as well as their related parameters have been taken place in the Balason channel. It is also noticed that the nature of changes in all the sections is almost the same, and the relationship among the hydrologic parameters of a particular gauge station would represent the similar relationship for other gauge stations. The nature of progressive change in the various hydrological parameters are tabulated in the table 7.1 and diagrammetrically represented in the figures nos. 7.3, 7.4, 7.5 and 7.6. The details of the analysis is given below.

7.3.1. Progressive change in the cross sectional area

To study the progressive changes in the cross-sectional area of the river Balason, the cross-sections have been constructed twice (monsoon and non-monsoon months) for the years 1998 to 2001 at three different stations, which have also been superimposed. The cross-sectional areas was then worked out from the two sets of cross-section and tabulated for comparison (table 7.1). The following conclusions could be arrived at about the changes in the cross-section areas:

i) It is evident that the changes in the cross-section areas between any two consecutive years do occur due to the process of scouring and silting. Such changes not only occur at a particular section point, but from station to station that leads to the formation of pools and riffles along the long profile of the river under study .

PROGRESSIVE CHANGE IN THE CROSS SECTIONAL AREA OF THE BALASON RIVER

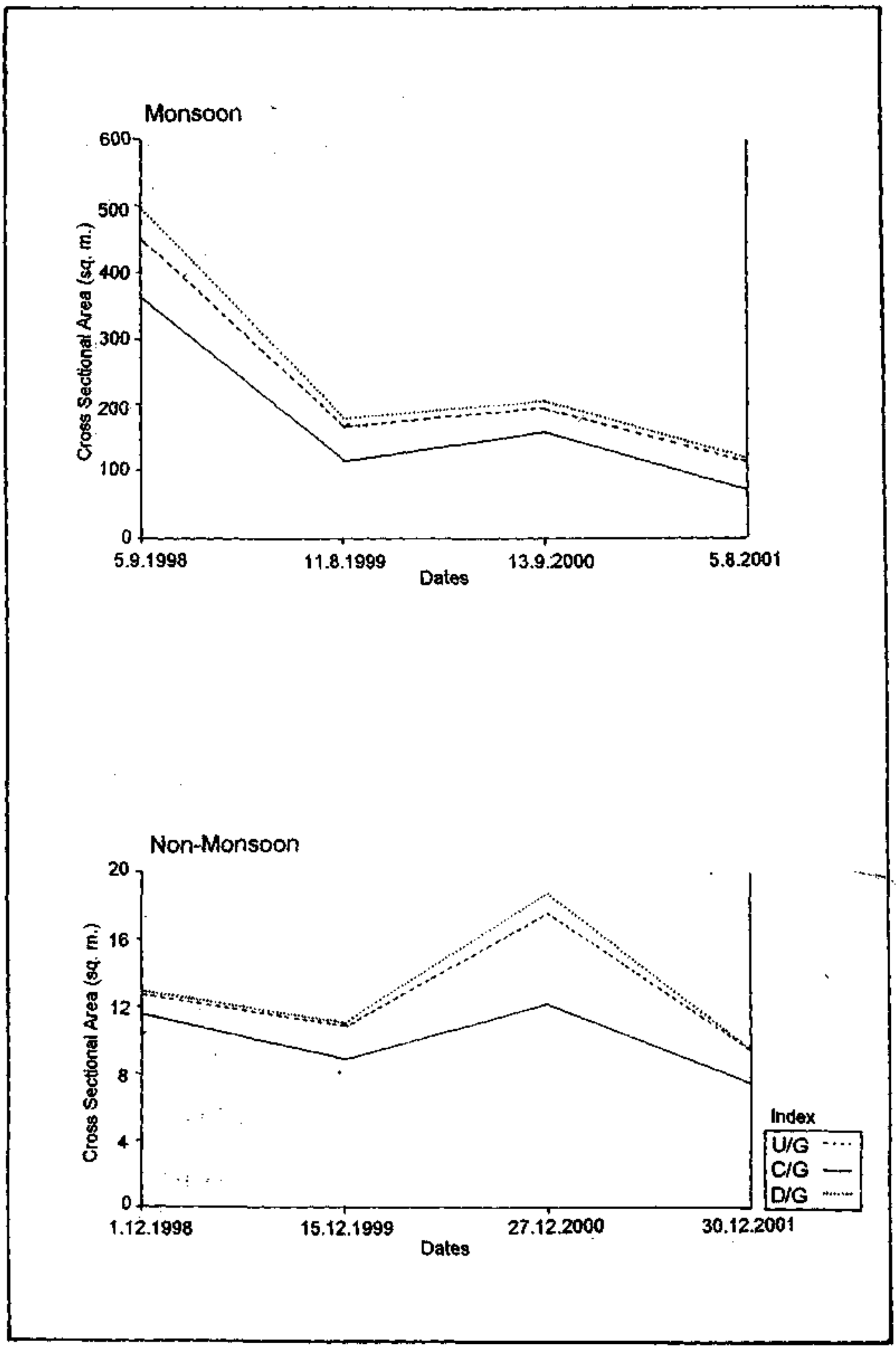

Figure 7.3

ii) The changes in the cross-section area for any particular section-point usually occur alternatively and in some sections three years might be elapsed before the process is completely reversed.

iii) No definite conclusion could be drawn about the progressive improvement or deterioration of the channel during the studied period. The changes are small and the reversal of the processes (silting alternate with scouring) in the consecutive year nullified its effect. This indicates the river has a remarkable adjusting capacity to its varying discharges and loads. The 1998 flood affected the channel by doubling the cross-sectional areas that was readjusted the following year. In 2001 the cross-sectional areas had been drastically reduced which may be due to the reduction of discharge from the upland and the supply of loads that reduced the channel conspicuously.

7.3.2 Progressive changes in the wetted perimeter along the cross section:

The wetted perimeters of various cross-sections for the years 1998 – 2001 have been tabulated (table 7.1) and diagrammetrically represented in the figure 7.4. The following conclusions have been made:

i. At all the sections, the wetted perimeters do not change in the same manner or to the same extent from year to year.

ii. At any particular section point the change in wetted perimeter from year to year is not so remarkable and three years might elapse before the process is completely reversed.

iii. From the comparative study between the up-stream gauge (U/G) and down stream gauge (D/G) it is seen that there is an increasing tendency for the wetted perimeters from the up stream to the down stream (excepting the flood year of 1998).

iv. No definite law or trend in variation of the wetted perimeters from year to year could be made except that at some sections changes do occur and these soon get readjusted as the river tries its best to get back its original position by means of lateral or vertical erosion and deposition.

PROGRESSIVE CHANGES IN THE WETTED PERIMETER OF THE BALASON RIVER

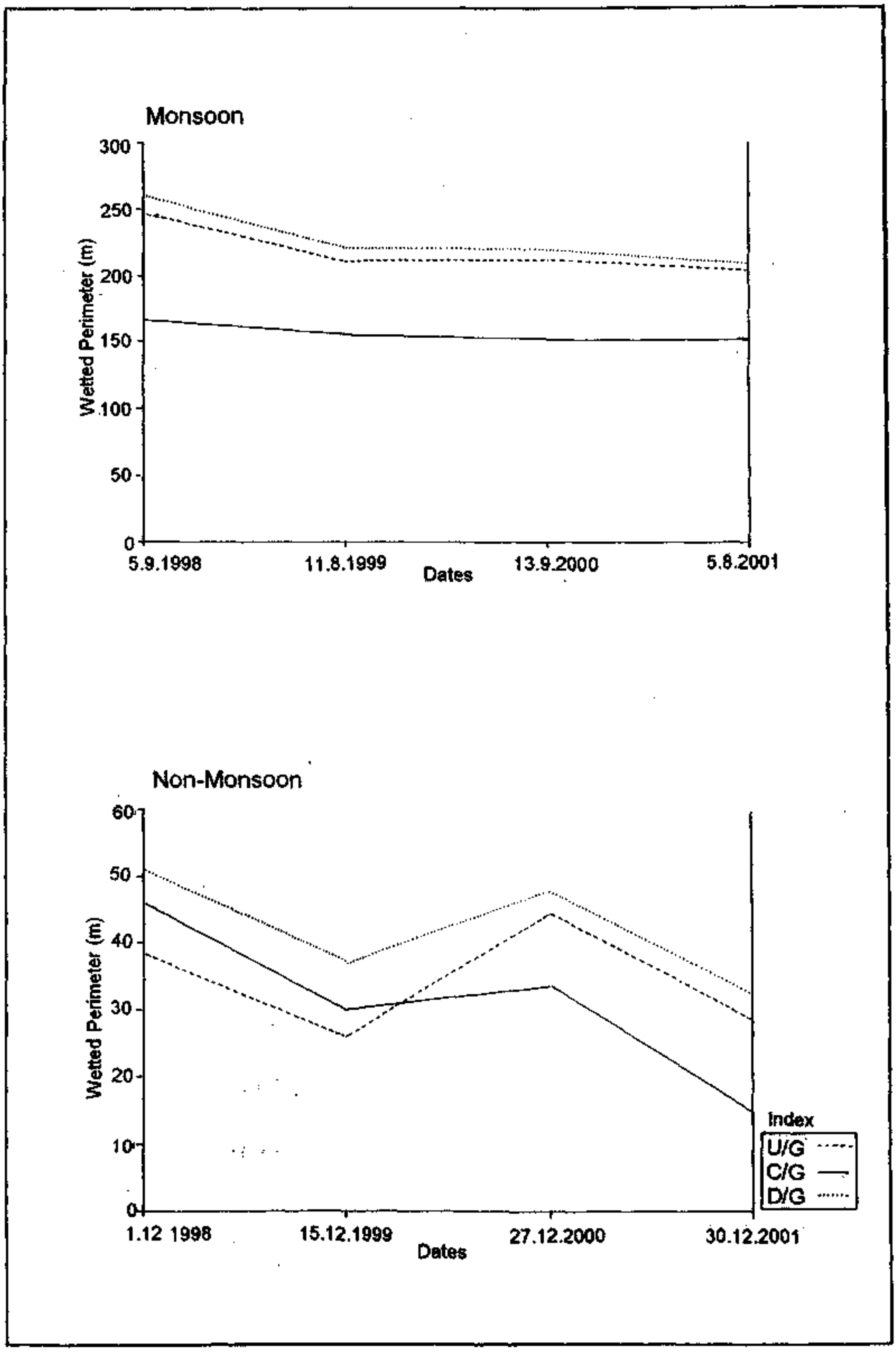

Figure 7.4

7.3.3 Progressive changes in hydraulic radii:

Table 71. and figure 7.5 show the hydraulic radii of the various cross sections for the years 1998 to 2001. The following conclusions may be made regarding the progressive changes in the hydraulic radii of studied section of the river:

i. Hydraulic radii in the studied sections do not change in the same way and to the same extent from year to year.
ii. There appear to be a few section-points (non-monsoon) with very little changes in hydraulic radii, compared to the other section points (monsoon).
iii. The hydraulic radius of a particular section tends to change alternately like most of the other hydrological parameters.
iv. The high value of hydraulic radius of the monsoon period of 1998 (2.387) is due to flooding and the remarkably low value of 2001 (0.667) is probably due to decrease in discharge.

7.3.4. Progressive changes in channel depth along the studied sections:

The study of progressive changes in the channel depth (table 7.1 and figure 7.6) reveals the following interesting points:

i. At all the sections, the depth of the channel does not change in the same way or to the same extent from year to year.
ii. At any particular section-point the change in depth from year to year usually occur alternately, due to the alternation of the process of channel scouring and silting.
iii. There is a tendency for the depth of the channel to decrease from upstream to down stream.
iv. No definite law or trend in variation of the channel depth from station to station and from year to year could be made due to insufficient data base. But, it is found that at some sections changes do occur and these soon get readjusted as the river try its level best to get back to its original position by means of either erosion or deposition.

PROGRESSIVE CHANGES IN THE HYDRAULIC RADII OF THE BALASON RIVER

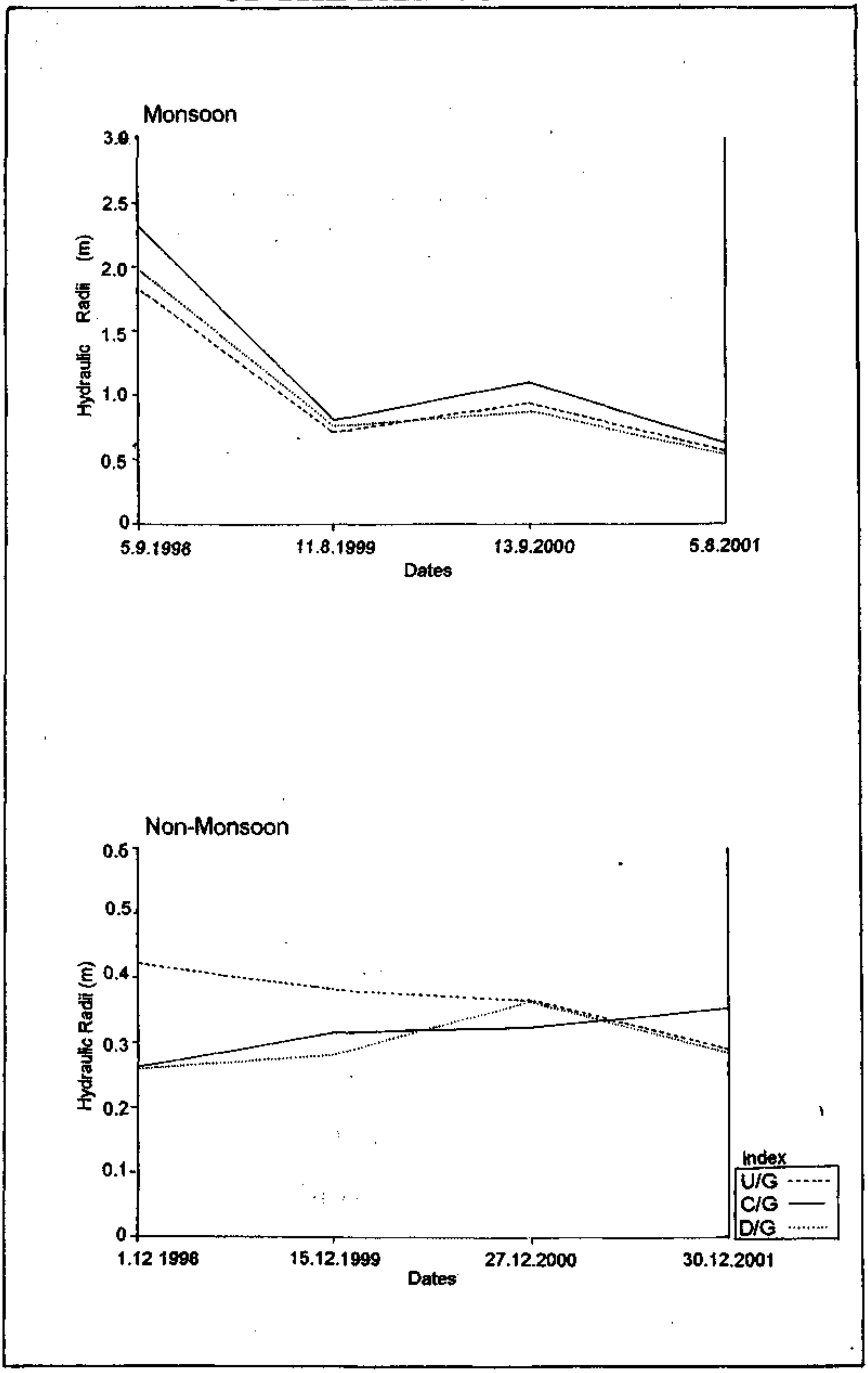

Figure 7.5

PROGRESSIVE CHANGE IN CHANNEL DEPTH

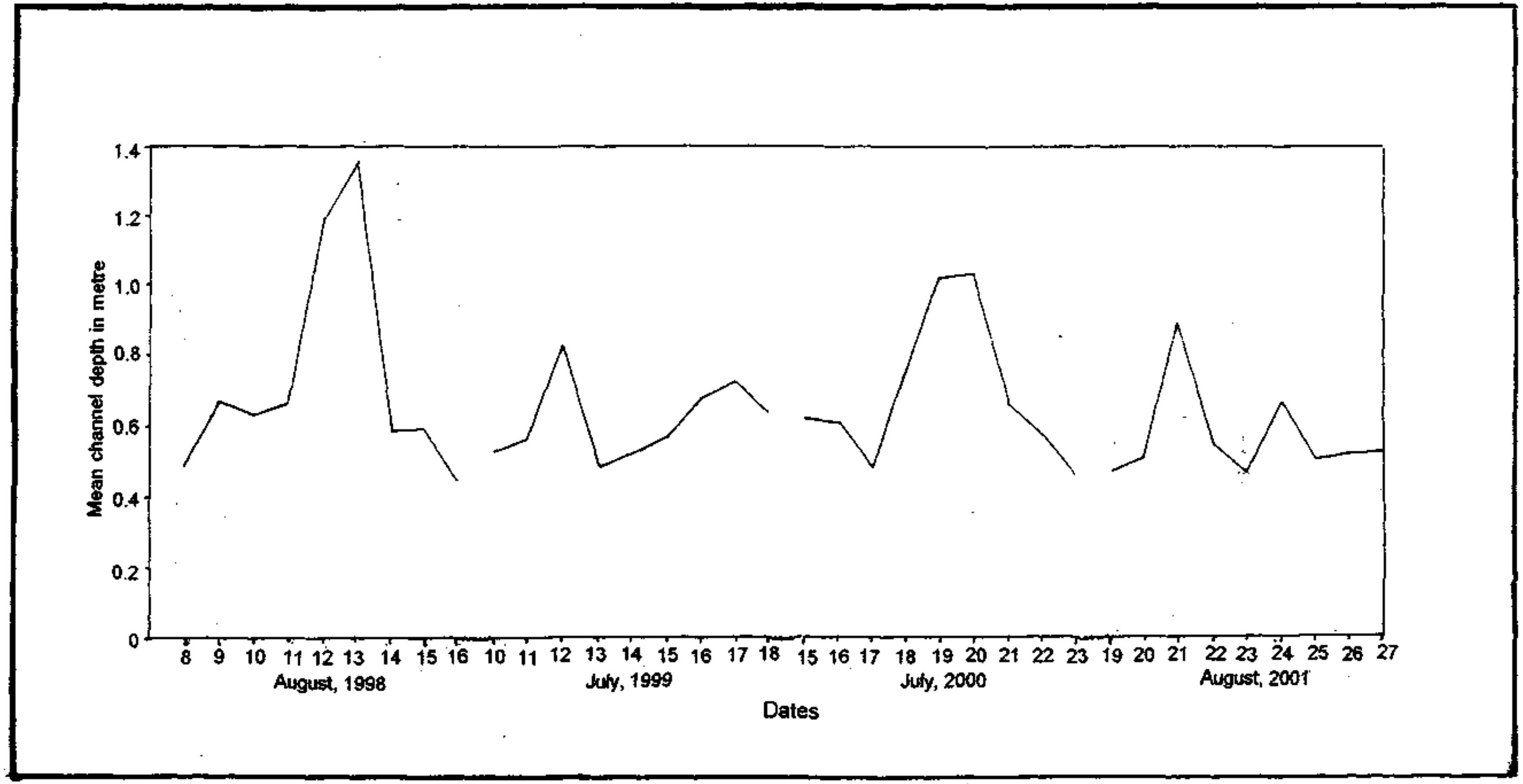

Figure 7.6

Table 7.2

Mean channel depth in metres*

Date	Mean channel depth (m)	Date	Mean channel depth (m)	Date	Mean channel depth (m)	Date	Mean channel depth (m)
8.8.1998	0.491	10.7.1999	0.527	15.7.2000	0.621	19.8.2001	0.466
9.8.1998	0.671	11.7.1999	0.576	16.7.2000	0.609	20.8.2001	0.506
10.8.1998	0.625	12.7.1999	0.825	17.7.2000	0.473	21.8.2001	0.879
11.8.1998	0.653	13.7.1999	0.493	18.7.2000	0.757	22.8.2001	0.553
12.8.1998	1.193	14.7.1999	0.524	19.7.2000	1.018	23.8.2001	0.470
13.8.1998	1.374	15.7.1999	0.569	20.7.2000	1.023	24.8.2001	0.675
14.8.1998	0.583	16.7.1999	0.684	21.7.2000	0.649	25.8.2001	0.503
15.8.1998	0.596	17.7.1999	0.726	22.7.2000	0.578	26.8.2001	0.514
16.8.1998	0.444	18.7.1999	0.637	23.7.2000	0.456	27.8.2001	0.517

*Mean value of 3 gauging points

7.3. Analysis of Hydraulic Parameters:

The Central Water Commission (CWC) maintains a gauging station in the river Balason on the NH 31 bridge at Matigara. Data on various hydrological parameters have been gathered from the site by the investigator from 1998-2001. An attempt has been made to analyze the data in the following section.

7.3.1 Mean monthly discharge

The mean monthly discharge of four consecutive years has been tabulated in table 7.3 and diagrammatically represented in four hydrographs, one each for the years from 1998 to 2001 (figure 7.7).

The hydrographs thus drawn reveal some striking phenomena relating to the hydrology of the river. It has been apparent that on an average 90% of the total volume of water is carried through the river during the monsoon months (June to October), and this again concentrates within some distinctly identifiable high intensity discharge periods. The total runoff estimated to be 1343.715 m.m^3 in 1998, 671.068 m.m^3 in 1999, 849.692 m.m^3 in 2000 and 655.077 m.m^3 in 2001. Thus the variation has been estimated to be +13.18% in 1998, -5.93% in 1999, -0.86% in 2000 and -6.39% in 2001 from the normal average of 879.89 m.m^3 (calculated based on the four recorded years).

PROGRESSIVE HYDROGRAPHS OF RIVER BALASON AT MATIGARA (1998 – 2001)

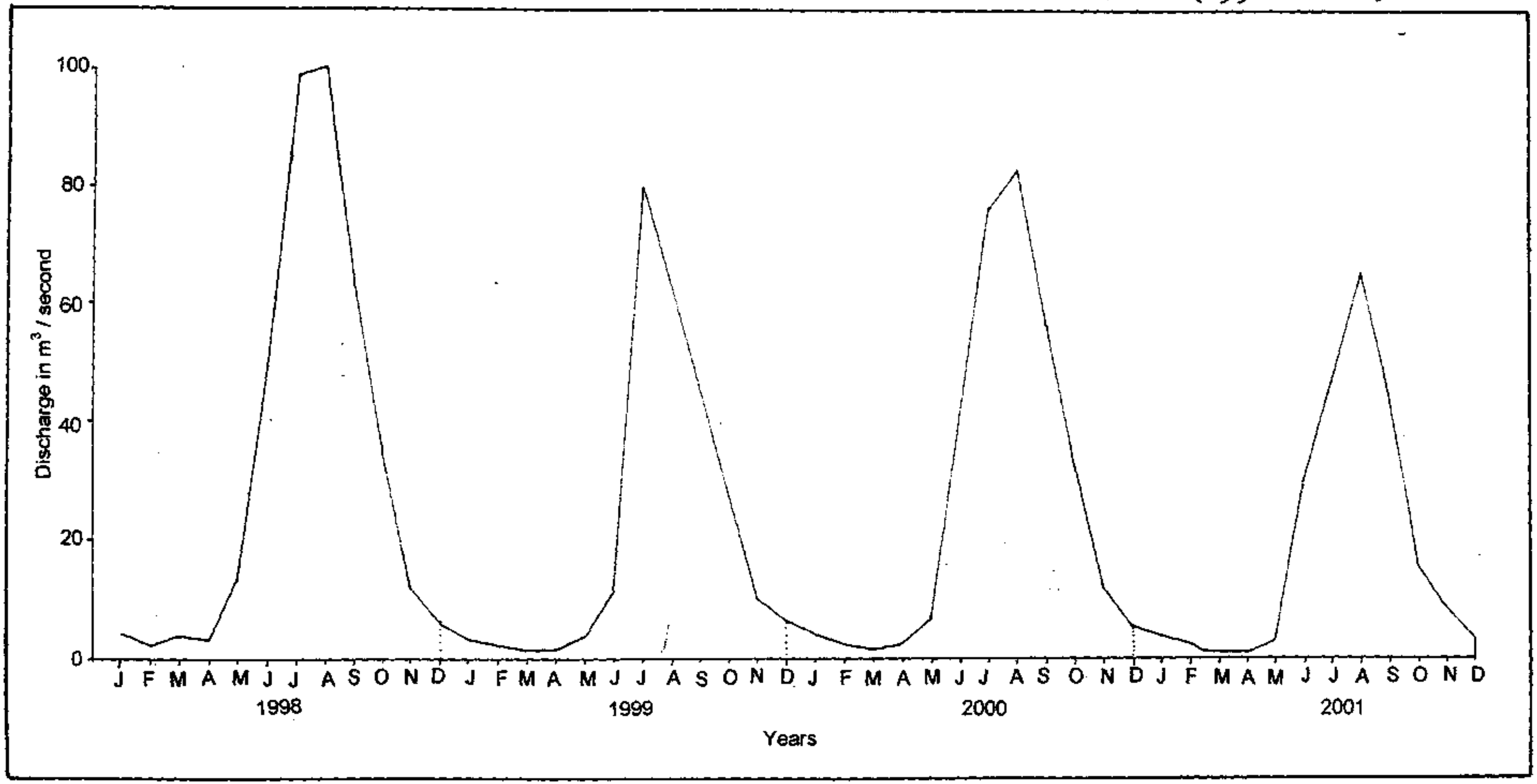

Figure 7.7

The volume of water through the river during the non monsoon months (November to April) remain more a less same for all four years but their contribution to the total volume of water varies from year to year depending on the intensity of monsoonal rainfall. Thus, in 1998 the non-monsoon months contributed only 5.37% (75.173m.m^3), in 1999 it amounted to 10.27% (68.896 m.m^3), in 2000 it contributed 8.62% (73.215 m.m^3) and in 2001 it contributed 8.55% (56.019m.m^3) to the total annual volume. Thus, the volume of water in non-monsoon months is inversely related to the total annual volume.

The hydrographs also reveal some peaks showing high intensity of discharge during the monsoon months which often invite devastating floods along the lower reaches of the river. These discharge peaks are concentrated within a few well defined periods. It has been found that phases of high discharge during the monsoon months, directly related to the nature of monsoon rainfall pattern which is generally associated with a number of successive rain storms. Moreover, the sudden increment in discharge during the late monsoon period often invites devastating flood along the lower reaches of the river.

7.3.1.1. Progressive changes in discharge:

The progressive changes in discharge of the river Balason during the period 1998-2001 has been assessed based on data given in table 7.2. The following conclusions can be drawn out of it :

i. The variation of discharge of the river in different years is due to the fluctuations of rainfall in the catchment area.
ii. There is a wide difference between the pre-monsoon and post-monsoon discharge.
iii. The variation in discharge can never be categorically proved as the deteriorating condition of one year is readily compensated in the very next year.
iv. The range of variation between the highest and lowest discharges among the four years (1998 – 2001) is too high, particularly in the monsoon season. It is because of the high intensity rainfall in the year

1998 the peak flood discharge has suddenly gone up to 940.3 m^3/sec causing devastating flood in the lower section of the basin.

Table 7.3

Mean monthly discharge of the river Balason at NH 31 bridge, Matigara.

Months	Mean discharge in cubic metre per second				
	1998	1999	2000	2001	Mean
January	5.004	3.312	4.053	4.132	4.125
February	3.069	3.01	3.107	2.997	3.046
March	3.789	2.013	1.639	1.265	2.177
April	4.013	1.685	3.015	1.798	2.628
May	15.002	4.103	6.998	4.019	7.531
June	50.025	13.157	34.872	29.367	31.855
July	99.913	81.189	75.973	45.811	75.722
August	100.498	61.476	82.987	64.96	77.480
September	61.956	52.989	56.521	44.338	53.951
October	36.143	23.476	33.141	17.431	27.548
November	12.247	10.134	13.068	10.012	11.365
December	6.098	7.069	6.113	5.101	6.095
Mean Annual	33.146	21.968	26.791	19.269	25.294

Based on the records of the Central Water Commission

7.3.2. Suspended load analysis

The monthly suspended sediment load of the river Balason for the period from 1998 to 2001 has been tabulated in the table 7.4 and diagrammetrically represented in the figure 7.8. The following grain size classification has been applied for the suspended load analysis:

a) Coarse (diameter 0.20 mm to 2.0mm)
b) Medium (diameter 0.075 mm to 0.2 mm) and
c) Fine (diameter below 0.075 mm)

The total volume of suspended sediment of the river during 1998 (Fig. 7.8a) has been estimated to be 611,787 metric ton of which 23.71% (145,059 metric ton) is coarse sediment, 31.74% (194,182 metric ton) is medium sediment and 44.54%

Table 7.4

Monthly suspended sediment load of the river Balason at NH-31 bridge, Matigara *

Months	1998 (in metric ton)				1999 (in metric ton)			
	Coarse	Medium	Fine	Total	Coarse	Medium	Fine	Total
January	158	8	9	175	11	13	27	51
February	98	5	4	107	4	4	9	17
March	184	50	141	375	1	1	2	4
April	19	40	20	79	32	39	79	150
May	513	2238	2388	5139	88	108	217	413
June	17382	16070	39343	72795	2304	2838	5718	10860
July	37841	66585	63644	168070	23478	28924	58275	110677
August	49482	20863	63116	133461	10475	12904	25999	49378
September	24053	72347	81344	177744	11071	13640	27481	52192
October	14421	14840	21123	50384	1557	1918	3864	7339
November	672	1065	1226	2963	590	726	1463	2779
December	235	70	190	495	390	481	969	1840
Total	145057	194181	272548	611787	49999	61596	124103	235700

Months	2000 (in metric ton)				2001 (in metric ton)			
	Coarse	Medium	Fine	Total	Coarse	Medium	Fine	Total
January	93	42	39	174	14	12	29	55
February	41	18	18	77	9	8	20	37
March	82	37	79	198	5	5	11	21
April	38	24	59	121	3	3	7	13
May	250	1031	1937	3218	36	32	76	144
June	42103	34858	117148	194109	2940	2616	6228	11784
July	58492	42452	124651	225595	10843	9646	22967	43456
August	19136	15112	31759	66007	19640	17473	41601	78718
September	11502	8594	10467	30563	16874	15012	35742	67629
October	16747	12272	24447	53466	228	203	483	914
November	1326	638	14	1978	148	132	313	593
December	206	77	36	319	28	25	60	113
Total	150016	115155	310654	575825	50769	45167	107537	203472

* Based on the data of gram / litre concentration from C.W.C. and sampling by the investigator

(272,548 metric ton) is fine sediment. It is interesting to note that 98.96% (605,416 metric ton) of the total suspended load has been discharged during the monsoon months (June to October). September experienced the highest amount of suspended load which accounted for 29.05% of the total (177744 metric ton) in 1998.The amount of suspended load was also high in July that accounted for 27.47% (168069 metric ton) during the same year.

SUSPENDED SEDIMENT LOAD OF THE RIVER BALASON AT MATIGARA (JUNE – OCTOBER) FROM 1998 – 2001

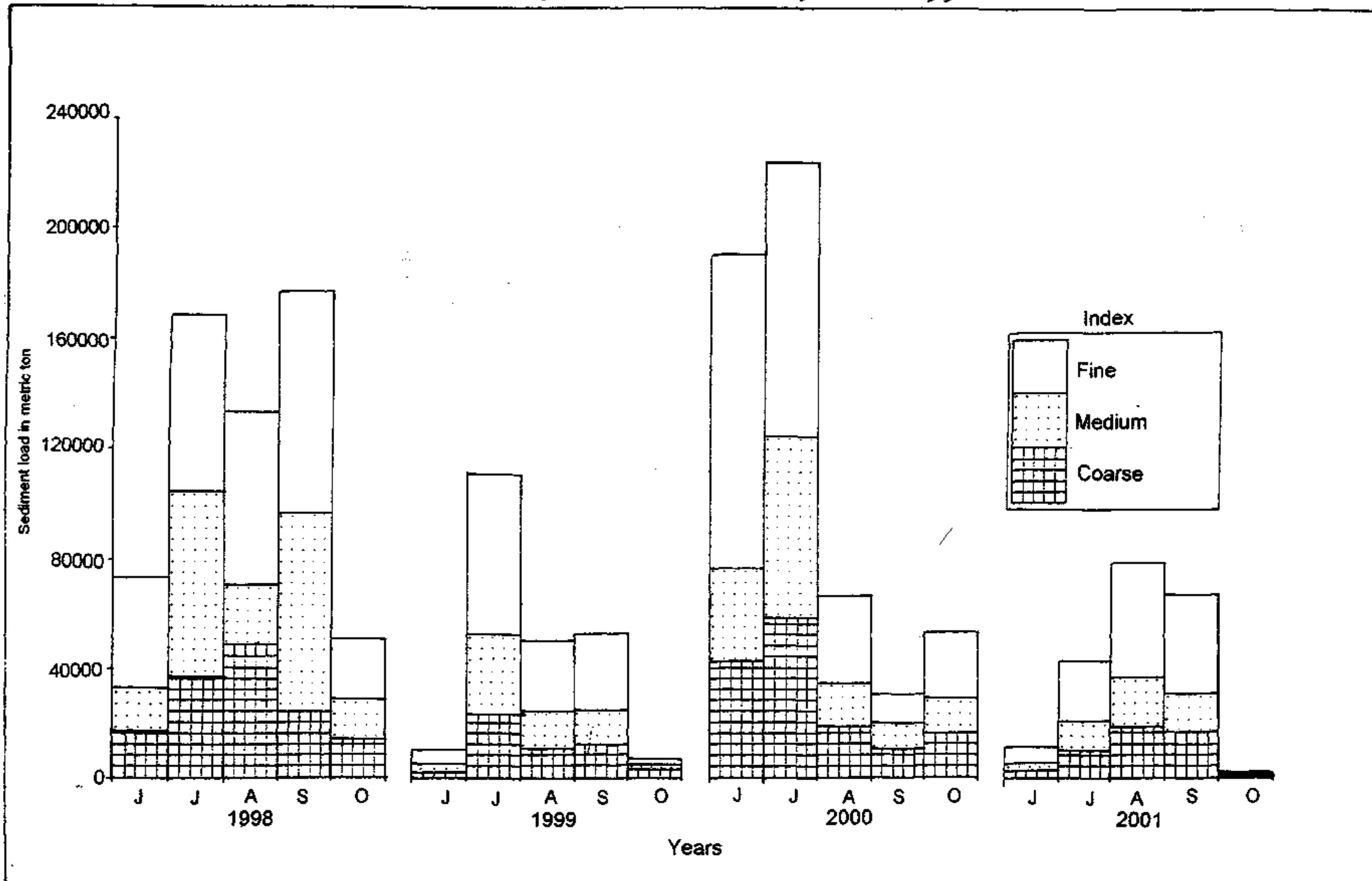

Figure 7.8

The total volume of suspended load in the river during 1999 (figure 7.8) has been estimated to be 235700 metric ton of which 21.21% (49999 metric ton) is coarse sediment, 26.14% (61598 metric ton) was medium sediment and the remaining 52.65 % (124103 metric ton) was fine sediment. About 98.95% (233225 metric ton) of the total suspended sediment was discharged during the monsoon months. Unlike the previous year July experienced the highest suspended load that amounted to 46.96% of the total discharge (110677 metric ton).

The total volume of suspended sediment of the river during 2000 (figure 7.8) has been estimated to be 575828 metric ton of which 26.5% (150017 metric ton) is coarse sediment, 19.99% (115157 metric ton) is medium sediment and 53.95% (310655 metric ton) is fine sediment. It is interesting to note that 99.29% (571719 metric ton) of the total suspended load has been discharged during the monsoon months (June to October). Like the previous year the highest discharge of suspended load which accounted for 39.185% of the total (225595 metric ton) was recorded in July.

The total volume of suspended load the river during 2001 (figure 7.8) has been estimated to be 203475 metric ton of which 24.95% (50769 tonne) is coarse sediment, 22.20% (45167metric ton) was medium sediment and the remaining 52.85% (107539 metric ton) was fine sediment. About 99.52% (202498 metric ton) of the total suspended sediment was discharged during the monsoon months. Unlike the previous year August experienced the highest suspended load that amounted to 20.45% of the total discharge (41601metric ton). From the above observation it can thus be concluded that the discharge of the river Balason remains high during the monsoon months that account for as much as 99 % of the total annual suspended sediment load.

7.3.2.1. Progressive change in suspended sediment load:

The progressive change of suspended sediment load of the river Balason is apprehended from the figure 7.4, which has been drawn based on the data provided in the table 7.4.

It was observed that the suspended sediment load of the river Balason showed fluctuations which were 611787 metric ton, 235700 metric ton, 575828 metric and 203475 metric ton in 1998, 1999, 2000 and 2001 respectively. A decrease of 159.56% in the sediment load was observed between 1998 and 1999. An increase of 58.77% in the sediment load was observed for 1999-2000. This sharp increase may be due to the concentrated monsoon rains that led to flooding in 2000. A decrease of 180.98% in the sediment load has been found in between 2000 – 2001.

7.3.3. Discharge Sediment Load correlation:

To determine the nature of correlation between the discharge and sediment load a rating curve has been fitted on the log log graph in figure 7.9 based on monthly data obtained from table 7.3 and 7.4.

RELATION BETWEEN DISCHARGE AND SEDIMENT LOAD (1998 – 2001)

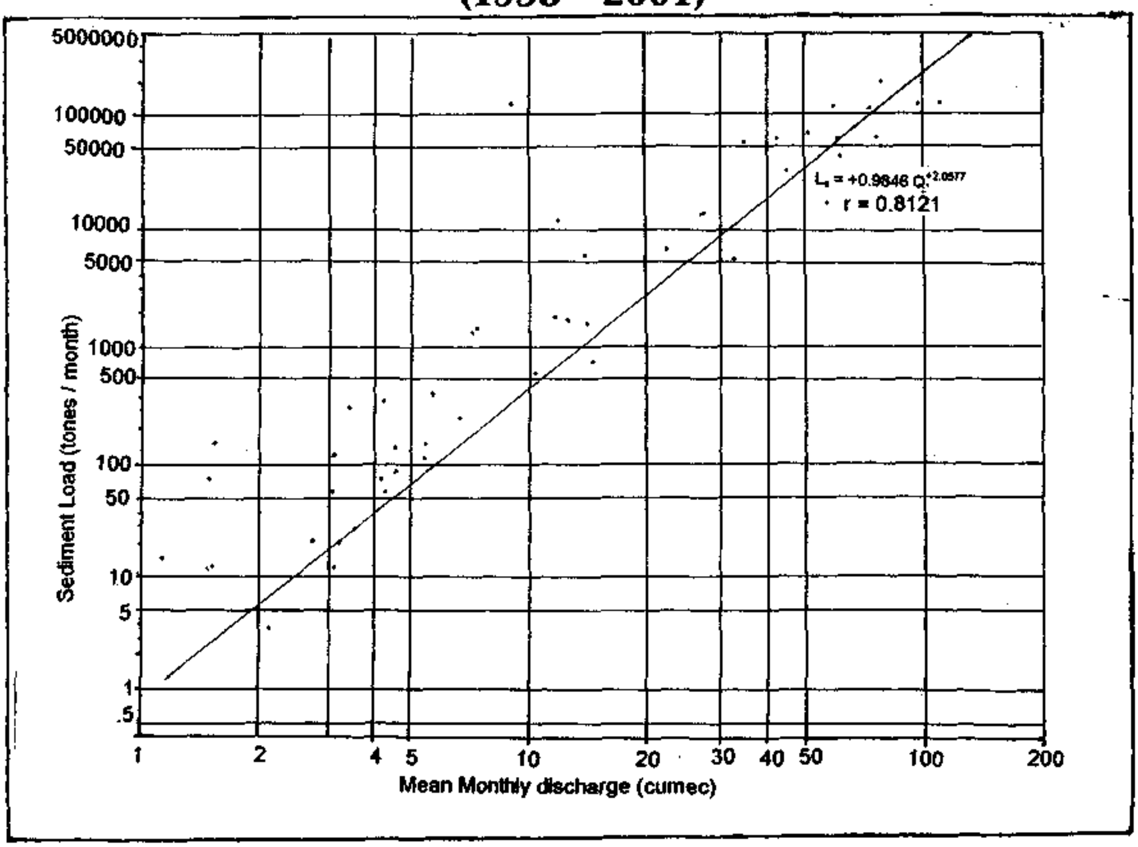

Figure 7.9

Such a line is defined by the expression

$$Ls = pQ^{j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7.1$$

in which Ls is the sediment load in tones d^{-1}, Q is the discharge $m^3 s^{-1}$ and p and j are numerical constants. Although there are many and varied factors that control the suspended load of a stream, the figure illustrates a rather well defined relation between the load and the concurrent discharge of the Balason river.

A linear regression and correlation between the discharge and sediment load has been carried out (figure 7.9) on the basis of the equation 7.1 and the following results have been obtained.

$$Ls = +\,0.9846\, Q^{+2.0577} \quad \ldots\ldots\ldots\ldots\ldots\ldots 7.2$$

[SE of Ls estimate = 0.364, SE of power Exp = 0.0689, r= 0.8121 and r^2 = 0.6595]

The values of correlation coefficient (r= 0.8121) and coefficient of determination (r^2 = 0.6595) of the above estimate indicates a steady relationship between the sediment load and corresponding discharge. Thus, from the above analysis it is clear that the mean monthly discharge of Balason basin has been closely associated with the sediment load in a regular manner provided that other parameters are constant.

Table No. 7.5

Mean monthly gauge height, bed elevation and hydraulic depth (in metre) at CWC station of the river Balason*

Months	Gauge heights				Bed elevation				Hydraulic depth			
	1998	1999	2000	2001	1998	1999	2000	2001	1998	1999	2000	2001
Jan.	122.769	122.097	122.123	122.085	122.510	121.772	121.724	121.823	0.271	0.337	0.411	0.274
Feb.	122.690	122.075	122.046	122.000	122.462	121.816	121.728	121.764	0.240	0.271	0.329	0.248
Mar.	122.671	121.995	121.974	121.919	122.422	121.822	121.755	121.699	0.261	0.185	0.231	0.232
Apr.	122.667	121.994	122.002	121.898	122.449	121.813	121.774	121.707	0.230	0.193	0.240	0.201
May	122.834	122.132	122.212	121.995	122.533	121.836	121.695	121.759	0.313	0.308	0.329	0.248
Jun.	123.094	122.324	122.567	122.302	122.570	121.937	122.111	121.771	0.536	0.399	0.468	0.543
Jul.	123.168	122.848	122.811	122.340	122.533	122.321	122.214	121.707	0.647	0.539	0.609	0.645
Aug.	123.100	122.803	122.807	122.396	122.517	122.259	122.157	121.805	0.595	0.556	0.662	0.605
Sep.	122.954	122.868	122.678	122.259	122.526	122.441	122.118	121.802	0.440	0.439	0.572	0.469
Oct.	122.900	122.686	122.626	122.050	122.470	122.269	122.212	121.546	0.442	0.431	0.426	0.516
Nov.	122.701	122.367	122.460	121.928	122.233	121.977	122.115	121.458	0.460	0.402	0.357	0.482
Dec.	122.516	122.190	122.277	121.847	121.925	121.881	121.973	121.406	0.572	0.321	0.313	0.451
Annual	122.839	122.365	122.382	122.065	122.429	122.012	121.981	121.667	0.419	0.365	0.412	0.410

*Data compiled from the CWC Records.

GAUGE HEIGHT, BED ELEVATION AND HYDRAULIC DEPTH OF THE RIVER BALASON FROM 1998 – 2001 AT MATIGARA.

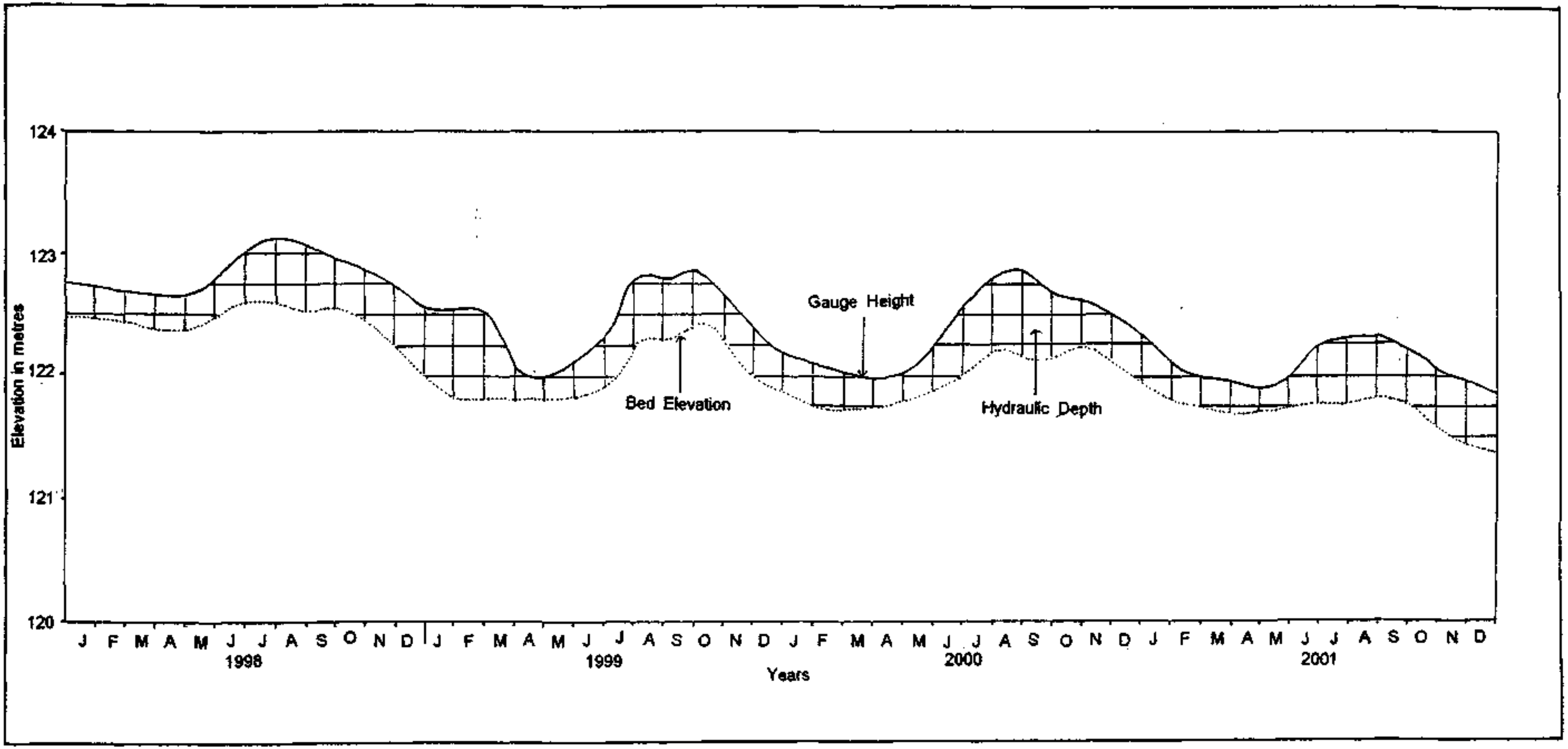

Figure 7.10

7.3.4. Study of stage and bed elevation of channel:

The mean monthly stage of the river Balason has been estimated from the mean monthly gauge height s for a period of consecutive four years, i.e. from 1998 to 2001. The mean monthly values of bed heights have obtained from the Central Water Commission field record. The mean monthly values of all these parameters plotted to get a clear picture at a glance (figure 7.10).

From the mean monthly stage and bed elevation diagram (figure 7.10) as well as from the table 7.4 it is noticed that the river bed is highly fluctuating due to scouring and filling in the monsoon and non-monsoon periods. The highest bed height is noticed in the month of June 1998 (122.570 m). Mean monthly bed elevation goes down to 121.408 m during the month of December 2001, a total fall of 1.162 meter over a period of 3 and half years. This sharp lowering of bed elevation near the NH-31 bridge is perhaps due to anthropogenic rather than natural which has been thoroughly discussed in the following section.

From the above study it is seen that the bed-elevation is higher in the monsoon months and lower in the non-monsoon months. Even the nature of fluctuation or oscillation of the bed heights has no rhythm for the studied period; the trend is increasing for the first year (1998-99) but decreasing for the remaining years (1999-2001) excepting the monsoonal months.

Bhattacharyya (1993) identified a different scenario in case of the river Rakti, a tributary to the river Balason where, he found a clear indication of increasing of river bed elevation. Perhaps, the extraction of bed materials from the Balason bed in and around the studied section is responsible for the fluctuation and even lowering of the bed elevation of the river. However, a detail discussion on this regard is made in the following section.

7.3.5. The mean monthly stage and discharge relationship:

A simple rating curve of the mean monthly stage and the discharge has been plotted in figure 7.11 to determine the nature of channel control.

STAGE DISCHARGE RELATION (1998 - 2001)

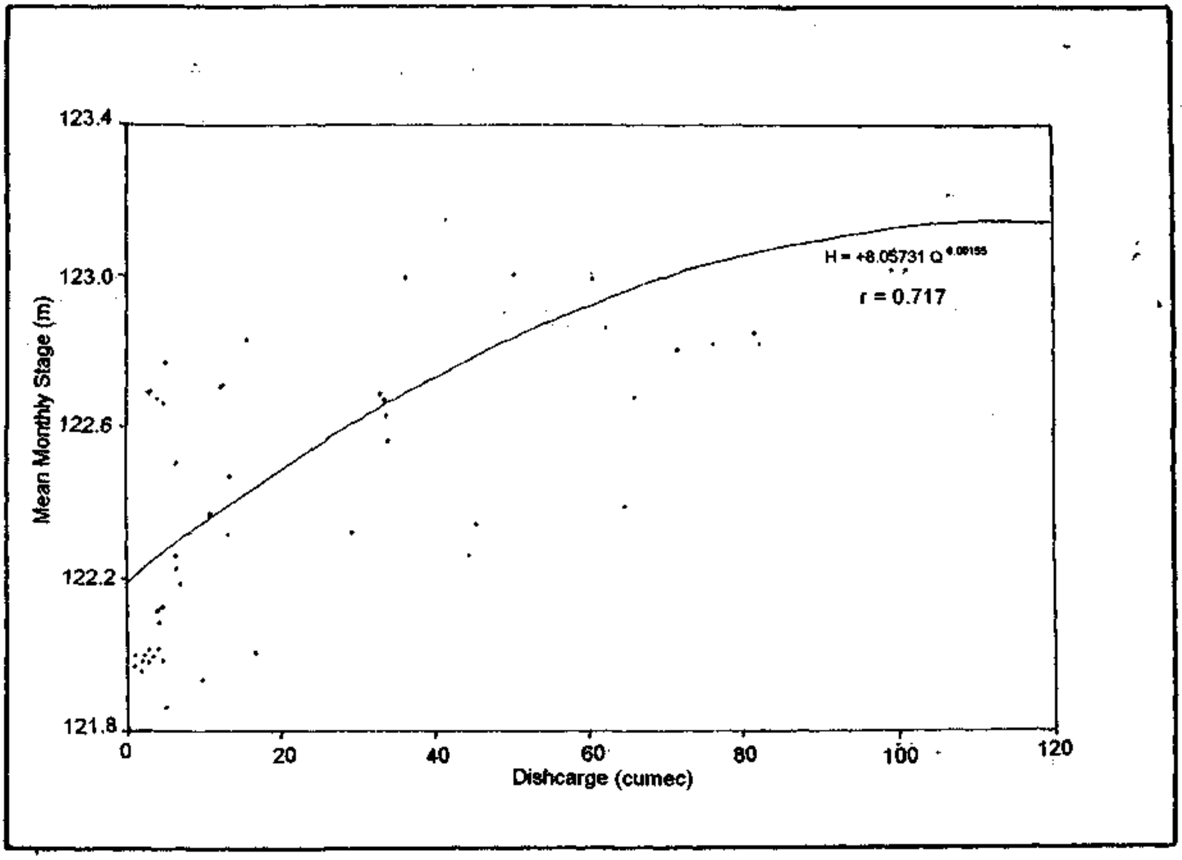

Figure 7.11

The channel control depends not only on the stage and discharge relationship but also on the cross-sectional area, shape, roughness etc. In the case of alluvial channel the shifting nature of channel control is prevalent because of the changing nature of hydraulic parameters (Baker,1988).

A rating curve has been formulated based on data provided in table 7.5 and 7.3 and represented in (figure 7.11) to show the nature of the relationship between the mean monthly stage and discharge values on the basis of the equation;

$$H= +8.05731\ Q^{0.00155} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 7.3$$

[SE of H estimate = 0.0093; SE of power exp. = 0. 2671; r= 0.717 and r^2= 0.514]

From the above expression the values of correlation coefficient (0.717) and coefficient of determination (0.514) indicates a moderate relationship between the stage and discharge of the study area. Such a result is very much common due to channel adjustment in the alluvial channel composed of sand, silt and gravels.

7.3.6. The study of peak – flood discharge:

Emphasis to determine the nature of discharge for the peak flood periods of the river Balason during the period 1998-2001 has been made. The hydrographs of peak-flood periods during the years have shown the degree of fluctuation in discharge (figure 7.12). It was noticed that the difference between the consecutive discharge values before the peak flood discharge was very high.

Similarly, in receding state, the discharges immediately after the peak flood, have also shown very steep fall in most cases. Thus, the sudden outburst of water in the peak-flood period is very much different from the characteristics of high mean monthly flow in the monsoonal months. The table 7.6 also reveals the daily fluctuation of discharge from the mean monthly discharge of the respective months. It records a very high level of fluctuation.

Table 7.6

Peak flood discharge of the river Balason

Date	Discharge in m^3/sec	Mean monthly discharge m^3/sec	Variation in %	Date	Discharge in m^3/sec	Mean monthly discharge m^3/sec	Variation in %
08.08.1998	70.01		30.55	10.07.1999	60.31		20.488
09.08.1998	96.29		4.27	11.07.1999	110.02		29.222
10.08.1998	74.60		25.98	12.07.1999	199.50		118.702
11.08.1998	140.75		40.19	13.07.1999	88.15		7.352
12.08.1998	415.22	100.560	314.66	14.07.1999	84.85	80.798	4.052
13.08.1998	379.89		279.33	15.07.1999	98.74		17.942
14.08.1998	123.83		23.27	16.07.1999	94.42		13.922
15.08.1998	127.00		26.44	17.07.1999	182.65		101.852
16.08.1998	83.86		16.7	18.07.1999	97.31		18.512
15.07.2000	107.42		31.347	19.08.2001	52.56		12.70
16.07.2000	63.73		12.343	20.08.2001	113.28		48.02
17.07.2000	45.85		30.223	21.08.2001	113.20		47.94
18.07.2000	149.10		73.027	22.08.2001	173.39		108.13
19.07.2000	251.30	76.073	175.227	23.08.2001	80.44	65.260	15.18
20.07.2000	245.97		169.897	24.08.2001	64.45		0.81
21.07.2000	69.20		6.873	25.08.2001	100.26		35.00
22.07.2000	96.95		20.877	26.08.2001	71.95		6.69
23.07.2000	59.45		16.623	27.08.2001	70.74		5.48

PEAK FLOOD DISCHARGE VARIATION (1998 – 2001)

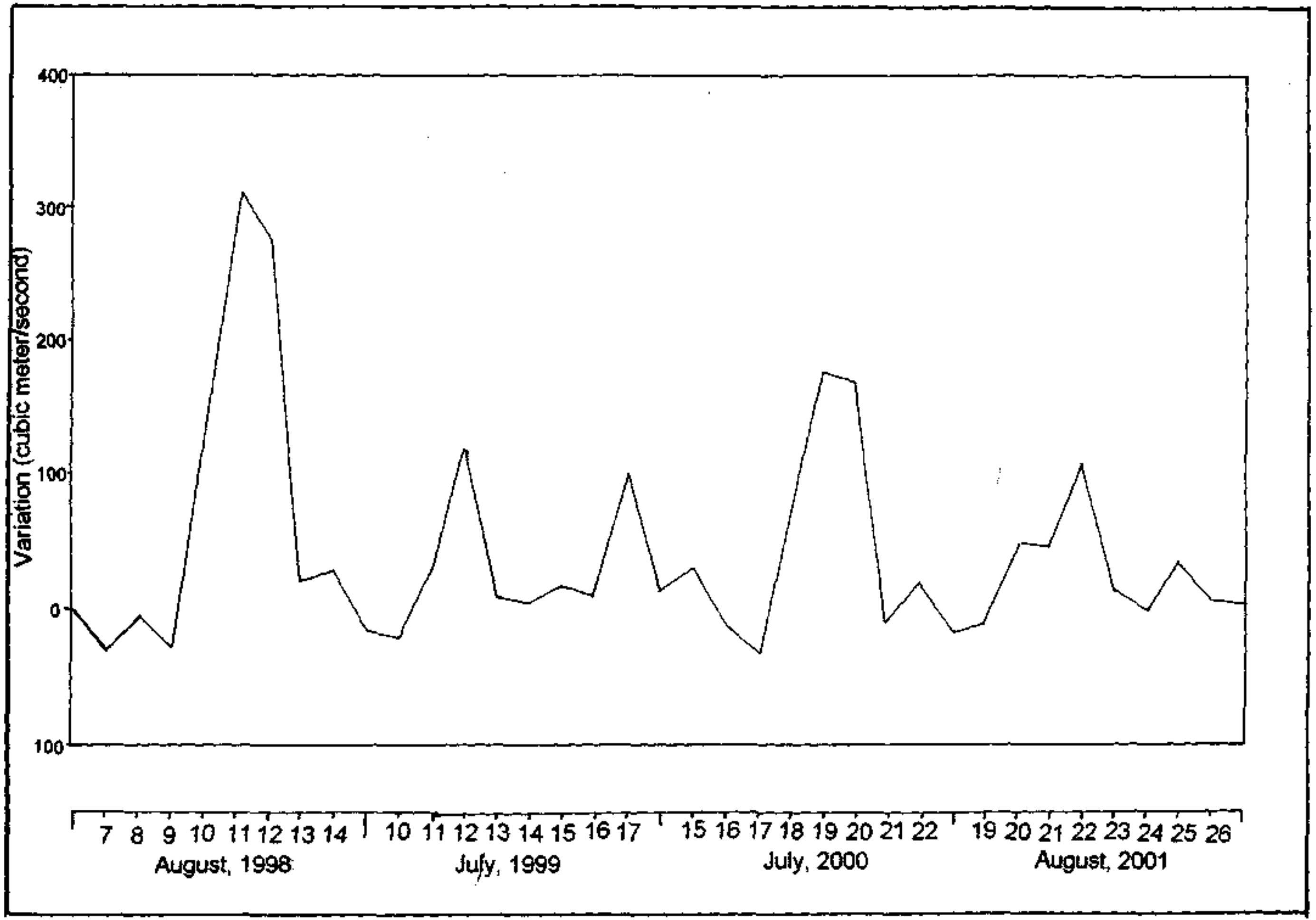

Figure 7.12

7.3.7. The study of peak flood run-off and sediment load relationship:

A simple graphical correlation has been made between the peak flood run-off and sediment load of the Balason river for a selected period from 1998 to 2001. It is interesting to note from table 7.7 as well as from (figure 7.13.) that in the year 1998 the amount of sediment load carried to the river by the peak run-off was 104163.

Table 7.7

Peak food rn-off and their crresponding sdiment load at Matigara*.

Date (1998)	Run-off Million cubic meter	Sediment load (tones d^{-1})	Date (1999)	Run-off Million cubic meter	Sediment load (tones d^{-1})
08.08	6.08	422.25	10.07	5.32	6067.26
09.08	8.35	6408.39	11.07	9.63	11181.26
10.08	6.49	3888.54	12.07	17.36	20278.04
11.08	12.34	10876.05	13.07	7.76	9016.59
12.08	35.99	104161.60	14.07	7.44	8339.49
13.08	32.84	53179.65	15.07	8.59	13373.72
14.08	10.78	7851.62	16.07	8.27	17313.93
15.08	11.01	7923.26	17.07	15.96	45385.97
16.08	7.31	4902.59	18.07	8.92	11572.36

Date (2000)	Run-off Million cubic meter	Sediment load (tones d^{-1})	Date (2001)	Run-off Million cubic meter	Sediment load (tones d^{-1})
15.07	9.28	12521.16	19.08	4.57	2679.00
16.07	5.51	4471.09	20.08	9.79	6199.46
17.07	3.96	2825.98	21.08	9.78	6271.85
18.07	12.88	30421.64	22.08	14.89	9682.96
19.07	21.71	57802.30	23.08	6.95	4650.22
20.07	21.25	45687.50	24.08	5.57	3092.82
21.07	5.98	3126.30	25.08	8.66	4715.66
22.07	8.38	6164.54	26.08	6.22	4057.40
23.07	5.14	4280.01	27.08	6.11	3621.09

7.4. Study of Bed load and Bed materials:

The river Balason is noteworthy for its transporting capacity of huge volume of coarse materials as bed load. No assessment has ever been attempted to measure the volume and size of bed materials of the river Balason. Extraction of

PEAK RUNOFF – SUSPENDED SEDIMENT LOAD CORRELATION

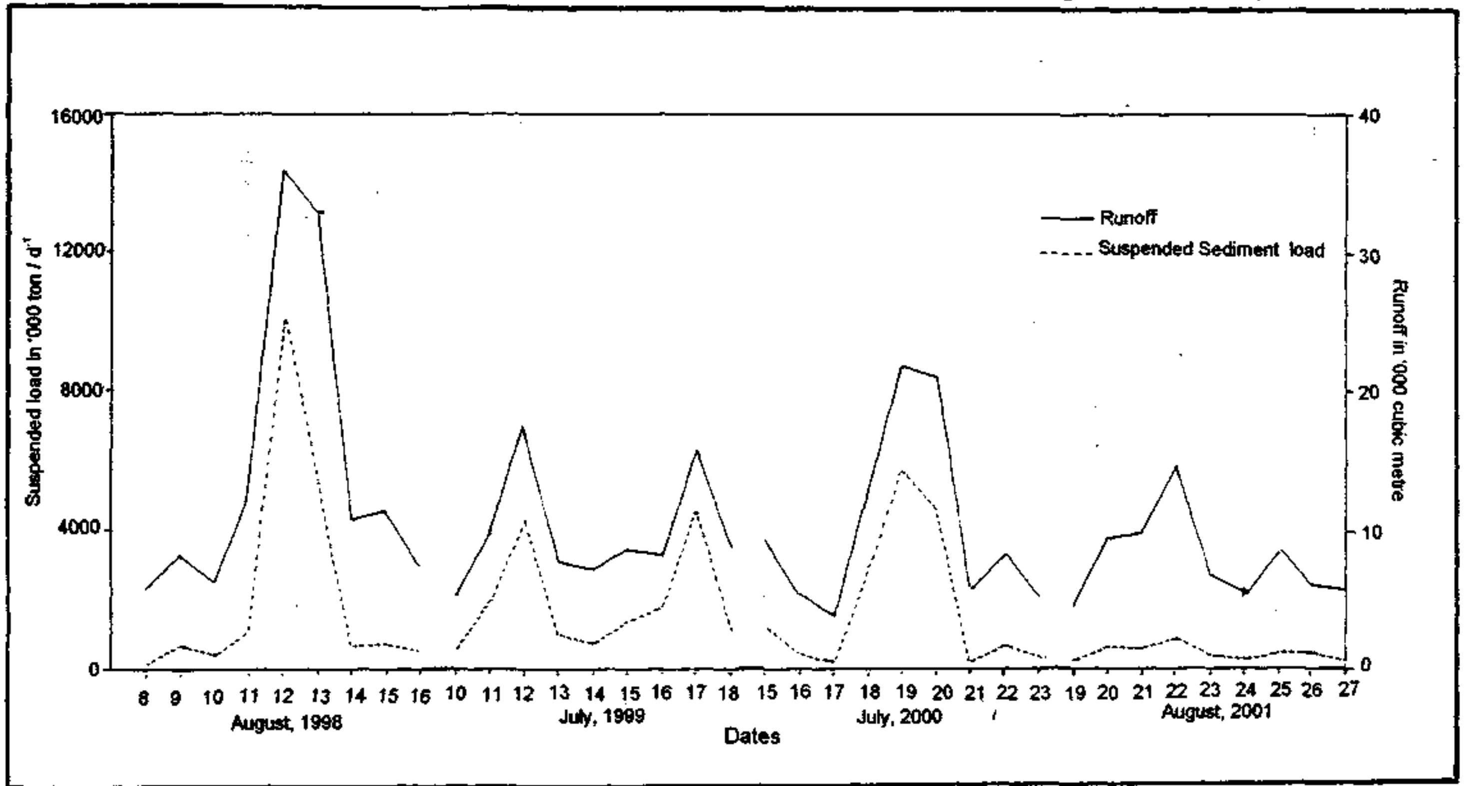

Figure 7.13

Photo 7.4 Removal of bed materials - Human interference

Photo 7.5 Massive aggradations along the Balason valley near Ambootia

bed materials of the river Balason at 4 different sites from NH-31 Bridge to Dudhiya has been started since 1990 onwards (photo 7.4). The investigator has tried to estimate the bed load of the river from the data on the amount of load extraction obtained regularly from the different sites during 1998-2001.The following Table 7.8 shows the amount of boulder and finer materials extracted from the river during 1998-2001, which is also shown diagrammatically in the Fig. 7.14

Table 7.8

Extraction of bed materials from different sections in between Dudhiya to NH-31 bridge near Matigara.

Months	Bed material extracted in cubic metre				
	1998	1999	2000	2001	Mean
January	120750	132170	110150	145000	127018
February	101400	114620	100500	106500	105755
March	96700	89980	94460	90330	92867.5
April	90400	85260	90010	81770	86860
May	75520	80190	76840	71150	75875
June	50190	45150	45000	60050	50097
July	20180	30110	15500	45690	27870
August	18290	20400	37560	40190	29110.5
September	58720	43300	86550	35500	55767
October	90600	81110	107500	72620	87957.5
November	98500	90170	121000	81620	97822.5
December	115460	108900	135000	95540	113725
Total	936710	921360	1018870	925960	950725

Source: Based on field survey.

It is thus revealed that total bed material extraction from the river Balason was 936710m^3 in 1998, 921360 m^3 in 1999, 1018870 m^3 in 2000 and 925960 m^3 in 2001. Thus the mean annual bed material extraction from the river bed was 950725 m^3 (1998-2001). It is also evident that the non-monsoon months (October to May) exhibit more extraction than the monsoon months (June–September). The total amount of bed load thus, extracted from the river bed may conveniently spread over the concerned section of the river bed (measured to be 5 million sq. metre approx.), gives an average of 20 cm lowering each year. Considering 70cm lowering of bed level over the period of 4 years (1998-2001) as revealed from

MONTHLY BED MATERIAL EXTRACTION FOR THE RIVER BALASON FROM 1998 – 2001

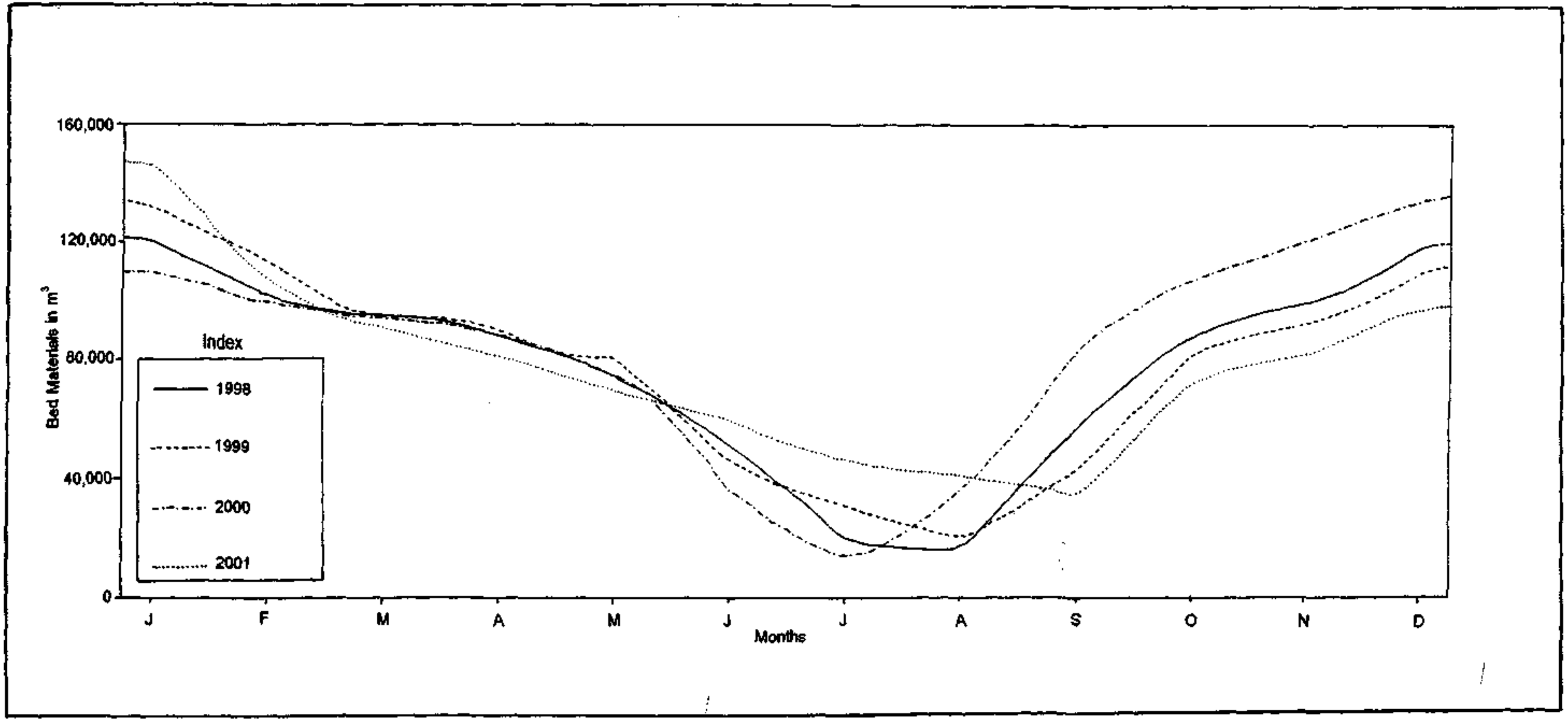

Figure 7.14

the CWC record (table 7.8 and figure 7.10) we may conclude that under natural condition the rising of river bed would be 2.5 cm / year. Extraction of bed materials perhaps prevent large scale river bed rising in case of the Balason which is incidentally rampant in most of the sub-Himalayan rivers in North Bengal.

7.5. Analysis of Braid-Plain Formation in the River Balason:

The braided alluvial plain is formed as a result of lateral accretion of the inactive part of the former channel during successive large floods. The vigorously changing nature of the braiding channel is non-systematic being dependent on the rate of lateral erosion. It is possible to distinguish gravelly, sandy, and silty depositional environments based on sedimentological classification of braided rivers (Albertson, 1964; Froehlich et al, 2000).

The divide or braided sections tend to have higher width-depth ratio than comparable sections in meander or straight reaches. While gravelly and sandy facies chiefly occur in the river Balason, bars with silty soils occur along the valley sides that have been formed and remains unchanged even after flood in some places (Starkel et al, 2000). The present investigator made a study of the character of braiding of the river Balason for 4 years during 1998 to 2001 (figure 7.15). For the study a 4 km long stretch in the lower part of the long profile of the river Balason has been chosen (i.e. 2 kms upstream and 2 kms downstream from the bridge of NH-31).

7.5.1. Geomorphology of the braid-plain:

The average width of the channel is about 240 m (± 50m, average of 21 cross section within 4 km stretch). Relatively deep (0.2-1.5m) and narrow (1.5-8.5) arc shaped troughs dissect the braid plain. While some of them carry water, others with pebble/ cobble deposits remain dry. In the upper parts the valley side bars are composed of sands and silts, while coarse grained deposits occur at the bottom. *Saccharum spontaneum* grow in small patches here and there with most of the lands remaining bare. The braiding process along some regions remain

MORPHOLOGICAL CHANGES IN BRAIDING (1998 – 2001)

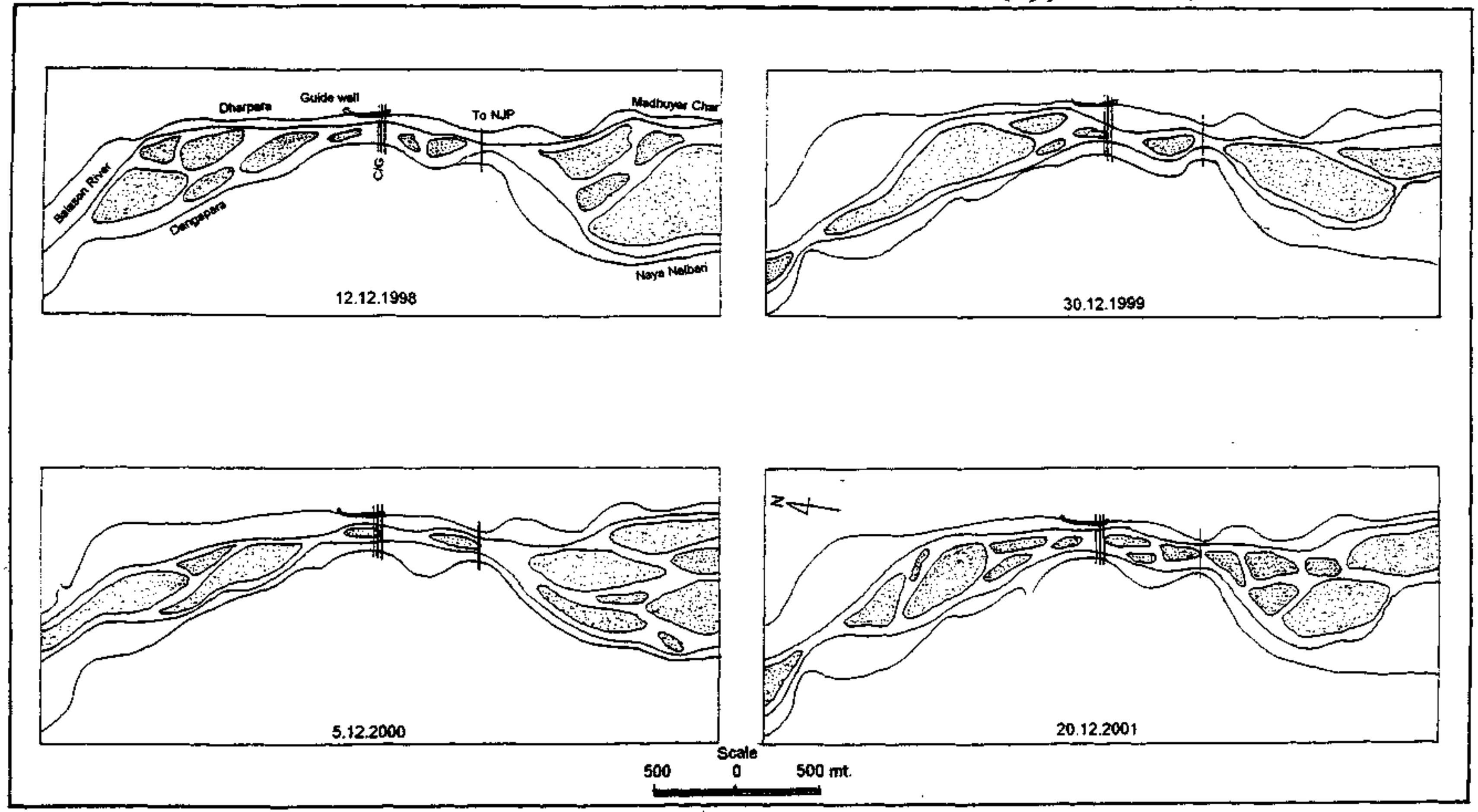

Figure 7.15

disturbed due to extraction of stones and sand for the purpose of construction by local people.

7.5.2. Role of Flood:

Floods generally play an important role in modifying the braiding character of any channel. However, in the case of the Balason river it is more pronounced as the annual peak-flow (annual flood) along with the big flood modifies the shape of the braids enormously. This modification is not only due to the exchange of the materials among the small bars, side- bars etc. but also due to the addition of materials from the banks and catchment areas. The reason for this is the total submergence of the pools and bars during the annual peak-flow period so that the transported materials doesn't block the way of the previous narrow channels. The high rate of deposition leads to large amount of pebbles / cobbles etc. being deposited mostly in the wider channels of the previous year, that leads to the vigorous change in their course. A greater change had occurred in 1998 due to flooding. An important feature of the river in the study stretch is that no active channel of the braiding can be identified during the peak flow period. This also leads to the creation of a new set of braiding.

The sudden outburst of the catastrophic flood in 1998 created a single new flood channel up to 350m wide and in the post flood period of the same year a new set of pools and riffles were formed, although the bank retreated only about 1.45 to 2.69 m. This was due to the fact that the bank is protected on either sides in two different sections, one of which is across NH-31 bridge and the other located across the railway bridge. The bank erosion along with braid plain formation has affected an area of about 29500 m^2 within the study area.

The great anthropogenic impact over the basin makes the determination of the actual vertical accretion very difficult from the field study. However, the measurements made during the field study showed that a 15 - 20 cm thick sandy cover was formed along the river bank underlain by a thick gravelly bed (figure 7.16). In the middle part of the braid scenario was quite different, where the upper

TRANSFORMATION OF BRAIDED CHANNELS IN THE LOWER BALASON VALLEY (1960 – 2001)

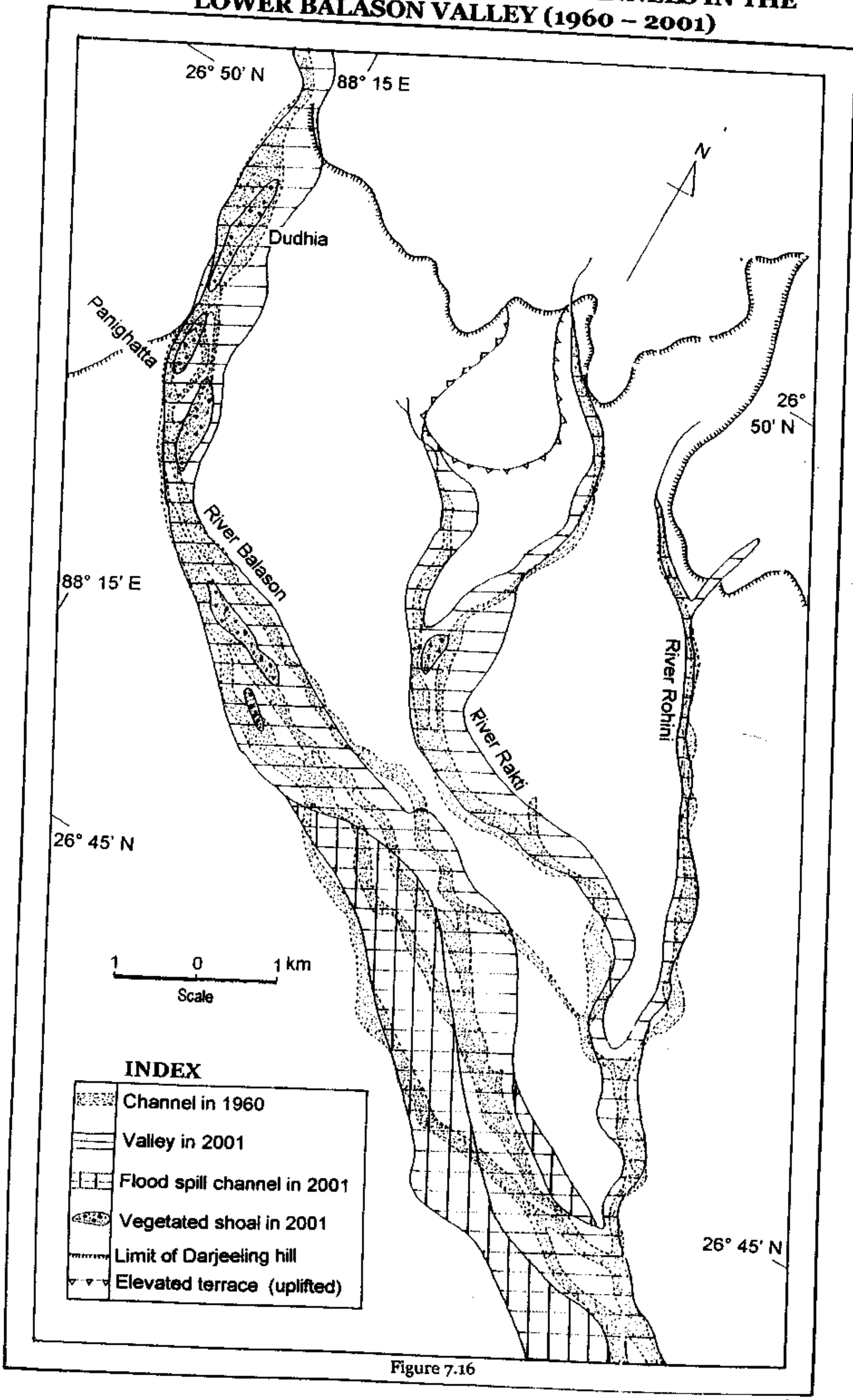

Figure 7.16

layer was composed wholly of pebbles, cobbles etc. with an average thickness of around 1 m, with the lower layer being composed of mixed deposits i.e. pebbles, cobbles, with sand, silt etc. (Starkel & Sarkar, 2000).

7.5.3. Summary:

- The construction of the braid–plain in the study area resulted from successive flood-channel formation even in the peak-flow period, related to non-systematic migration or avulsion of flood channel.
- As all of the bars and shoals remain submerged in the peak-flow period it can be concluded that the materials of the braid plain are of recent origin.
- Characteristically, the nature of braiding in the study area show annual changes, but remarkable changes occurs during each catastrophic flood that forms new flood channel.
- Frequent changes in braiding are an indication of successive erosion (lateral accretion) as well as enormous deposition within the river bed that enhance flood situations.

7.6. Conclusion:

The cross-sectional areas of the river Balason vary little from year to year, in the case of non-monsoon months, while these vary more in the monsoon period. But, when such changes do occur, the river quickly re-adjusted itself by means of either erosion or deposition.

No definite law or trend in variation of the wetted perimeter from station to station and from year to year could be made except that at some sections changes do occur and these soon gets readjusted as the river tries its level best to get back to its original position by either lateral erosion or vertical corrosion.

The hydraulic radii of the river tend to change in a small degree in conformity with small changes in cross-sectional areas, but these soon get re-adjusted or the river tends to come back to its original position.

Whether the discharge of the river is progressively increasing or decreasing in recent years, can never be categorically proved as the deteriorating condition of one year is usually compensated in the very next year. However, from the hydrograph analysis it may be concluded that high intensity discharge concentrating within a short period, relates to rainstorms, thus causing severe floods.

From the analysis of the suspended load of the river, it becomes clear that the silt load has progressively been on the increase. These along with increasing bed load caused increasing of braiding tendency of the river.The contemporaneous deposition of coarse sediments is progressing upstream into the mountains. The supplies of debris from steep slopes cause the overburdening of the river. The aggradation is progressing about 15 km upstream, up to the outlet of the tributary of landslide valley of Ambootia, (photo 7.5) with extensive torrential fans. The annual floods remove these boulders and gravels to the foreland, where they are intensively exploited at the level of 20 cm / year and thereby, eliminating the possibilities of large scale river bed rising as it is seen in most of the rivers in sub-Himalayan West Bengal.

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CHAPTER 8

WATER RESOURCE OF THE BALASON BASIN

8.1 Introduction

The river Balason, originating from Lepchajagat at an elevation of 2416 m, flows through the district of Darjeeling, is noteworthy for its erosional and depositional hazards, causing occasional flood in its lower catchment. The discharge of the river at Matigara, varies from a negligible amount of 0.409 cumecs during the dry season (March – April) to a high of over 940 m^3/second during the rainy season (July-August). The mean annual sediment discharge is very high and it was estimated to be 87365 metric tons. The mean annual rainfall in the catchment area is 3359.81 mm, based on long-term average data of 22 rainfall recording stations situated within the catchment area.

The Balason basin is unable to hold back water due to excessive deforestation, overgrazing and extensive unscientific agricultural use of land in its catchment area. As a result, most of the precipitated water goes down the slope, giving rise to severe soil erosion and landslips.

The amount of load transported not only provides an indication of the rate of mechanical denudation in a basin, but also has wider implications for the economic management of the fluvial system. The river is incompetent to cope with the enormous amount of debris load that is transported to its lower course during the monsoon months (June-September). All these processes themselves generate certain responses within the river channel. Flooding is thus, the result of the continuous set of possible responses within the fluvial system.

On the other hand, during the non-monsoon months (November to April) negligible amount of water flows through the narrow braided channel and this paucity of water hinders the local people from reaping any benefit out of the soil in conjunction to the river itself. The overall economic situation has become very grim and is deteriorating day by day. Effective ways to control the situation are necessary. Thus, there is a growing and perceived need for the assessment of water resource of the drainage basin and suggestion for its sustainable effective management.

The **aim** of this chapter is to assess the annual water resource of the basin, its seasonal distribution, its present utilization and conservation. The emphasis has been given on the estimation of the annual water resource of the basin on the following aspects:

- the study of rainfall and runoff,
- the study of evaporation,
- estimation of total water resource,
- the problems of the conservation of water resource.

8.2 Study of Rainfall - Runoff

Runoff is that balance of rain water which flows or runs over natural ground surface other than water losses by evaporation, interception and infiltration. Several empirical formulae, curves and tables relating to the rainfall and runoff have been developed, Khosla (1950); Ghatwar and Basu (1984); Ghatwar, 1986; Sarkar (1989 & 1998). However the present investigator has chosen the formula of Khosla (1950) due to its wide applicability in the Indian context. According to Khosla (1950), runoff is the function of precipitation and temperature i.e.

$$R = \propto P/T \quad \text{..........} 8.1$$

where R = runoff, P = precipitation after the deduction of losses and T= temperature.

The common loss due to evaporation and transpiration, generally known as evapo-transpiration is the function of temperature of the area concerned. Thus Khosla's formula reads as follows:

$$R_m = \propto P_m/L_m \quad \text{..........} 8.2$$

where R_m *= monthly runoff,* P_m *=monthly precipitation and* L_m *= monthly evaporation.*

Again the amount of monthly evaporation (L_m) is given as:

$$L_m = T_m{}^\circ C / 0.274 \quad \text{.......................... 8.3}$$

For determining the loss by evaporation and the resultant runoff, following Khosla's formula, the average monthly rainfall data was collected from various recording stations, mainly tea gardens. As the temperature data was not available for all the stations, it was computed by interpolation and extrapolation methods. Distribution of average monthly rainfall and evaporation loss for some selected recording station were calculated. (appendix 8.1).

After carefully studying the calculated figures as well as the map, (figure 8.1) it is interesting to note that in the upper catchment areas as well as in the central hilly parts, some pre-monsoon rainstorms during March to May, yield a considerable amount of run-off. The tea gardens like Margaret's Hope, Gopaldhara, Dooteriah, Selimbong, Tumsong and Chamong record a higher amount of run-off as to the percentage of total annual rainfall during April and May, due to low temperature and low of evaporation loss.

The stations located just below the upper catchment i.e. in the central, south, eastern parts of the basin like Sungma, Manjwa, Pubong and Pankhabari show comparatively lower amount of runoff as percentage to the total rainfall in May. The entire foothills and plains display almost the similar higher trend regarding run-off as percentage to total rainfall e.g. Panighatta (68.68%), Longview (69.86%), Marionbari (67.63%) and Matigara (57.03%).

The amount of runoff as percentage to the total rainfall increases with the onset of the monsoon season and the month of June the runoff exceeds to over 70% in all the stations of the study area, with very high being recorded over Longview (87.65%), Sungma (84.34%), Nagri farm (82.42%), Selimbong (81.53%), Nagri (82.55%), Thurbo (82.75%), Balason (88.27%, Manjwa (86.25%, Panighatta (85.43%, Ambootia (88.54%), Chamong (84.18%), Marionbari (86.5%) and Matigara (82.9%). The amount increases with the establishment of the southwest

PRECIPITATION AND EVAPORATION LOSS OF SOME SELECTED STATIONS OF THE BALASON BASIN

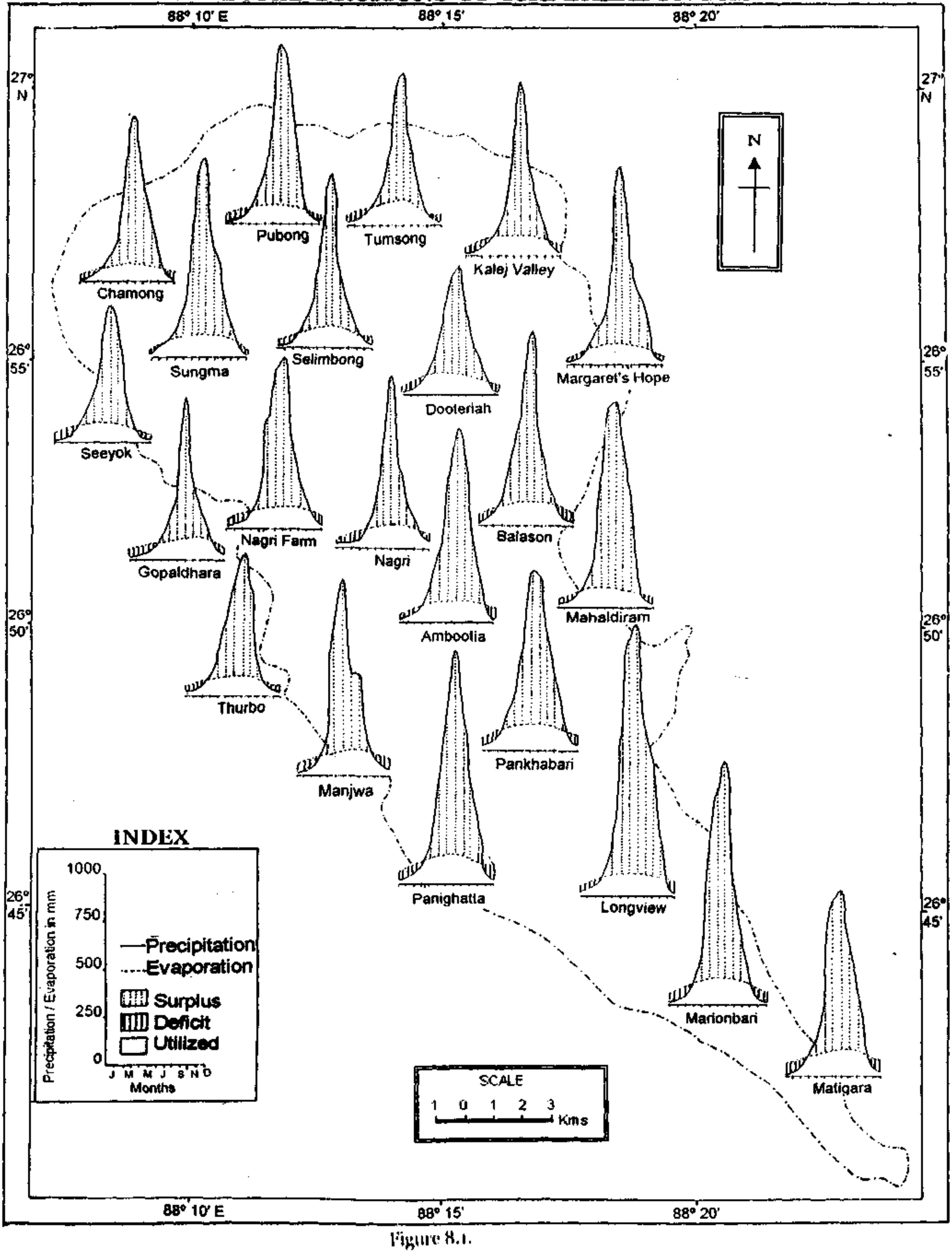

Figure 8.1.

monsoon to a remarkable extent and goes above 80% in all the stations during the month of July, which is the rainiest month in the study area.

Table 8.1

Mean annual rainfall in mm, temperature in °C, evaporation in mm and runoff in mm of selected stations in Balason basin*

Stations	Altitude in m.	Rainfall	Temperature	Evaporation loss	% of evaporation loss to rainfall	Runoff	Run off as % of rainfall
Ambootia	948	3922.51	20.27	1172.94	29.90	2749.57	70.10
Balasun	1127	2842.80	19.33	1118.66	39.35	1724.14	60.65
Chamong	1520	2961.80	16.52	955.74	32.27	2006.06	67.73
Dooteriah	1380	2597.80	18.74	1084.28	41.74	1513.52	58.26
Gopaldhara	1560	2324.70	16.23	938.75	40.38	1385.95	59.62
Kalej Valley	1400	2502.30	18.54	1072.52	42.86	1429.78	57.14
Longview	610	5116.50	21.29	1231.53	24.07	3884.97	75.93
Mahaldiram	1676	4060.00	15.58	895.52	22.06	3164.48	77.94
Manjwa	690	3430.30	20.77	1201.46	35.02	2228.84	64.98
Margret's Hope	1403	3009.10	18.54	1072.50	35.64	1936.60	64.36
Marionbari	249	4335.80	23.66	1368.80	31.57	2967.00	68.43
Matigara	121	3734.10	24.19	1399.09	37.47	2335.01	62.53
Nagri	1348	2631.70	18.84	1090.31	41.43	1541.39	58.57
Nagri farm	1342	2832.00	18.89	1092.86	38.59	1739.14	61.41
Panighatta	255	4018.40	22.38	1294.61	32.22	2723.79	67.78
Pankhabari	1030	3564.60	24.96	1239.25	34.77	2325.35	65.23
Pubong	1644	2848.90	15.68	907.29	31.85	1941.61	68.15
Seeyok	1520	2296.80	16.52	955.90	41.62	1340.90	58.38
Selimbong	1700	2440.70	15.24	881.49	36.12	1559.21	63.88
Sungma	1727	2589.40	15.06	871.60	33.66	1717.80	66.34
Thurbo	1451	2680.60	17.34	1003.37	37.43	1677.23	62.57
Tumsong	1533	2396.82	19.99	950.00	39.64	1446.82	60.36

*Data collected from tea gardens and other sources.

Such high trend of runoff as percentage to the rainfall exists upto the month of September. Runoff as percentage to precipitation starts to decrease from the month of October and reaches below 40% in most of the areas, e.g. Matigara (27.61%), Panighatta (24.57%), Pubong (27.16%), Balason (30.39%), Thurbo (5.61%), Pankhabari (22.54%), Sungma (5.01%), Seeyok (17.15%) during October. The lowest runoff during this month is however recorded over Nagri farm with the percentage amounting to 8.35% and at Nagri with just 0.29%. Such variation in runoff percentage is generally due to the uneven spatial distribution of monsoon rainfall.

The winter season (November to February) receives an insignificant amount of rainfall which cannot flow as runoff due to evaporation, transpiration and infiltration through the soil and due to this, during these months on an average only 0.41 cumecs discharge has been recorded in the river Balason during the year 1998 to 2001.

Table 8.2

Monsoon rainfall in mm, temperature (°C), evaporation (mm) and runoff (mm) of selected stations in Balason bBasin*

Recording stations	Altitude in m.	Rainfall	Temperature	Evaporation loss	Evaporation loss in % to rainfall	Runoff	Runoff as % of rainfall
Ambootia	948	3123.70	23.90	576.17	18.45	2547.53	81.55
Balasun	1127	2318.00	23.14	557.96	24.07	1760.04	75.93
Chamong	1520	2501.70	20.08	484.09	19.35	2017.61	80.65
Dooteriah	1380	2117.50	22.29	537.34	25.38	1580.16	74.62
Gopaldhara	1560	1968.40	19.78	476.81	24.22	1491.59	75.78
Kalej Valley	1400	2112.80	22.16	534.28	25.29	1578.52	74.71
Longview	610	4380.30	24.83	598.70	13.67	3781.60	86.33
Mahaldiram	1676	3817.08	18.84	545.08	14.28	3272.00	85.72
Manjwa	690	3020.00	24.31	586.17	19.41	2433.83	80.59
Margret's Hope	1403	2488.40	22.16	534.28	21.47	1954.12	78.53
Marionbari	249	3660.90	27.20	655.70	17.91	3005.20	82.09
Matigara	121	3245.60	27.70	667.03	20.55	2578.57	79.45
Nagri	1348	2242.4	22.50	542.48	24.19	1699.92	75.81
Nagri farm	1342	2407.20	22.54	543.45	22.58	1863.75	77.42
Panighatta	255	3386.70	25.94	625.36	18.47	2761.34	81.53
Pankhabari	1030	3114.60	25.01	602.94	19.36	2511.66	80.64
Pubong	1644	2513.70	19.23	463.70	18.45	2050.00	81.55
Seeyok	1520	1861.10	20.09	484.33	26.02	1376.77	73.98
Selimbong	1700	2077.70	18.67	450.19	21.67	1627.51	78.33
Sungma	1727	2313.90	18.50	445.94	19.27	1867.96	80.73
Thurbo	1451	2084.20	20.71	499.42	23.96	1584.78	76.04
Tumsong	1533	2023.87	19.99	482.12	23.82	1541.75	76.18

Data collected from tea gardens and other sources.

8.2.1 Rainfall runoff correlation.

There is often a very close relationship between the rainfall and runoff. An effort has been make to analyse the nature of relationship between the rainfall and runoff for both annual and monsoonal through linear regression (figure 8.2). The

RAINFALL AND RUNOFF CORRELATION

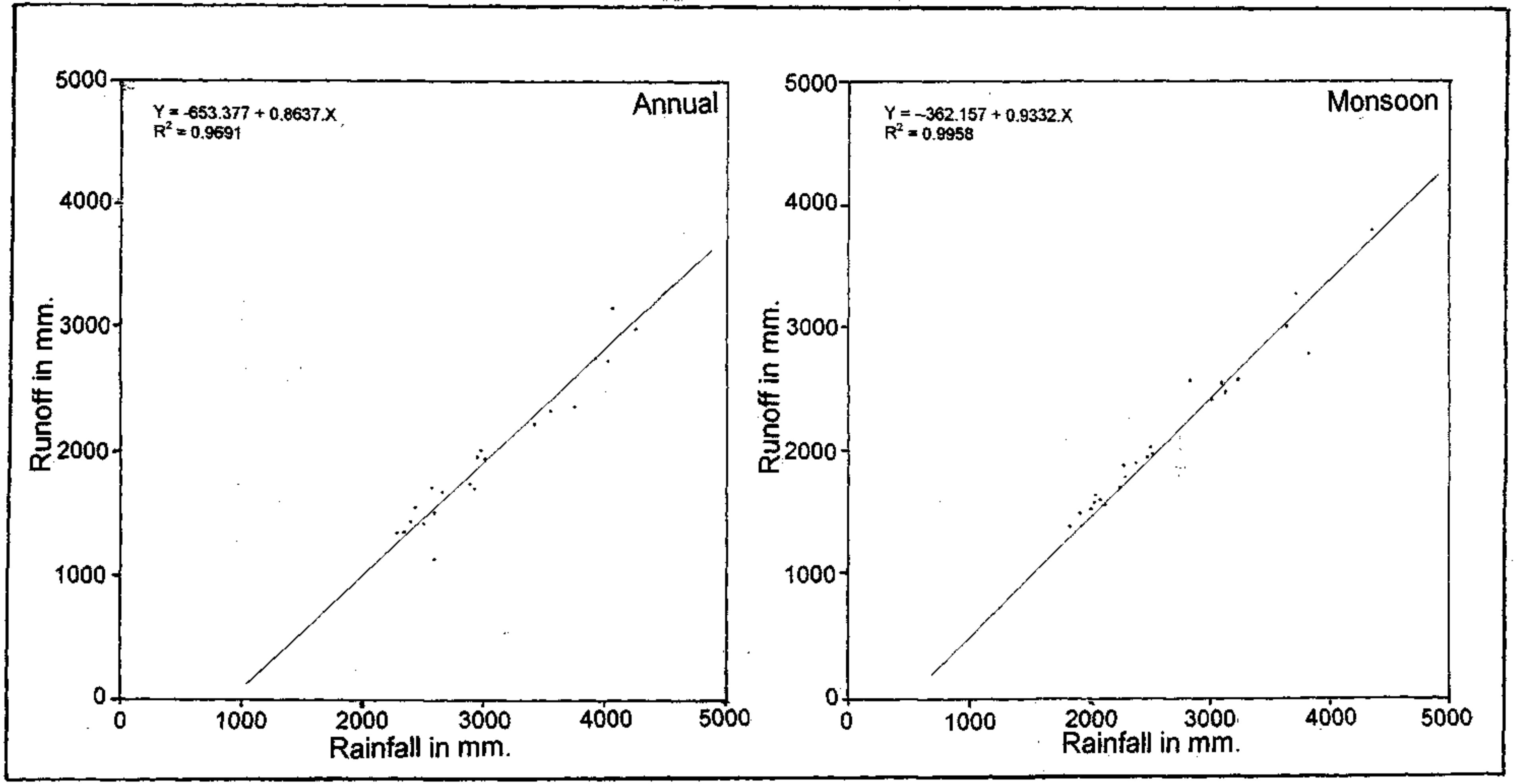

Figure 8.2

data required for such analysis has been obtained from 22 stations (table 8.1 & 8.2).

8.2.1.1 Annual rainfall-runoff correlation:

The correlation co-efficient between mean annual rainfall (X) and mean runoff (Y) is very high (r=0.9844) and have a 't' value of 25.0968 which is significant at the level of 99.9%. This indicates a very close relationship between these two attributes. The regression equation between the mean annual rainfall (X) and mean annual runoff (Y) is as follows:

$$Y = -653.377 + 0.8637\,x$$

In the above equation, the slope of the regression line (b = 0.8637) is of some value if comparison is to be made between this relationship and that which exists in other areas. Moreover, the coefficient of determination ($r^2 = 0.9691$) indicates that 96.91% of the total variation in Y has been explained by the respective X values and only 3.09 %.remain unexplained (table 8.1).

8.2.1.2 Monsoon rainfall runoff correlation:

The same situation is prevalent also in the relationship between mean monsoon rainfall (X) and the respective runoff (Y), where r = 0.9976. The linear regression equation in this case is:

$$Y = -362.157 + 0.9332\,x$$

Here the value 'b' or the slope of the regression line (i.e. 0.9332) is also important to make comparison between this and the other areas of established relationships. Moreover, the coefficient of determination ($r^2 = 0.9958$) shows that 99.58% of the total variation in Y has been explained by the respective X (table 8.2).

8.3 Study of Evaporation

Evaporation is another important factor in determining the surface runoff. An effort has been made to calculate the amount of monthly evaporation loss on the basis of the equation 8.3. A detailed station wise amount of evaporation loss has been tabulated (appendix 8.1.) and diagrammatically represented in the figure 8.1.

From the appendix 8.1. as well as from figure 8.1 it is seen that the foothills of the study area i.e. around Longview tea garden experiences minimum amount of evaporation loss (i.e.24.07% to the total annual rainfall). The highest amount of evaporation loss has been estimated in and around the north-western part of the basin that ranges from 40.38% to 42.86% to the annual rainfall. In the remaining stations the loss ranges between 30% to 40%. Though the region loses a considerable amount of valuable water through evaporation, this amount, on an average does not exceed 30% of the total amount of water received through rainfall.

In the monsoon period, although the trend is almost the same, the amount of monsoon evaporation loss in respect of total rainfall is low. The lowest amount of evaporation loss with respect to mean monsoon precipitation is noticed in and around the Longview area (13.67%), while the highest value of 25.38% is found around Dooteriah. On an average, the amount of monsoon evaporation does not exceed 20% of the total monsoon rainfall.

8.4 Estimation of Runoff of the Basin

The water resource of the Balason basin has been estimated in two different ways: (i) the empirical estimation of runoff based on long term average rainfall and temperature data of the catchment area (Khosla, 1950) and (ii) the estimation of runoff based on discharge data of 4 consecutive years (1998 - 2001) at Matigara (NH 31 bridge).

The empirical estimation of the runoff for the basin has been determined for both the rainy months and for the whole year. These two estimates will provide us with the basic information about the long term average available surface water resource of the study area. Although it is possible to estimate the runoff of the basin from the discharge data recorded near Matigara, but these do not seem to be enough for the purpose of water conservation plan of the study area. In fact, the water resource of a basin cannot be determined only from the discharge data because, water inputs through precipitation are exchanged through a complex 'process – response' system.

8.4.1 The mean monsoon (June to October) runoff:

Based on the calculated value of the total monsoon runoff of different recording stations (table 8.2), a monsoon runoff map has been prepared (figure 8.3.). Six major runoff classes have been identified and the corresponding area coverage of each class has been determined and tabulated in table 8.3. The estimated water resource of each class has been estimated by multiplying the area with respective mean runoff. The total water resource has been estimated by summing up all the calculated values, which is 8,53,421 million cubic metre.

Table 8.3

Monsoon (June - September) Runoff of the Balason basin

Sl. No.	Runoff classes (in mm)	Area in sq. km.	% of area to the total area	Estimated runoff in million m^3	% to total run off.
1	Below 1500	41.20	11.21	51.500	6.03
2.	1500-2000	109.22	29.73	191.135	22.4
3	2000-2500	54.70	14.89	123.075	14.42
4	2500-3000	103.46	28.16	284.515	33.34
5	3000-3500	34.91	9.50	113.458	13.29
6	3000 and above	23.93	6.51	89.738	10.52
	Total	367.42	100	853.421	100

Among the monsoon runoff classes 2500 – 3000 mm runoff class contributes the maximum monsoon water resource of the basin i.e., 284.515 m.m^3 (33.34 %) which covers an area of 103.46 sq. km. (28.16 %) of the total area of the basin identified along the entire south central part of the study area.

On the other hand, the lowest runoff class i.e. (<1500 mm), accounts for only 51.50 mm^3 (6.03 %) of the total water resource covering an area of 41.20 sq. km. (11.21 % of the total study area) identified in the extreme north eastern and north western part of the basin. The very high run-off class of above 3000 mm, covers the lowest area of 23.93 sq. km. (6.51 % of the total study area) and contributes 89.738 mm^3 (10.52 %) of the water resource of the basin, identified in the east central part of the study area i.e. southern slope of the Selim Hill..

The monsoon runoff of the Balason basin, as estimated by empirical methods, seems to be higher than other part of the country. It is most probably due to a very

MONSOON RUNOFF OF THE BALASON BASIN

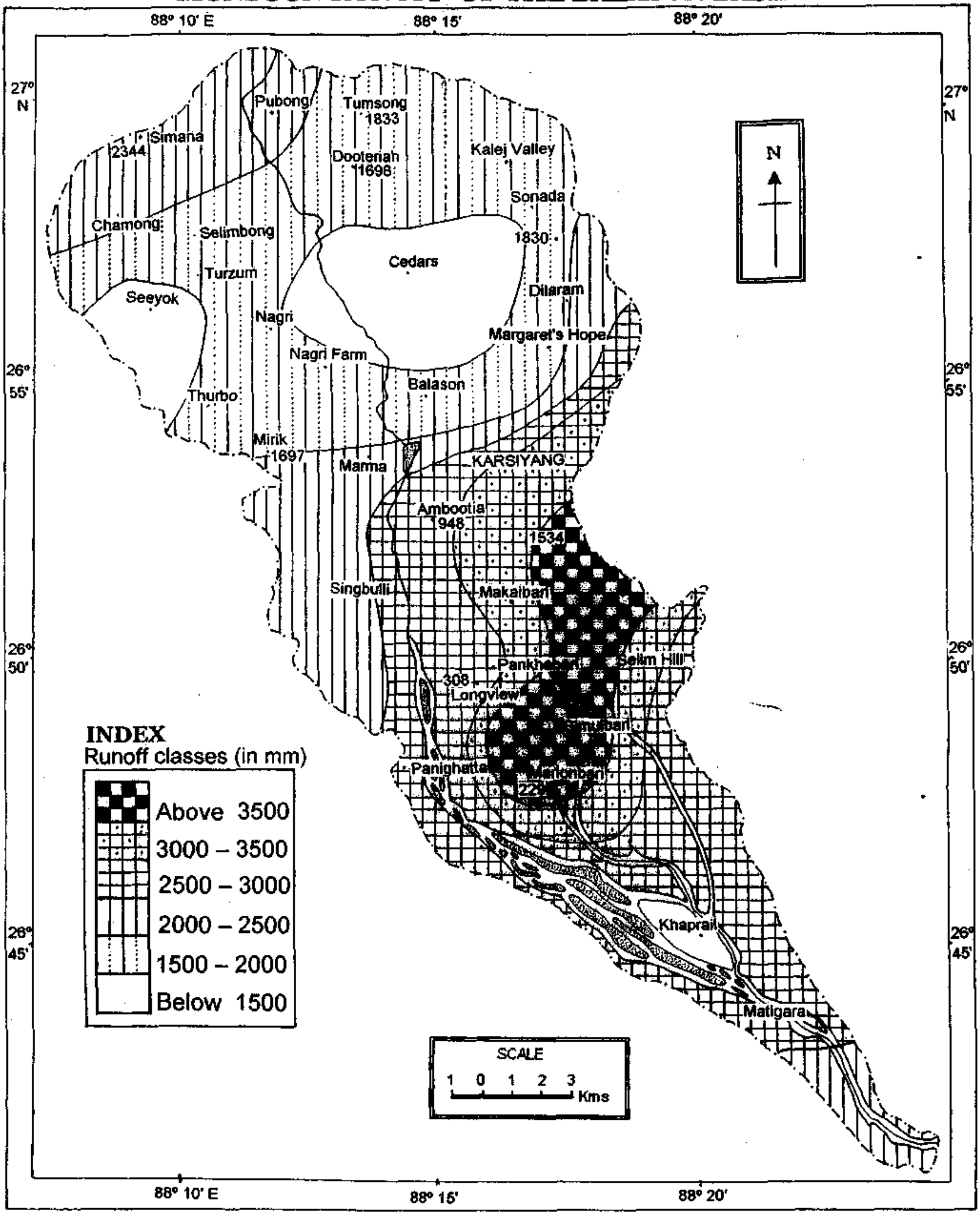

Figure 8.3

high amount of rainfall on a deforested steep slope, which permits quick runoff generation and minimum infiltration and / or retention within the catchment area.

8.4.2 The total water resource

The nature and amount of annual runoff of the basin has been estimated from the figure 8.4 which was drawn on the basis of the collected data from 22 .recording stations (table 8.4). Six classes have been identified to calculate the total annual runoff of the basin and the contribution of each class to the total annual water resource.

Table 8.4.
Mean annual water resource of the Balason basin.

Sl. No.	Runoff classes (in mm)	Area in sq. km.	% of area to the total area	Total runoff in million m^3	% to total water run off.
1	Below 1500	66.57	18.12	83.21	10.59
2	1500-2000	112.45	30.61	196.79	25.04
3	2000-2500	71.79	19.54	161.53	20.56
4	2500-3000	78.27	21.30	215.24	27.38
5	3000-3500	28.08	7.64	91.26	11.61
6	3500 and above	10.26	2.79	37.96	4.83
	Total	367.42	100	785.99	100

Out of the total annual surface water resource of the basin (785.99 m.m^3), the runoff class 2500-3000 mm contributes to the highest amount i.e., 215.243 m.m^3 or 27.38 % of the total. The highest area falls in the 1500-2000 mm runoff class, covering 112.45 sq. km. and contributing to 196.788 (25.04 %) million m^3, which is 25.04 % of the total. The very high runoff class (above 3500 mm) covers only 2.79 % of the total area and contributes about 4.83 % of the total annual water resource of the basin. The very low runoff class (< 1500 mm) shares 66.57 % of the total area but contributes only 10.59 % of the total runoff. The total annual runoff of the basin has been estimated to be 67.477 m.m^3 less than that of the monsoon runoff which indicates that the non-monsoon rainfall have negative influence on run-off.

8.4.3. Estimation of run-off from the discharge record at Matigara

The estimation of runoff has also been carried out based on the daily average discharge data of the river at Matigara for 4 consecutive years (1998 - 2001). The

ANNUAL RUNOFF OF THE BALASON BASIN

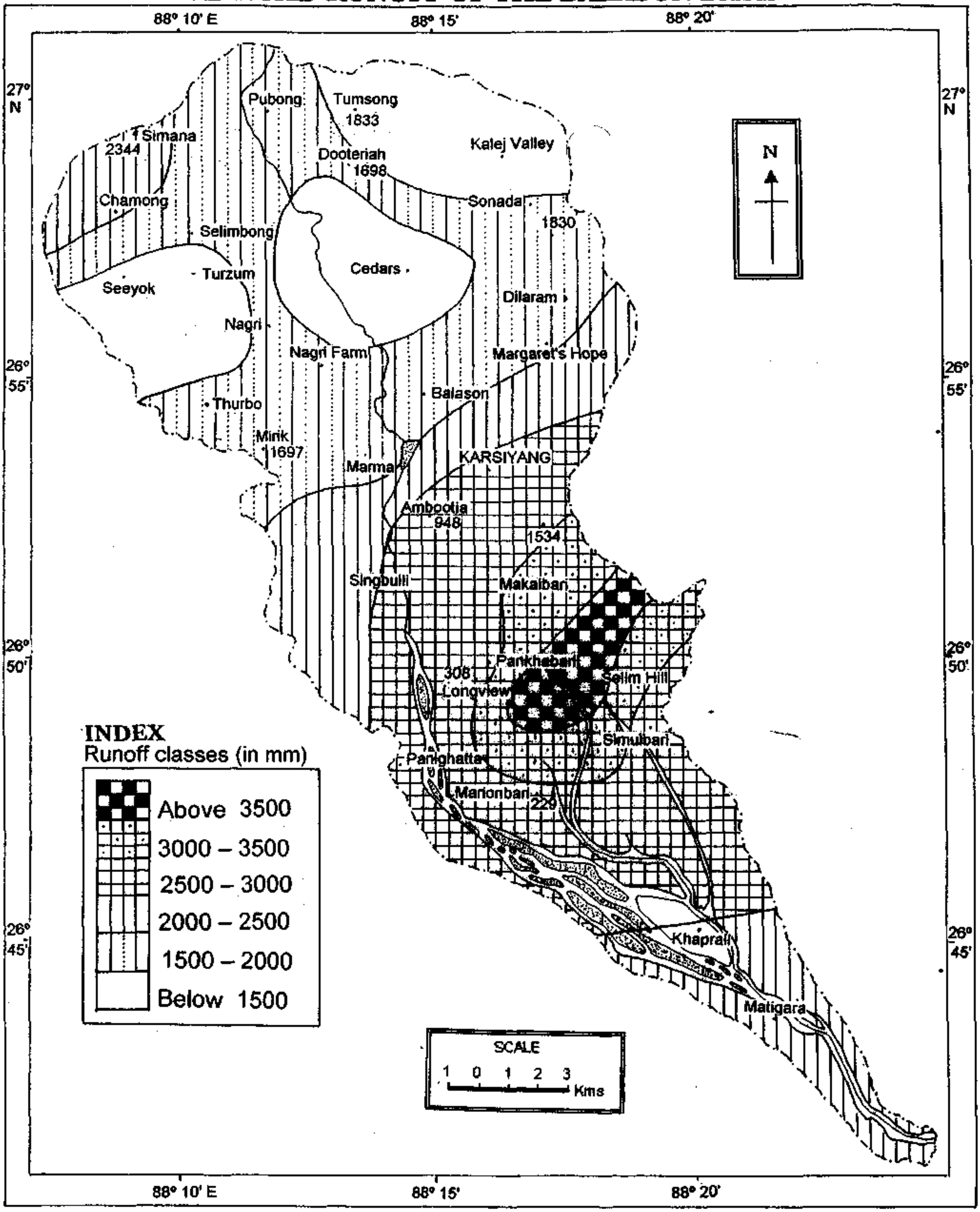

Figure 8.4

total annual runoff has been calculated using the equation 8.4 and based on the data tabulated in table 8.5.

$$Tr = Td \times 86400 \qquad (8.4)$$

where, Tr = total annual runoff, Td = daily average discharge in cubic meter / second.

Table 8.5.

Runoff of different years based on discharge run-off model.*

Year	Annual water resource (million m³		Monsoon water resource m³ million m		Non-monsoon water resource in million m³	
	Total	per Km²	Total	per Km²	Total	per Km²
1998	1343.715	3.66	1263.126	3.44	80.589	0.22
1999	671.068	1.83	592.549	1.61	78.519	0.21
2000	849.692	2.31	722.214	1.97	127.478	0.35
2001	655.077	1.78	587.589	1.60	67.488	0.18
Average	879.89	2.39	791.369	2.15	88.519	0.24

*Based on data compiled from CWC records.

8.5. Estimation of Surface Water Resource of the Balason Basin

The estimation of water resource of the Balason basin has been attempted based on (a) long term mean rainfall of the basin using empirical model and (b) estimation of daily discharge record of the river at down stream near Matigara. The Table 8.6 depicts the salient feature of surface water resource of the basin and also offer an unique opportunity to make a comparative analysis of different estimates of surface water resource of the study area.

Table 8.6

Surface water resource of the Balason basin

Methods	Mean annual		Mean of monsoon months (June to September)		Mean of non monsoon months (October to May)	
	Total	Per km²	Total	Per km²	Total	Per km²
30-60 years average*	785.994	2.139	853.421	2.323	- 67.427	-0.184
Based on discharge (1998 – 2001)	879.89	2.39	791.369	2.15	88.519	0.24
Range	93.896	0.251	-62.052	-0.173	155.946	0.424
Mean	832.942	2.265	822.395	2.2365	10.546	0.028

*Long term water resource based on empirical formula.

From the estimated values it is noticed that the total annual water resource in the year 1998 was 1343.715 million m^3 out of which 1263.126 million m^3 belongs to monsoon period. In 1999, the total annual water resource was estimated to be 671.068 million m^3 of which 592.549 million m^3 belongs to the monsoon period.

In the years 2000 and 2001 the annual water resource was estimated to be 849.692 million m^3 and 655.077 million m^3 respectively, while in the monsoon the amount were estimated to be 722.214 million m^3 and 587.589 million m^3 respectively.

It is interesting to note that the long term average estimates of water resource is considerably less than that of the 4 years (1998 – 2001) mean discharge of the river. In case of non-monsoon months, the empirical model yields a negative value of - 67.427 while, the estimation based on discharge shows a value of 88.519 $m.m^3$. Such difference may be due to the following reasons:

i). The empirical estimation of the water resource of the basin has been carried out on the basis of rainfall and temperature data of some selected stations and thereby, they are reliable for their respective stations only, while the actual estimation has been based on the daily average discharge of the river Balason near Matigara, for the 4 consecutive years (1998 to 2001).

ii). Subterranean water flows as springs (locally known as 'jhora') even in the non-monsoon months contribute considerable runoff and this may account for the positive value of 88.519 million m^3 during non – monsoon months.

iii). The recharge of water through sewage disposal may also play an important role in the overall estimation of surface water resource.

8.6. Conclusion

The high intensity rainfall on steep degraded slopes of the Balason basin of lower Darjeeling Himalaya causes high runoff and thereby, less amount of water becomes available to saturate soil and recharge aquifers, inducing phenomenal degradation along the hill slopes. While, moderately dense forest cover along the foothills reduces the run-off as well as the soil erosion and keeps some water available to form good ground water reserve.

Out of the total surface water yield of 832.942 $m.m^3$ (mean of empirical and discharge method), nothing has yet been utilized commercially. Similarly, its vast sub-surface water reserve remains commercially untapped. It is thus, imperative to find out suitable ways and means to conserve such huge unutilized water resource both surface and sub-surface.

The construction of a number of check-dams across the river at suitable sites to preserve the monsoon supply for re-distribution during the non-monsoon months would serve the immediate purpose adequately. Construction of mini-hydel projects, tapping the mountain torrents at suitable sites, such as Rinchintong Khola, may provide with the vital energy for domestic and industrial activities in the sub-Himalayan West Bengal. Such a comprehensive approach would require taking more than a theoretical interest in the protection of forest resource and needing serious involvement in the task of soil and water conservation measures in the catchment area.

Hence the problem of water management of the region under study by their very nature, are not such as can be tackled by any single discipline. All disciplines concerned with good land and water management should be brought together. This systematic approach to water management should be brought together for the maximization of regional welfare.

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CHAPTER 9

ENVIORNMENT IMPACT ASSESSMENT

9.1. Introduction

Every environmental system, whether natural or man-made, is unique, and is the outcome of the interrelationships and interactions between the biotic and abiotic factors. In some man-made environment, in addition to these physical, chemical and biological factors, the cultural factors may be involved, within which the system is composed. It has of late been realized, that man is but a part of his environment and he can never be outside or above it, and any human intervention, on whatever scale, exercises an influence – positive or negative on the environmental system.

With man trying to improve the quality of life, utilizing the various natural resources, an impact in the form of the degradation of the natural environment occurs. It is realized that an approach has to be made which is to be cautious, after a careful understanding of the environment, if the development is to be sustainable. Any exercise without proper understanding can lead to unforeseen calamities which can be disastrous, endangering not only the other countless life forms but even man himself. Thus, the promotion of the quality of man's environment, should involve the estimation of the carrying capacity, a sustainable and balanced use of natural resources, cautious management of the changes, conservation and promotion of biological and cultural diversity.

The overall impact, that the developmental activities in the Balason region has had on the environment, is an explicit form of degradation, which the region has undergone over the years, like in the other parts of the Darjeeling hills. Scars from landslides, loss of fertile top soil due to soil erosion, loss and changes in the species diversity of plants and animals have resulted in developmental works without proper understanding and planning. These natural and unnatural interactions, between the soil, water, vegetation and man in the region have led to drastic changes in the environment. Thus, the main objectives of the environment impact assessment is to understand:

- The important factors responsible for contributing to the environmental degradation of the region,
- The intensity and magnitude of the environmental degradation so caused and
- The significance, effects and repercussions of the impact on man and the environment.

9.2. Impact Identification

9.2.1. Aims and methods :

Impact identification brings together various developmental project characteristics and baseline environmental characteristics with the aim of ensuring that all potentially significant impacts (adverse or favourable) are identified and taken into account in the EIA (Environment Impact Assessment) process. Among the different states of EIA processes i.e., impact identification, impact prediction, impact evaluation, impact communication, impact mitigation, impact presentation, impact monitoring and impact auditing, the investigator of the present study has decided only to perform impact identification, as through this, she will be able to locate the places of impact magnitude of various degree within the Balason basin.

A wide range of methods has been developed (Stover, 1972; Munn, 1979; Lee, 1987; Wood & Lee, 1987). Soresen and Moss (1973) note that the present diversity, '*should be considered as a healthy condition in a newly formed and growing discipline*'. The methods are divided into the following categories:

- Checklist
- Matrices
- Quantitative methods
- Network and
- Overlay maps

Among the different methods, matrices are the most commonly used method of impact identification in E.I.A. Matrices are, essentially, expansions of checklists that acknowledge the fact that different components of development projects have impacts. Placing a cross in the appropriate cell identifies actions likely to have an impact on an environmental component. The main advantage is the incorporation of *cause-effect relationships.*

The best-known type of quantified matrix is the Leopold matrix (1971). This matrix is based on a horizontal list of 100 project activities and a vertical list of 88 environmental components. In the present study ,the quantified Leopold matrix has been used for the Environmental Impact Assessment of the study area with minor modifications (Table 9.1). This is based on a horizontal list of 39 developmental activities under 9 broad headings and a vertical list of 58 environmental components under 4 broad and 12 sub-headings that are applicable for the study area.

The scope of possible interaction between the developmental activities and the environmental components is wide, as the overall impact is being considered from the time development started to date, and therefore, the assessment could aid in future planning. In each appropriate cell, two numbers are recorded. The number on the left of the back slash represents the impacts magnitude from +10 (very positive) to –10 (very negative). That on the right represents the impact's significance from 10 (very significant) to 1 (insignificant). The modified Leopold Matrix as applied for the said purpose is represented along with a "unit example of Mirik region in table 9.1. To establish a quantitative value of such impact from the matrix, this investigator has applied the following simple calculation:

Impact Magnitude $\frac{\Sigma P - \Sigma N}{TP} x100$ ....9.1.

Impact Significance = $\frac{ES}{TP} x100$ ....9.2.

Table No. 9.1.

Impact identification in Mirik area

A. Modification of Regime

		Exotic Fauna/Flora Introduction (a)	Modification of Habitat (b)	Alteration of Ground (c)	Alteration of Ground water Hydrology (d)	Alteration of Drainage (e)	Irrigation (F)	Weathering Modification (g)	Burning (h)	Surface or Paving (I)
A	1.Earth Mineral Res. Soils Landform	-3/4	-3/4	-2/3		-2/3		-1/1	-3/4 -2/3	-3/3 -3/4
A	2.Water Surface Underground Quality Recharge	-3/3 -3/3	-2/3 -2/3	-2/3	-2/2			-3/4 -3/3 -3/4	-2/3 -1/2 -1/2	-3/4 -2/3
A	3.Atmosphere Atmosphere Quality Rainfall Temperature								-1/1	-3/4
A	4. Process Flood Erosion Deportation Compaction Stability Earthquakes			-2/2	-3/3 -2/2 -2/2					-1/1
B	1.Flora Trees Shrubs Grass Crops Microflora Aqatic Rare species	-3/3 -3/3 -4/5 -2/2 -3/3	-3/3 -3/3 -3/3 -2/2 -3/3	-3/3 -3/3 -4/4 -2/2 -3/3						
B	2.Fauna Birds Mammals Fish Insects Microfauna Rare Species	-2/2 -3/3 -3/3 -3/3 -2/2	2/2 -3/3 -3/3 -3/3 -2/2	2/2 -3/3 -3/3 -3/3 -2/2	-2/2				-3/3 -3/3 -3/3 -2/2	

B. Land Transformation & Construction

		Urbanisation (a)	Industrial sites and Buildings (b)	Highways, Bridges, Roads and Rails (c)	Transmission and Pipe lines (d)	Barriers including fencing (e)	Channel Revetments (f)	Recreational structures (g)	Blasting and Drilling (h)	Cut and Fill (I)
A	1.Earth	-1/2 -1/2	-6/7 -5/6	-1/2	1/1		1/2	-2/1 -1/1	-5/6 -5/4	-2/3 -3/3
A	2.Water							-1/1		-3/3
A	3.Atmosphere	-1/1								
A	4. Process	-3/3 -3/3	-2/2 -2/2	-6/6 -3/3 -5/5			1/1 1/1 1/1		-2/3	-3/3 -2/2 -2/2
B	1.Flora	-3/3 -3/3 -2/2 -1/1	-1/1 -1/1 -1/1	-2/2 -2/2 -2/2						
B	2.Fauna	-3/3 -4/4 -2/2	-2/2 -1/1	-3/3						

C. External; D. Processing; E. Alteration

		C. Surface excavation (a)	C. Clear Felling & Lumbering (b)	D. Farming (a)	D. Hunting and Grazing (b)	D. Lumbering (c)	E. Erosion Control / Terracing (a)	E. Landscaping (b)
A	1.Earth	-5/6 -5/3	-1/2 -2/3	-4/5	-1/2	-4/5	3/3 -5/6	-1/1 -1/2
A	2.Water	-2/3	-4/6 -3//2	-2/2 -2/3 -2/2		-3/3 -3/3	-3/3	-1/1
A	3.Atmosphere							
A	4. Process		-4/4 -6/5 -3/3 -4/4	-4/4	-1/1	-3/4 -4/4 -3/3 -3/3	4/4 5/5	
B	1.Flora		- 3/3 -3/3 -2/2 -2/2			-4/4 -3/3 -2/2		
B	2.Fauna		-4/4 -4/4 -3/3 -2/2		-3/3 -3/4 -4/4			

F. Renewal; G. Traffic

		F. Reforestation, Wildlife, Stocking & Management (a)	F. Fertilizer Application (b)	F. Waste Disposal (c)	G. Railway, Automobile & Trucking (a)	G. Trails (b)	G. Communication (c)	G. Pipeline (d)
A	1.Earth	4/5	-3/4	-3/3	-2/2	-3/3	-4/5	-1/1
A	2.Water	4/5 5/5	-2/2	-2/2		-1/2	-4/4	
A	3.Atmosphere				-4/5			
A	4. Process							
B	1.Flora	4/4 4/4 -4/4 2/2 3/3						
B	2.Fauna	3/3 3/3 3/3						

H. Waste Disposal; I. Chemical

		H. Emplacement of Spoils / Overburden (a)	H. Municipal Waste & Junk disposal (b)	H. Septic Tank (c)	H. Smoke and Exhaust Emission (d)	H. Spent Lubricants (e)	I. Fertilization (a)	I. Weed & Insect Control (b)
A	1.Earth	-3/4 -1/1	-2/3	-2/2	-1/1	-1/1	-2/3	-3/4
A	2.Water	-4/4 -1/2	-4/4 -4/4	-3/3		-2/3	-3/3	-4/5
A	3.Atmosphere							
A	4. Process	-1/1 -4/5 -4/4 -3/3						
B	1.Flora							-3/3 -2/2
B	2.Fauna							-4/4 -4/4 -3/3

.... continued....

	A. Modification of Regime								
	a Exotic Fauna/Flora Introduction	b Modification of Habitat	c Alteration of Ground	d Alteration of Ground water Hydrology	e Alteration of Drainage	F Irrigation	g Weathering Modification	h Burning	i Surface or Paving
C 1.Landuse									
Open Space.	-2/3	-3/3	-3/3						
Wet Lands		-2/2	-2/2	-3/3	-2/2				
Forestry	-4/5	-3/3	-3/3						
Agriculture	-3/3								
Grazing	-3/3	-3/3	-3/3						
Residential									
Commercial									
Industrial									
Mining/ Quarrying									
2.Recreation									
Camping/	2/2								
Picnicking	2/2								
3.Aesthetic									
Scenery	3/3								
Wilderness									
Landscape									
Reserves	-3/3	-3/3	-3/3						
4. Cultural Status									
Health									
Employment	5/5								
Population density	7/7								
5. Man made Structures									
Transport									
Utility									
Waste									
D Diseases									
Food chain	-2/2	-3/3	-2/2					-3/3	
Others									

	B. Land Transformation & Construction								
	a Urbanisation	b Industrial sites and Buildings	c Highways, Bridges, Roads and Rails	d Transmission and Pipe lines	e Barriers including fencing	f Channel Revetments	g Recreational structures	h Blasting and Drilling	i Cut and Fill
C 1.Landuse									
Open Space.	-2/3	-1/1	-3/3						
Wet Lands	-2/2	-1/1	-2/2	-1/1					-2/3
Forestry	-3/4	-1/1	-3/3				-1/1		
Agriculture	-3/3	-1/1							
Grazing	-3/3	-1/1	-3/5		1/1				
Residential									
Commercial									
Industrial									
Mining/ Quarrying									
2.Recreation									
Camping/									
Picnicking							4/4		
3.Aesthetic									
Scenery	-4/4	-1/1	-2/2						
Wilderness									
Landscape									
Reserves	-3/3	-1/1	-4/5	-1/1			-1/1		
4. Cultural Status									
Health	-3/3								
Employment	5/5	3/3	4/4						
Population density	5/6	2/2	3/3						
5. Man made Structures									
Transport				8/8					
Utility									
Waste		-5/5	-2/2						
D Diseases		-3/3							
Food chain		-3/3	-1/1	-2/2					
Others									

	C. External		D. Processing			E.Alteration		F. Renewal		
	a Surface excavation	b Clear Felling & Lumbering	a Farming	b Hunting and Grazing	c Lumbering	a Erosion Control / Terracing	b Landscaping	a Reforestation, Wildlife, Stocking & Management	b Fertilizer Application	c Waste Disposal
C 1.Landuse										
Open Space.			-2/2							
Wet Lands		-3/3		-4/4	-3/3	3/3		2/2		
Forestry		-4/4	-1/1			4/4		6/6		
Agriculture		-3/3	1/1					4/4		
Grazing								-3/3		
Residential										
Commercial										
Industrial										
Mining/ Quarrying										
2.Recreation										
Camping/								3/3		
Picnicking										
3.Aesthetic										
Scenery										
Wilderness										
Landscape										
Reserves		-4/4				3/3		5/5		
4. Cultural Status										
Health										
Employment			4/4		3/3					
Population density			3/3							
5. Man made Structures										
Transport										
Utility										
Waste										
D Diseases										
Food chain				-3/3					4/4	
Others										

	G. Traffic				H. Waste Disposal					I. Chemical	
	a Railway, Automobile & Trucking	b Trails	c Communication	d Pipeline	a Emplacement of Spoils / Overburden	b Municipal Waste & Junk disposal	c Septic Tank	d Smoke and Exhaust Emission	e Spent Lubricants	a Fertilization	b Weed & Insect Control
C 1.Landuse											
Open Space.											
Wet Lands											
Forestry											
Agriculture					-3/3						
Grazing											
Residential											
Commercial											
Industrial											
Mining/ Quarrying											
2.Recreation											
Camping/		3/3									
Picnicking											
3.Aesthetic											
Scenery											
Wilderness											
Landscape											
Reserves											
4. Cultural Status											
Health									-4/4		-3/3
Employment	5/5										
Population density											
5. Man made Structures											
Transport											
Utility											
Waste											
D Diseases						-3/3	-3/3	-2/2			-3/3
Food chain											-4/4
Others											

A= Physical and Chemical Conditions B= Biological Conditions C= Cultural Condition D= Biological Relations *where P = positive impact; N = negative impact; TP = total parameters and S = significance.*

The matrix has been applied as a 'check list' in 45 different sites within the study area for gaining an idea on the spatial distribution of environment impact of the various developmental activities in the Balason basin..This helps in producing two maps:

(i) impact magnitude
(ii) impact significance

9.2.2. Impact magnitude :

Figure 9.1. depicts the different zones of the magnitude of environmental impact of development activities. Impact magnitude are found to vary from highly positive (300) to highly negative (-300). In general various magnitude of positive impacts have been found to be more wide spread in the northern half of the study area; while the negative impacts of different magnitude predominated the southern foothills of the study area. The present investigator with the help of the following classes has attempted a more specific distribution of the different kinds of impact magnitude.

Class I. High positive impact occurs in two very narrow strips bordering the extreme north-western (along Simana) and north eastern peripheries of the study area. These areas are still under virgin forest cover and hardly affected by adverse developmental impact on environment.

Class II. Moderate positive impact has been identified in the southern sections of the former zone, extending through Pubong and arching further east, culminating just above Kalej Valley. A wedge like protuberance extends south-eastwards. A small wedge occurs in and around Panighatta. These tracts are still under natural forest cover of different species. Positive impact of silviculture activities can also be observed.

MAGNITUDE OF ENVIRONMENTAL IMPACT IN THE BALASON BASIN

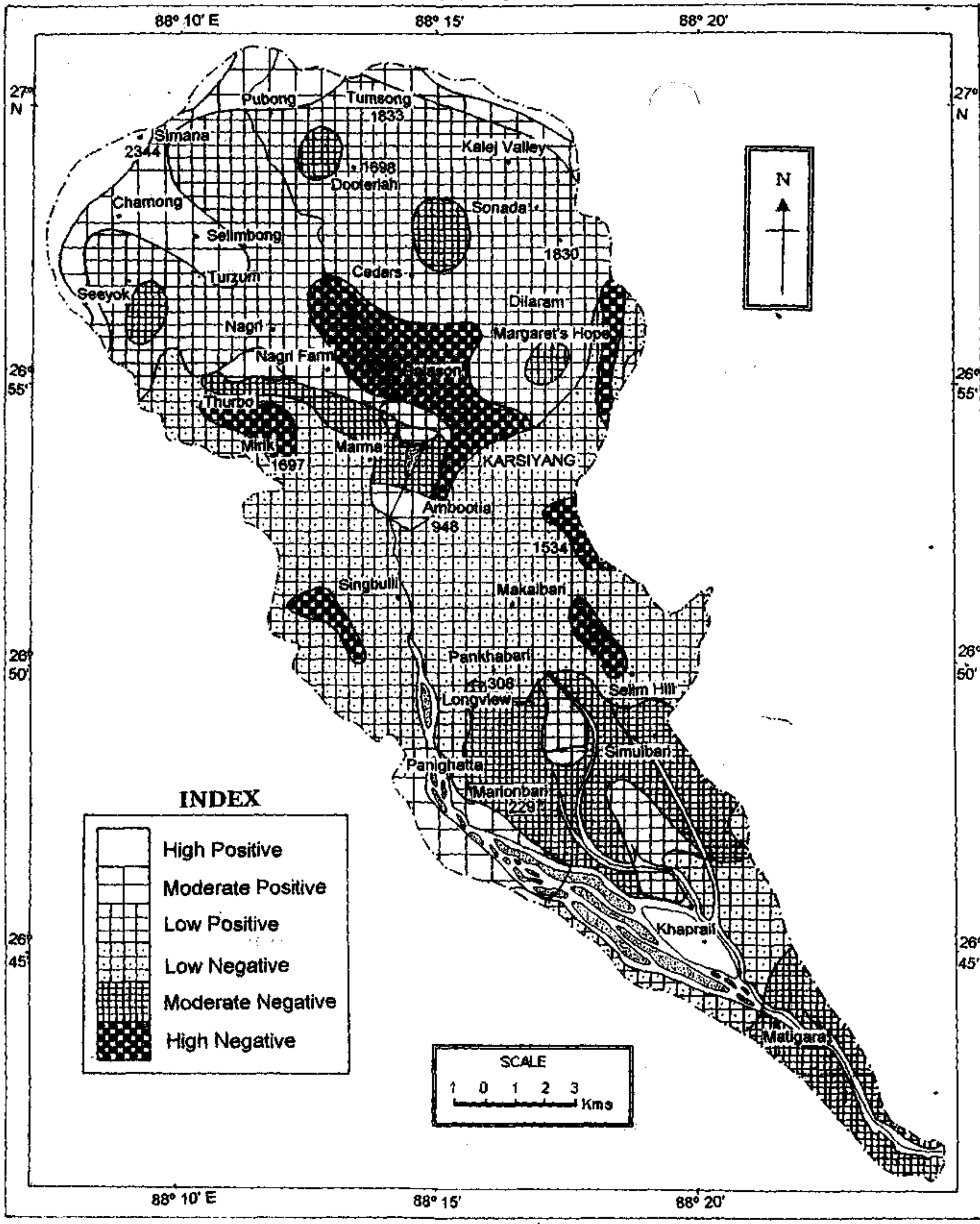


Figure 9.1

Class III. Low positive impact predominates over the northern half of the study area from Seeyok in the west to Tumsong in the north, through Kalej valley, Sonada and Dilaram in the east and as a narrow elongated strip along Nagri farm in the southern section of this zone. These tracts are dominated by tea plantations and forested areas. Although, the large scale plantations have detrimental effect on biodiversity, these plantations also have a beneficial impact on landscape and soil-water management since soil erosion is checked and ground water aquifers are recharged. Consequently, a low degree of positive impact is attained.

Class IV. Low negative impact covers an extensive section in the central region of the study area from Mirik through Karsiyang, Ambootia and then to Singbuli, Makaibari and Selim Hill. The Khaprail region also exhibits low negative impact. In this zone human settlements and large scale cultivation and arable farming along with the introduction of tea gardens have destroyed the regional biodiversity, thereby exerting a negative impact on the environment.

Class V. Moderate negative impact spreads throughout the study area. In the northern sections, they are found in small pockets around the Dooteriah, Cedar, Seeyok and Margaret's hope tea gardens. A narrow strip occurs just north of Thurbo and extends eastwards into Marma. In the southern half of the study area, more extensive regions are marked from Longview and Simulbari into Marionbari. Another wedge occupies the southern extremity along Matigara. These zones are mostly tea garden areas.

In the northern hilly areas large scale destruction of forest in the steep slopes have induced many unfortunate environmental repercussions like landslides and soil erosion. In the plain areas surrounding Matigara, the presence of Chandmoni tea garden (recently converted to a township) and dense human settlements with associated human activities like rock quarrying and road blasting, arable farming etc. have had a negative impact on this region.

Class VI. High negative impact are found scattered in pockets in the central section of the study area. The most noteworthy is in a broad wedge east of Nagri Farm along the Balason tea garden. This area is characterized by the highest degree of deforestation and excessive human settlements. Consequently, haphazard constructions, inadequate drainage and unsystematic landuse have established a vicious circle of degradation leading to a high to very high negative impact of the 'developmental activities' on the environment.

9.2.3 The impact significance :

The spatial distribution of environmental impact significance has been identified based on modified Leopold matrix (table 9.1.). Such semi-quantitative rating value has been obtained from 45 sites chosen randomly and plotted on the map. The impact significance map thus prepared based on interpolation method (figure 9.2). It has been found that the impact significance varies from very high (8) to insignificant (1). The following significant classes have been identified:

Class I. Highly significant impact has been identified along a few elongated tracts i.e., along the Dilaram-Karsiyang areas, Mirik-Thurbo-Soureni areas, east of Singubuli, a large area engulfing the Nagri, Nagri Farm and Balason tea garden, Ambootia, Makaibari-Selim Hill region . These areas experienced most devastating impact of development activities on environment. Ever increasing population growth and unplanned developmental activities are also found responsible for such high significance of environment impact.

Class II. Moderately significant impact is most widespread and has been identified in most of the tea garden areas. Large scale destruction of hill slope biodiversity exerts tremendous stress on the delicate hill ecosystem. Use of fertilizers, pesticides and herbicides to augment tea production also have detrimental effects on the quality of land, water and atmosphere of the area. Innumerable

ENVIRONMENTAL IMPACT SIGNIFICANCE IN THE BALASON BASIN

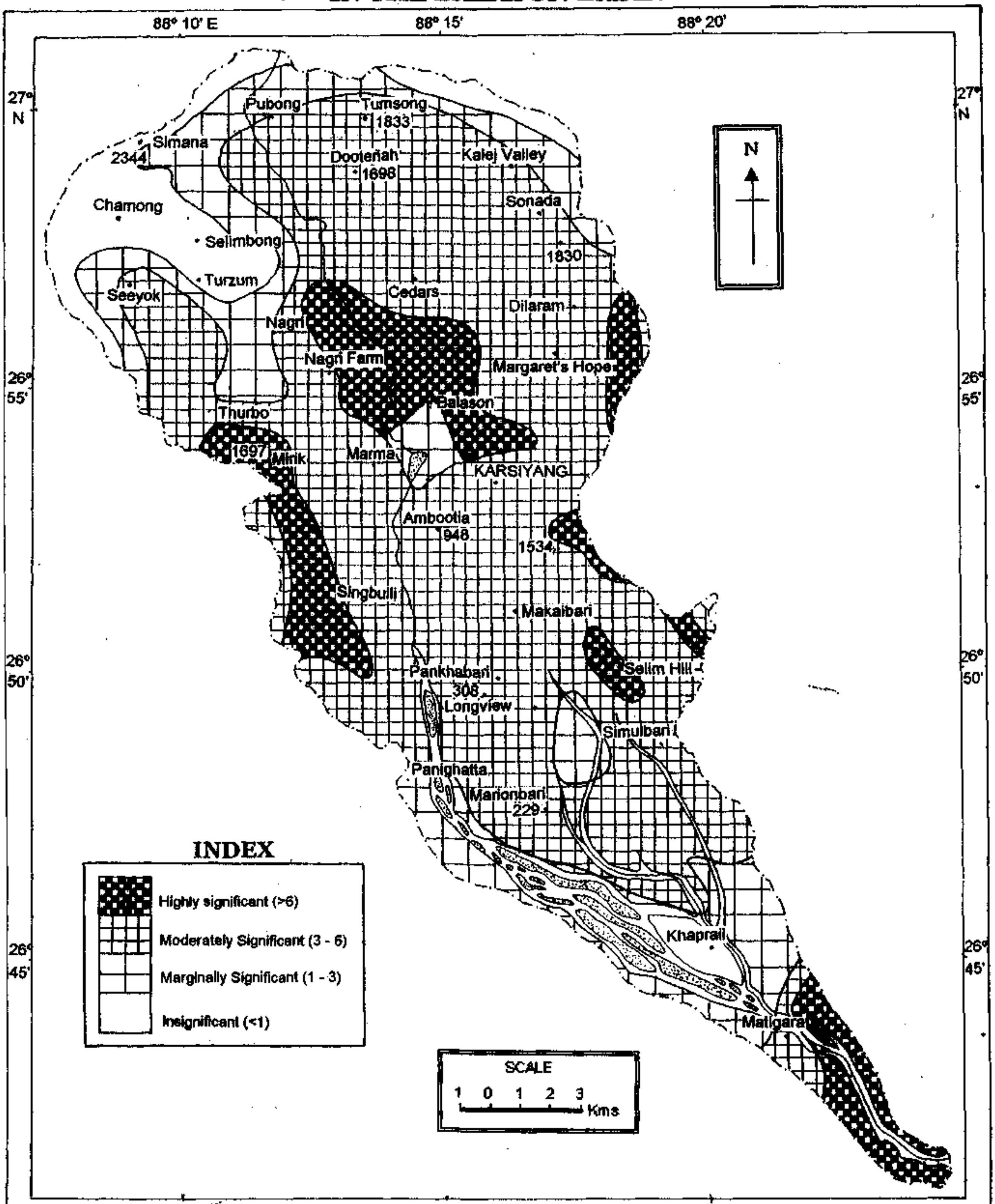


Figure 9.2

unprotected roads, footpaths and trails cause heavy loss of surface soil and often invite landslides.

Class III. Marginally significant impact has been noticed in degraded forested areas and in plantation tracts. Reduction of biodiversity and natural regeneration, coupled with marginal development activities, have exerted such adverse impact.

Class IV: Insignificant environmental impact has been noticed in the north western part of the study area around Simana Busty, Chamong, Selimbong and Turzum and in the Panighatta and Khaprail area in the southern part of the study area. These areas are still free from any significant development and/or modification impact and are largely covered by dense natural forests. An overview of the matrix suggests high interactions between the components under modification of regime with those of flora, fauna and land-use. The modification of regime brought about by the introduction of new species and management practice has negative impact on the environmental components, particularly flora and fauna and is quite significant.

The impacts of such interactions are best comprehended in the following case studies on vegetational analysis of plantations of exotic species. The other development activity having high interaction is land transformation and construction, which has influenced the processes like flood, soil erosion and landslide, with high magnitude, the impact of which is very significant. This has been clearly revealed in the specific case study on landslide caused by construction activity.

9.3. Case Studies

9.3.1. The impact of *Cryptomeria japonica* (Dhupi) plantation on the environment :

With the advent of the tea plantation in the British era, *Cryptomeria japonica* was introduced primarily to make tea boxes. However, due to certain environmental factors the fibers of this plants were thickened and thus unsuitable for such use. However, due to its quick growing characteristics, it was soon adopted for commercial forestry. Now it has been more or less understood, that the introduction of this exotic species has had a negative effect on the local vegetation.

To understand the impact of the effects of dhupi plantation, the investigator carried out vegetational analysis in the middle hill areas near Mirik to determine the impact of growing monocrop of dhupi on the biodiversity with particular reference to the plant species (photo 9.1). A similar investigation had been earlier carried out in Mahaldiram block of Kurseong Forest Division, one having natural forest consisting of miscellaneous species and the other of pure dhupi plantation of 1929-31 (Bhutia, 2000).

Vegetational analysis were carried out by utilizing quadrats of different sizes for trees, shrubs, climbers and sampling and the herbaceous cover (Santra, Chatterjee and Das, 1989). For the trees 30 randomly placed quadrats of 20 x 20m were utilized in each of the forest types i.e. the natural mixed forest and the dhupi monoculture forest. Within each of these two 5 x 5m quadrats were placed for the study of the saplings, under trees, shrubs and climbers. Within each 5 x 5m quadrat a 1 x 1m quadrat was placed for the study of the herbaceous ground cover.

The different data obtained, showing the number of quadrats has been represented in which, the total count relative frequency, relative abundance and the importance value of each species has been calculated (appendix 9.1a, 9.1b, 9.1c) Analysis of the data has been carried out to come to the conclusion of the effect that the dhupi plantation has on the overall detrimental effect on the vegetation of the region. Frequency class diagram (figure 9.3) of the natural forest and dhupi plantation were prepared and compared with the Raunkiaer's frequency class diagram. Raunikiaer's frequency class is given in the table 9.2.

The Mirik natural forest was found to comprise of 41 different tree species, while only 15 species were found in association with the *dhupi* plantation. Moreover the number of trees, in the natural forest was greater, the total number being 663 as compared

Photo 9.1 Mirik-site of impact analysis of *Cryptomeria Japonica*

Photo 9.2 Flattened Mirik Dome : note the deep gully formation

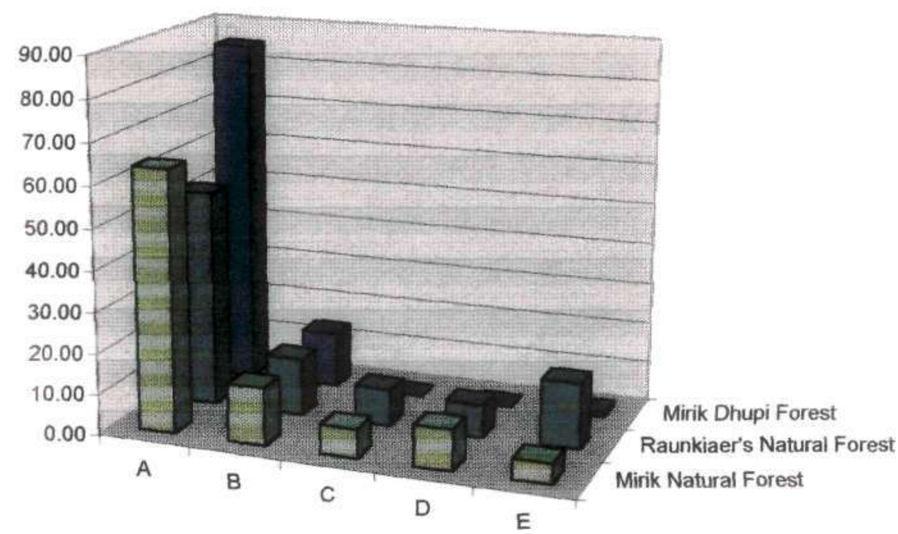
Photo 9.3 A dumping ground for construction refuge- a future hazard

Table 9.2

Raukiaer's frequency class

Frequency class	% of the Frequency
A	0-20%
B	21-40%
C	41-60%
D	61-80%
E	81-100%

FREQUENCY CLASS DIAGRAM



	A	B	C	D	E
Mirik Natural Forest	63.83	14.18	7.09	9.93	4.96
Raunkiaer's Natural Forest	53.00	14.00	9.00	8.00	16.00
Mirik Dhupi Forest	85.00	13.75	0.00	0.00	1.25

Figure 9.3

to 487 in the *dhupi* plantation, with the number of *dhupi* alone being 362. The upper storey in the natural forest chiefly comprised of trees like *Acer campbellii, Castanopsis indica, Engelhardia spicata, Symplocus theafolia, Tetractum fraxinifolia, Brassiopsis hainla* etc., the middle storey was occupied by smaller trees like *Eurya* *acuminata, Ehertia wallichiana,* with *Alnus nepaulensis* occurring along the steep slopes.

The lower storey of shrubs chiefly were *Osbeckia nepalensis, Urtica dioica, Girardina palmate, Eupatorium adenophorum,* and climbers like *Cuscuta reflexa, Stephania elegans, Ipomea tumifolia* etc.; the understorey in the *dhupi* plantation was less dense with the more open spaces being occupied by exotic shrubs like *Lantana camara, Eupatorium adenophorum, Artemesia indica.* The effects on the lower layers were more pronounced, with respect to both the number of species and the total number of individual species. While 39 species were recorded in the natural forest with 28 being shrubs and 11 climbers, the number of shrubs and climbers were 18 and 4 respectively in the plantations.

The ground cover in the natural forest comprised of 41 species as compared to 28 found in the dhupi plantation. Regeneration of trees were also found to be much lower in the dhupi plantation with seedlings of 11 species recorded in the natural forest as compared to only 7 species in the plantation. Thus, the dhupi plantation, which was initiated during the British era has been shown to have a detrimental effect on the natural vegetation of the region. The thick dense canopy does not allow penetration of sufficient light thus checking the growth of the lower tiers and the ground cover.

Moreover the acidic secretion of its roots have allelopathic effects and does not allow the growth of the lower storey (Sarkar,1985). The absence of undergrowth in such plantations may also increase the surface run-off leading to more soil erosion, particularly where slope gradient is more.

A similar situation can be observed in the lower reaches of the study area where monoculture of *Tectona grandis* (teak) are being carried out in large scales along the lower parts of the hills and the foot hills. This includes regions like Pankhabari and Simulbari. The teak plant also does not support the growth of the under storey like the dhupi plant. The overall ecological impact of such mono-cultural practices need to be studied in greater depths although it can be said that introduction of exotics have always had detrimental effects on the natural vegetation of any region.

A comparative analysis based upon Raunkiaer's Frequency Class of the two types of forests (figure 9.3) shows that the dhupi plantation deviates widely from that of Raunkiaer's normal forest thus, indicating that it constitutes biotically a highly disturbed site. The natural forest is close to the Raunkiaer's normal forest, but here too slight deviation can be observed, which shows that group with the highest relative frequency i.e. Class E of Raunkaer's Class is effected. This may be due to removal of some of the plants of commercial importance, grazing by domestic animals and removal of forest products and produce.

9.3.2. Impact of ridge-top cutting and throwing of talus material downhill :

The disposal of talus materials, resulting from the excavation of hill slopes and hill tops for so called development purposes, and in many cases into jhoras and kholas is a common practice in the study area. This particular case exemplifies how such an action has initiated a series of landslides that have affected the road communication, agricultural fields and threatened the fluvial environment of the river Marma, an important tributary to the river Balason (photo 9.2).

The Darjeeling Gorkha Hill Council in 1995, undertook an ambitious project of constructing a helipad in Mirik area to boost tourism. The Mirik Dome was selected for the purpose and operations to cut the dome and level the area started in a war footing by engaging heavy bulldozers and hundred of labourers, (Bhutia, 2000). The excavated materials was thrown downhill into the area which formed the source of Marma Khola ignoring the consequence of such heedless action. The project was abandoned in 1996 for certain reasons but the damage was already done, as landslides occurred immediately during the monsoons resulting in the disruption of

CONTOUR PLAN OF THE MIRIK LANDSLIDE **GEOLOGICAL AND GEOMORPHOLOGICAL SET UP OF THE MIRIK LANDSLIDE**

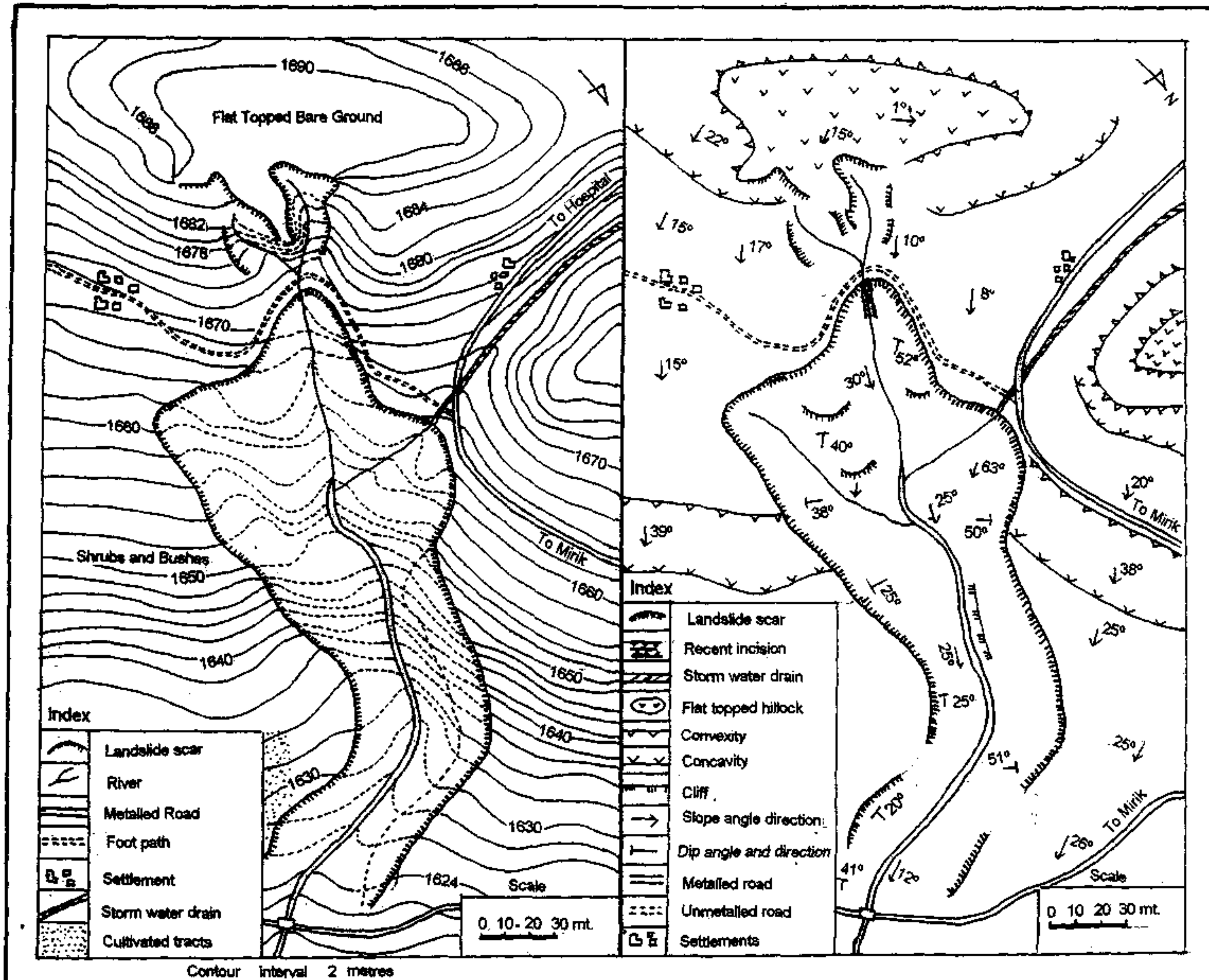


Figure 9.4

Table 9.3

Morphology of Mirik Landslide

Pre-slided conditions	Post slided conditions (1997)*	Post slided conditions (2000)**	Remarks
1.Rocks: Moderate to highly decomposed jointed granite, gneiss interbedded felspathic veins. The rocks are dipping at an angle of 20°– 60° towards NE-SW, NNE-SSW and EES-WWN. A number of joints have been identified.	1.Length of the scar: 270 meter. 2. Width of the scar: Max. 95 meter Min: 10 meter Ave: 52.5 meter 3.Depth of the scar: Max. 5.1 meter Min: 0.3 meter Ave: 2.7 meter	1.Length of the scar: 340 meter. 2.Width of the scar: Max.:15 meter Min: 12 meter Ave:63.5 meter 3.Depth of the scar: Max. 7.2 meter Min: 0.3 meter Ave: 3.75 meter	Within a short period the link between Mirik and hospital will be affected. Immediate proper storm water draining system and protective walls are recommended.
2. Altitude: 1620 to 1690 meter	4. Shape: Triangular	4.Shape: Triangular	
3. Slope: Convex (25° – 30°)	5.Total area affected 14,175 sq meters. 6.Total volume of materials displaced: 38,272.5 m^3	5. Total area affected 21,590 sq meters. 6. Total volume of materials displaced: 80962.5 m^3	
4.Natural vegetation: Scattered shrubs. Land use: Tea garden is situated just below the threatened area. Mirik to Hospital road passes through this affected area. Shrubs are found scattered here and there.	7. Process responsible for the landslide: Removal of basal support by toe cutting makes the stage ready for the slide. Spontaneous liquefaction due to heavy rainfall and cutting of the ridge tops for helipad has actually provided the so-called trigger mechanism.	7. Process responsible for the landslide: Removal of basal support by toe cutting makes the stage ready for the slide. Spontaneous liquefaction due to heavy rainfall and cutting of the ridge tops for helipad has actually provided the so-called trigger mechanism.	Ridge top cutting materials were thrown away along the natural stream down slope. These unconsolidated materials have undergone massive gully erosion during the monsoon months. Such stream action along with continuous toe cutting has actually invited disastrous landslides along the upper landslides al9ng the upper valley of the river Marma, a tributary of Balason
5. Soil Colour Top: 10 YR 4/4 (Dusky red) Mid: 2.5 YR 4/4 (Reddish Brown) Base: 5YR 4/3 (Reddish brown)	8.Modified slope: Concave and irregular (12° – 60°) 9.Type of slide: Debris flow 10. Special features: A number of gullies have developed, incisions have also been noticed.	8.Modified slope: Concave and irregular (12° – 65°) 9.Type of slide: Debris flow 10. Special features: A number of gullies have developed, incisions have also been noticed.	

*Based on Bhutia and ** field observation by the investigator.

communication and loss of agricultural areas along the banks of the jhora. Bhutia (2000) has excellently documented the causes and effects of landslide that has taken place during the monsoon of 1997 (figure 9.4). The follow-up study reveals how unscientific and irrational activities of man can cause irrevocable damage to the environment. The dumping of excavated materials into the source of Marma Khola has initiated landslides along the entire tract of the entire tract of the khola, causing a series of chain reaction leading ultimately into deterioration of the hydrological regime of the river Balason.

9.4. Conclusion

From the above studies, it can be concluded that unscientific developmental activities, without taking into consideration the fragile nature of the Himalayan ecosystem can lead to serious environmental degradation. The impact of such activities have been adverse and if not heeded, could lead to extensive damage to both human life and environment.

It has thus become necessary that extensive studies be carried out and analysis of the impact of development activities be made, before undertaking any such activities in this region. Under the prevailing conditions of environmental degradation in the study area, it has become absolutely necessary to have a comprehensive plan to offer every remedial measure, for each and every kind of adverse environmental effect of development project. This would also help to adopt precautionary measures that are pertinent and need to be followed, before undertaking any development activity. These have to be taken up seriously and followed carefully if the development activity is to have the minimal adverse effect on the ecology of the region.

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ABSTRACT

The Balason basin includes the south-western part of the Darjeeling hills and a section of the North Bengal *terai,* falling within 26° 41' N to 27° 01' N latitudes and 88° 7' E to 88° 24' E longitudes, covering an area of 367.42 sq. km.

Implementation of various development schemes, construction of human settlements and roads to cater to the ever-increasing population, exploitation of forest produce to generate employment, unscientific agricultural practices, growth in tourism, tea plantation and quarrying have triggered huge and complex disasters, on a scale, never encountered before in the fragile Balason basin.

Geologically, it can be seen that the study area is a young, fragile region, with intensely metamorphosed rocks like phyllites, schists, slates and gneisses covering most of the area. These rocks are highly weathered, fractured and jointed and have a tendency to produce slope instability during intense rainstorm.

The Balason basin can be geomophologically classified into two broad zones: while the northern hilly part forms the erosional zone; the lower southern piedmont zone constitutes the accumulative form. Active down cutting is evident in a number of places along the Balason valley. The numerous geomorphic forms that occur in the study area are a result of tectonic disturbances and neo-tectonic activities. Major geomorphic forms have been identified in the study area that include denuded outliers, dome like summits, broad ridges, trough- like valleys, wide valleys, landslide scars, landslide tongues, debris fans, deep V-shaped valleys, alluvial fan plains, river terraces etc.

The quantitative analysis of the various morphometric properties of 55 third order basins also reveal some striking results regarding their multiple process-response

relationships. That the basin area (A_3) is often highly correlated to many other morphometric variables is very much apparent. The strong correlation between the basin area (A_3), the stream lengths ($\Sigma L_3, L_1, L_2$ and L_3) and stream numbers (ΣN_3, N_1, and N_2) suggest that local reorganization of drainage basin area may be expected to lead to a reduction in stream length and number. On the contrary, the negative relationship between basin area (A_3) with drainage density (D_3), stream frequency (F_3) and relief ratio (Rh_3) suggest that they are likely to increase as the basin area decreases. The increase in the efficiency of the drainage network may be responsible for the reduction of first order streams within the third order basins, as fewer streams are needed to meet the conditions in the area in which it has entered in the early stages. The still young and active Balason basin is in a state of inequilibrium and moving towards a state of early maturity in the future.

The soils of the Balason Basin can, basically, be sub-divided into 2 orders, 4 sub-orders, 4 great groups and seven sub-groups. The soils have an inherent low nutrient status. The entire southern half of the study area shows deficiency in organic matter, nitrogen and phosphate. The dominant soil taxonomic order has been recognized as the Inceptisols, which cover the entire northern hilly tracts and show deficiency in phosphate and potassium.

The drastic reduction of the natural forest, combined with the high annual rainfall exceeding 3000 mm in most parts of the basin, makes the area highly vulnerable to soil erosion and landslides, reducing the soil fertility, choking the streams and leading them to change their courses. Thus, the study area, which is geologically highly vulnerable and experiences very high precipitation, coupled with heedless deforestation and unscientific changes in the land-use pattern, poses a threat to both the life and property of the local inhabitants.

Pedological studies reveal that the soil of Balason basin is erosion prone and is extremely precarious along the northern hilly tracts. Very high slope gradient (30° -

40°), along with high and concentrated rainfall (2500–4500 mm) aggravate erosional hazards. Solum mixing, truncation and the presence of coluvial stone horizons have been identified in many cases, due to excessive soil erosion.

Observations from several statistical relationships show that while most of the soil properties are inversely related to the slope, the rate of infiltration is positively related to the slope. This is most probably due to complex interactions among a number of variables like soil texture, organic matter, thickness of A horizon etc. The multiple correlation studies also show some striking results. The spatial distribution of the relationships and their interactions in different lithological, altitudinal and slope environment are analysed statistically.

Significant relationships have been found around the broad summits in the northern hilly part, i.e. the gneissic area, with higher elevation (>1000 m), and southern, undulating plains having a gradient of less than l5°. But the pedo-geomorphic parameters obtained from areas having unconsolidated parent materials with moderate altitude (300 –1000 metre), steep gradient (>15°) fail to achieve statistically significant relationships. This is most probably due to the fact that the northern summit and the southern undulating plains of the Balason basin have achieved, pedo-geomorphically, a more stable state where the pedogenic and geomorphological processes have achieved some sort of equilibrium as a process - response system.

The northern, non-gneissic terrain and the southern piedmont areas experience heedless deforestation, mass movements and the streams draining through the region are in the habit of depositing enormous amounts of fresh silts during rains each year. Thus, the continuous depletion of the slope materials in the northern hilly terrain and the continuous increment of highland refuges in the southern piedmont areas have detrimental effect towards achieving the stability of the pedo-geomorphic parameters.

The assessment of soil loss by water erosion has been attempted through the study of its process and mechanisms and apprehending a number of diagnostic criteria. The heedless destruction of the forest cover has had its toll on the natural landscape. The degradation of the forest cover with increasing population pressure has elevated the natural soil erosion manifold. The complete severance of the fertile topsoil has gradually led to the loss of fertility and the natural regeneration of the forest cover has dwindled. Thus, the compactness of the soil of the study area has been lost and this has led to various environmental hazards.

The worst affected area lies in the central parts of the Balason basin. This area is deforested and characterized by skeletal soil and very steep slope (>30°); and needs the immediate implementation of conservation measures. Special attention must be given to areas along the roads, railways, tea gardens, agricultural terraces and existing settlements.

Large-scale afforestation, with suitable tree species, along with terracing and drainage facilities is necessary to check massive soil loss. The southern parts have shown very low to negligible soil loss, below 5 tons/h^{-1}/y^{-1}. Among the various conservation measures, the agronomic measures should be given preference because they are less expensive and deal effectively in reducing the impacts of raindrops, increasing infiltration, reducing run-off volume and decreasing water velocities.

An examination of the geological setup, process of slope evolution, precipitation, slope cover, landuse, soil characteristics and hydro-geomorphic processes shows that the study area has a high potential for landslide hazards. The landslides are more frequent in densely settled areas, along transportation lines tea gardens and steep deforested valley side slopes. The study area exhibits various types of slope failures, of which slumps, soil-slips, debris-slides, mud-rock flows and debris-flows are important.

A close look at the landslides of the area reveals that the unscientific and unplanned human interferences have greatly contributed to the disruption of the fragile hill eco-system. In some other cases, the slides have been caused by toe-erosion of the drainage elements. The present study emphasizes the fact that the choice of remedial measures to prevent the landslides should be made after careful analysis of the causative factors. Consequently, the preventive structures should be designed taking the geomorphological and geological framework of the region and the strength of the materials involved in the landslide. Treatment of slope configuration, improvement of drainage facilities and retaining walls, afforestation and restricting human settlements are identified as the most important corrective and preventive measures to be adopted in the study area.

The cross-sectional areas, the wetted perimeter and hydraulic radii of the Balason river reveal very little variations from year to year in the dry months; while the variations are pronounced in the monsoon months. However, the river quickly readjusts itself, either by erosion or deposition, in the instances when changes do occur. An analysis of the hydrograph reveals that high intensity discharge concentrating within a short period, relates to rainstorms, consequently, causing severe floods. The analysis of the suspended load of the river shows an increasing trend, which, accompanied by similarly increasing bed load has resulted in an increase in the braiding tendency of the river. The boulders and gravels carried to the foreland by the annual floods of the river are intensively exploited at the rate of 20 cm/year, thereby eliminating the possibilities of large-scale river bed rising as can be seen in most of the other sub-Himalayan rivers of West Bengal.

Moderately dense forest cover along the foothills reduces the run off as well as the soil erosion, keeping some water available to form good ground water reserves. On the other hand, high intensity of rainfall on steep degraded slopes of the Balason basin causes high runoff and thereby, less amount of water becomes available to saturate soil and recharge aquifer and inducing phenomenal degradation along the hill slopes. Consequently constructing a number of check dams, across the river at suitable sites to preserve the monsoon supplies for re-distribution during the non-monsoon months, would serve immediate purpose adequately.

A quantitative assessment of the environmental impact of the developmental activities has been attempted based on Leopold's matrix. Under the prevailing conditions of environmental degradation in the study area, it becomes essential to create a comprehensive plan to offer remedial measures for each and every kind of adverse environmental effect of development projects. The pertinent precautionary measures will then have to be taken up and followed seriously, if the developmental activity is to have minimal adverse effect on the environment.

Unscientific development activities, without taking into consideration the fragile nature of the Himalayan ecosystem, can lead to serious environmental degradation. And at this juncture, whether we opt for a 'green earth' or a 'barren landscape' – the choice is entirely ours ! And if the rampant, heedless exploitation of Mother Nature continues at the present rate, Hans Reiger has already sounded the alarm : *" There is only one Himalaya to lose ! ! "*

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CHECKLIST OF THE IDENTIFICATION OF LANDSLIDE-PRONE AREAS

Locality : *Pankhabari*
Observer : *Indira Lepcha (nee Lama)* Date: *18th November, 2000.*

I. Relief

	Rating	*1*		*2*		*3*		*4*
a) Valley depth:	Small	....	Moderate	....	Large	3	Very large	....
b). Slope steepness	Low	....	Moderate	....	Steep	3	Very steep	....
c). Cliff	Absent	1					Present	....
d). Height difference between different valleys	Small	....	Moderate	2	Large shallow		Very large	
e) Valley slide slope	Spur	....	Straight	2	cove	......	deep cove	....

II. Drainage

	Rating	*1*		*2*		*3*		*4*
a) Drainage density	Low	....	Moderate	2	High	....	Very high	....
b) River gradient	Gentle	....	Gentle	....	Steep	3	Very steep	....
c) Slope undercutting	None	1	None	....	Severe	....	Very severe	....
d) Concentrate seepage flow	Absent	....					Present	4
e) Standing water	Absent	1	Absent	.....	Moderate	.....	High	.....
f) Recent incision	Absent	1	Absent	....	High	....	High	....
g) Pore water pressure	Low	....	Low	....	High	3	Very high	....

III. Bed Rock:

	Rating	*1*		*2*		*3*		*4*
j. Jointing density	Low	....	Moderate	2	High	....	Very high	....
b) Amount of dip	Horizontal	....	Small	....	Moderate	3	Large	....
c) Strong bed over weak bed	Absent	1		....			Present	....
d) Hardness	High	....	High	....	Moderate	3	Low	....
e) Texture	Very fine	....	Fine grained	....	Medium	3	Coarse	....
f) Degree of Weathering	None	....	Small	....	Moderate	3	Large	....
g) Compressive strength	High	.....	Moderate	2	Low	.....	Very high	.....
h) Porosity & permeability of bed rocks	Very low	....	Low	....	Moderate	3	High	....

IV. Soils:

	Rating	1		2		3		4
a) Site	Valley floor	.....	Gentle Slope	.....	Moderate Slope		Steep Slope	.....
b) Angle of rest	Low	....	Moderate	2	Steep	.....	Very steep	.....
	Small	.....	Moderate	.....	Large	3	Very large	.....
c) Depth	High	.....	Moderate	.....	Low	.....	Very low	.....
d) Shear strength	Low	1			High	3	Very high	......
e) Liquidity index			Moderate	2		....		
f) Volume of Expension	Low	....	High	2	High	....	Very high	....
	Very high	....			Moderate		Low	....
g) Organic matter			Moderate	2		....		
h) Porosity & sand permeability	Low	....			High	....	Very high	....
i) Coherent bed over incoherent bed	Absent	1					Present	....

V. Legacies from the Past:

	Rating	1		2		3		4
a) Previous landslides	Absent	....	Rare	....	Some	3	Many	....
b) Deep weathering	None	....	Slight	....	Moderate	3	Much	....
c) Fossil solifluction	Absent	1	Slight	....	Some	....	Many	....
d) Evidence of active soil erosion	Absent	....	Slight	....	Some	....	Many	4

VI. Man Made Features:

	Rating	1		2		3		4
a).. Excavation depth	None	...	Small	2	Small	...	Large	...
b). Excavation position	Hill crest	...	High valley	2	Low valley	...	Bottom valley	...
c). Reservoir	Absent	1	Small	...	Deep	...	Very deep	...
d). Drainage diversion across hill side	Absent	1					Present	...
e). Cutting of basal support	Absent	...	Slight	...	Moderate	...	Present	4
f). Loading of upper valley	None	...	Slight	2	Moderate	...	Large	...
g). Deforestation	Absent	...	Slight	...	Moderate	3	High	...
h). Root crop cultivation	Absent	...	Slight	...	Moderate	3	High	...
i). Unscientific construction	Absent	...	Slight	2	Moderate	3	High	...
j). Unscientific terracing	Absent	...					High	...

Modified from Cooke and Doornkamp, 1974.

$$Degree..of..suscepitibility = 100x\sqrt{\frac{Total..Rating..Value}{Total..Number..of..Studied..Items}}$$

$$= 100x\sqrt{\tfrac{94}{44}} = 146.16$$

Appendix 8a.

DISTRIBUTION OF RAINFALL, TEMPERATURE, EVAPORATION LOSS AND RUN-OFF (MONTHLY) OF DIFFERENT STATIONS

Selimbong

Months	Temperature in °C	Rainfall in mm	Evaporation loss in mm	Evaporation loss as % of rainfall	Runoff in mm	Run-off as % of rainfall
January	9.1	10.9	43.88		-32.98	
February	9.91	12.3	47.78		-35.48	
March	12.64	13.8	60.95		-47.15	
April	16.18	99.9	78.01		21.89	
May	17.58	175.5	84.76	48.30	90.74	51.70
June	19.33	504.5	93.20	18.47	411.30	81.53
July	19.81	844	95.52	11.32	748.48	88.68
August	20.21	422.2	97.44	23.08	324.76	76.92
September	17.87	198.6	86.16	43.38	112.44	56.62
October	16.15	108.4	77.87	71.83	30.53	28.17
November	13.46	39.4	64.90		-25.50	
December	10.58	11.2	51.01		-39.81	

Nagri

Months	Temperature in °C	Rainfall in mm	Evaporation loss in mm	Evaporation loss as % of rainfall	Runoff in mm	Run-off as % of rainfall
January	11.16	9.7	53.81		-44.11	
February	14.08	22.3	67.89		-45.59	
March	17.36	30.8	83.70		-52.90	
April	20.25	109.3	97.64		11.66	
May	21.23	196.8	102.36	52.01	94.44	47.99
June	22.24	614.5	107.23	17.45	507.27	82.55
July	23.56	889.6	113.60	12.77	776.00	87.23
August	23.77	422.6	114.61	27.12	307.99	72.88
September	22.28	215.8	107.43	49.78	108.37	50.22
October	20.66	99.9	99.61	99.71	0.29	0.29
November	16.36	14.8	78.88		-64.08	
December	13.18	5.6	63.55		-57.95	

Nagri Farm

Months	Temperature in °C	Rainfall in mm	Evaporation loss in mm	Evaporation loss as % of rainfall	Runoff in mm	Run-off as % of rainfall
January	11.2	15.4	54.00		-38.60	
February	14.21	31.7	68.51		-36.81	
March	17.4	44.8	83.90		-39.10	
April	20.28	114.6	97.78		16.82	
May	21.27	189.6	102.56	54.09	87.04	45.91
June	22.28	610.9	107.43	17.58	503.47	82.42
July	23.61	886.8	113.84	12.84	772.96	87.16
August	23.8	568.8	114.75	20.17	454.05	79.83
September	22.32	231.8	107.62	46.43	124.18	53.57
October	20.7	108.9	99.81	91.65	9.09	8.35
November	16.41	20.1	79.12		-59.02	
December	13.18	8.6	63.55		-54.95	

Kalej Valley

Months	Temperature in °C	Rainfall in mm	Evaporation loss in mm	Evaporation loss as % of rainfall	Runoff in mm	Run-off as % of rainfall
January	10.82	7.5	52.17		-44.67	
February	13.83	22.7	66.68		-43.98	
March	17.12	49.3	82.55		-33.25	
April	19.91	118.4	96.00		22.40	
May	20.9	165.5	100.77	60.89	64.73	39.11
June	21.9	429.8	105.59	24.57	324.21	75.43
July	23.23	918.4	112.01	12.20	806.39	87.80
August	23.42	385.8	112.92	29.27	272.88	70.73
September	21.94	216.3	105.79	48.91	110.51	51.09
October	20.32	162.5	97.97	60.29	64.53	39.71
November	15.23	22.6	73.43		-50.83	
December	13.62	3.5	66.63		-63.13	

Dooteriah

Months	Temperature in °C	Rainfall in mm	Evaporation loss in mm	Evaporation loss as % of rainfall	Runoff in mm	Run-off as % of rainfall
January	10.95	11.4	52.80		-41.40	
February	13.96	23.2	67.31		-44.11	
March	17.25	68.1	83.17		-15.07	
April	20.11	114.6	96.96	84.61	17.64	15.39
May	21.03	203.4	101.40	49.85	102.00	50.15
June	22.04	481.6	106.27	22.07	375.33	77.93
July	23.36	663.9	112.63	16.97	551.27	83.03
August	23.55	512.7	113.55	22.15	399.15	77.85
September	22.07	286.4	106.41	37.16	179.99	62.84
October	20.45	172.9	98.60	57.03	74.30	42.97
November	16.16	48.4	77.92		-29.52	
December	13.95	11.2	67.26		-56.06	

Sungma

Months	Temperature in °C	Rainfall in mm	Evaporation loss in mm	Evaporation loss as % of rainfall	Runoff in mm	Run-off as % of rainfall
January	6.93	9.8	43.06		-33.26	
February	9.74	12.2	46.96		-34.76	
March	12.46	15.3	60.08		-44.78	
April	16.05	97.1	77.39	79.70	19.71	20.30
May	17.41	108.4	83.94	77.44	24.46	22.56
June	19.15	589.8	92.33	15.66	497.47	84.34
July	19.64	972.6	94.70	9.74	877.90	90.26
August	20.04	405.1	96.62	23.85	308.48	76.15
September	17.69	255.8	85.29	33.34	170.51	66.66
October	15.97	90.6	77.00	84.99	13.60	15.01
November	13.28	23.8	64.03		-40.23	
December	10.41	8.9	50.19		-41.29	

Longview

Months	Temperature in °C	Rainfall in mm	Evaporation loss in mm	Evaporation loss as % of rainfall	Runoff in mm	Run-off as % of rainfall
January	13.83	23.2	66.68		-43.48	
February	15.91	55.8	76.71		-20.91	
March	19.93	78.4	96.09		-17.69	
April	22.51	107.2	108.53		-1.33	
May	24.63	394.1	118.76	30.13	275.34	69.87
June	24.7	964.1	119.09	12.35	845.01	87.65
July	25.01	1359.1	120.59	8.87	1238.51	91.13
August	25.92	998.9	124.98	12.51	873.92	87.49
September	24.81	791.8	119.62	15.11	672.18	84.89
October	23.73	266.4	114.42	42.95	151.98	57.05
November	18.63	53.9	89.83		-35.93	
December	15.81	23.6	76.23		-52.63	

Seeyok

Months	Temperature in °C	Rainfall in mm	Evaporation loss in mm	Evaporation loss as % of rainfall	Runoff in mm	Run-off as % of rainfall
January	10.26	6.4	49.47		-43.07	
February	11.06	18.9	53.33		-34.43	
March	13.81	36.4	66.59		-30.19	
April	17.34	98.6	83.61	84.79	14.99	15.21
May	18.75	249.9	90.41	36.18	159.49	63.82
June	20.46	341.7	98.65	28.87	243.05	71.13
July	21.15	701.8	101.98	14.53	599.82	85.47
August	21.37	503.9	103.04	20.45	400.86	79.55
September	19.05	206.5	91.85	44.48	114.65	55.52
October	16.42	107.2	88.81	82.85	18.39	17.15
November	14.64	17.3	70.59		-53.29	
December	11.94	8.2	57.57		-49.37	

Gopaldhara

Months	Temperature in °C	Rainfall in mm	Evaporation loss in mm	Evaporation loss as % of rainfall	Runoff in mm	Run-off as % of rainfall
January	10.01	10.9	48.26		-37.36	
February	10.81	9.2	52.12		-42.92	
March	13.56	11.6	65.36		-53.76	
April	17.08	105.6	82.35	77.99	23.25	22.01
May	18.49	181.6	89.15	49.09	92.45	50.91
June	20.03	308.4	96.58	31.32	211.82	68.68
July	20.89	837.2	100.72	12.03	736.48	87.97
August	21.12	416.2	101.83	24.47	314.37	75.53
September	18.79	230.8	90.60	39.25	140.20	60.75
October	18.06	175.8	87.08	49.53	88.72	50.47
November	14.38	28.8	69.33		-40.53	
December	11.48	8.6	55.35		-46.75	

Margaret's Hope

Months	Temperature C	Rainfall mm	Evaporation loss mm	Evaporation loss as % of rainfall	Run off mm	Run off as % of rainfall
January	10.82	22.3	52.17		-29.87	
February	13.83	26.6	66.68		-40.08	
March	17.12	70.1	82.55		-12.45	
April	19.91	158.5	96.00	60.57	62.50	39.43
May	20.9	201.2	100.77	50.09	100.43	49.91
June	21.9	415.8	105.59	25.40	310.21	74.60
July	23.23	996.8	112.01	11.24	884.79	88.76
August	23.42	561.8	112.92	20.10	448.88	79.90
September	21.94	361.1	105.79	29.30	255.31	70.70
October	20.32	152.9	97.97	64.08	54.93	35.92
November	15.23	31.5	73.43		-41.93	
December	13.82	10.5	66.63		-56.13	

Panighatta

Months	Temperature in °C	Rainfall in mm	Evaporation loss in mm	Evaporation loss as % of rainfall	Runoff in mm	Run-off as % of rainfall
January	14.93	15.2	71.99		-56.79	
February	16.89	31.6	81.44		-49.84	
March	20.96	57.2	101.16		-43.96	
April	23.7	95.2	114.27		-19.07	
May	25.69	395.5	123.87	31.32	271.63	68.68
June	26.13	864.6	125.99	14.57	738.61	85.43
July	26.22	1173.9	126.42	10.77	1047.48	89.23
August	26.75	698.5	128.98	18.46	569.52	81.54
September	25.96	492.2	125.17	25.43	367.03	74.57
October	24.64	157.5	118.80	75.43	38.70	24.57
November	19.69	19.7	94.94		-75.24	
December	16.92	17.3	81.58		-64.28	

Manjwa

Months	Temp. in C	Rainfall in mm	Evaporation loss mm	Evaporation loss as % of rainfall	Runoff mm	Run-off as % of rainfall
January	13.31	10.3	64.18		-53.88	
February	15.39	17.1	74.20		-57.10	
March	19.41	46.8	93.59		-46.79	
April	21.99	109.3	106.03	97.01	3.27	2.99
May	24.11	189.3	116.25	61.41	73.05	38.59
June	24.18	847.6	116.59	13.75	731.01	86.25
July	24.49	1168.3	118.08	10.11	1050.22	89.89
August	25.4	451.1	122.47	27.15	328.63	72.85
September	24.29	459.9	117.12	25.47	342.78	74.53
October	23.21	93.2	111.91		-18.71	
November	18.11	31.6	87.32		-55.72	
December	15.29	5.9	73.72		-67.82	

Tumsong

Months	Temp. in C	Rainfall in mm	Evaporation loss mm	Evaporation loss as % of rainfall	Runoff mm	Run-off as % of rainfall
January	10.18	10.41	49.08		-38.67	
February	10.98	21.31	52.94		-31.63	
March	13.73	30.03	66.20		-36.17	
April	17.26	101.8	83.22		18.58	
May	18.67	188.44	90.02	47.77	98.42	52.23
June	20.42	373.75	98.46	26.34	275.29	73.66
July	21.07	790.8	101.59	12.85	689.21	87.15
August	21.29	458.88	102.65	22.37	356.23	77.63
September	18.97	297.21	91.47	30.77	205.74	69.23
October	18.24	103.23	87.95	85.19	15.28	14.81
November	14.56	15.66	70.20		-54.54	

Thurbo

Months	Temperature in °C	Rainfall in mm	Evaporation loss in mm	Evaporation loss as % of rainfall	Runoff in mm	Run-off as % of rainfall
January	10.48	18.9	50.53		-31.63	
February	13.61	24.3	65.62		-41.32	
March	16.65	59.1	80.28		-21.18	
April	17.41	96.3	83.94		12.36	
May	19.39	329.6	93.49	28.36	236.11	71.64
June	20.67	577.6	99.66	17.25	477.94	82.75
July	21.76	766.9	104.92	13.68	661.98	86.32
August	22.74	458.7	109.64	23.90	349.06	76.10
September	19.95	186.7	96.19	51.52	90.51	48.48
October	18.46	94.3	89.01	94.39	5.29	5.61
November	14.96	39.8	72.13		-32.33	
December	12.02	28.4	57.96		-29.56	

Pankhabari

Months	Temp. in C	Rainfall in mm	Evaporation loss mm	Evaporation loss as % of rainfall	Runoff mm	Run-off as % of rainfall
January	13.92	19.4	67.12		-47.72	
February	16.16	21.8	77.92		-56.12	
March	21.24	49.6	102.41		-52.81	
April	22.63	110.9	109.11		1.79	
May	24.71	211.8	119.14	56.25	92.66	43.75
June	24.99	814.9	120.49	14.79	694.41	85.21
July	25.4	916.9	122.47	13.36	794.43	86.64
August	25.98	722.8	125.27	17.33	597.53	82.67
September	24.87	511.6	119.91	23.43	391.69	76.57
October	23.81	148.2	114.80	77.46	33.40	22.54
November	18.11	26.7	87.32		-60.62	
December	15.2	9.8	73.29		-63.49	

Balason

Months	Temp. in C	Rainfall in mm	Evaporation loss mm	Evaporation loss as % of rainfall	Runoff mm	Run-off as % of rainfall
January	11.69	10.8	56.36		-45.56	
February	14.75	14.7	71.12		-56.42	
March	17.75	27.6	85.58		-57.98	
April	20.51	106.4	98.89		7.51	
May	21.5	327.3	103.66	31.67	223.64	68.33
June	22.67	516.5	109.31	21.16	407.19	78.84
July	23.87	981.3	115.09	11.73	866.21	88.27
August	24.85	429.9	119.82	27.87	310.08	72.13
September	22.76	240.9	109.74	45.55	131.16	54.45
October	21.57	149.4	104.00	69.61	45.40	30.39
November	16.67	24.2	80.38		-56.18	
December	13.42	13.8	64.71		-50.91	

Pubong

Months	Temp. in C	Rainfall in mm	Evaporation loss mm	Evaporation loss as % of rainfall	Runoff mm	Run-off as % of rainfall
January	9.46	8.7	45.61		-36.91	
February	10.27	11.7	49.52		-37.82	
March	13.01	48.6	62.73		-14.13	
April	16.54	94.5	79.75	84.39	14.75	15.61
May	17.94	149.6	86.50	57.82	63.10	42.18
June	19.69	503.7	94.94	18.85	408.76	81.15
July	20.17	959.6	97.25	10.13	862.35	89.87
August	20.57	589.3	99.18	16.83	490.12	83.17
September	18.23	345.2	87.90	25.46	257.30	74.54
October	17.51	115.9	84.43	72.84	31.47	27.16
November	13.82	16.4	66.63		-50.23	
December	10.94	5.7	52.75		-47.05	

Matigara

Months	Temp. in C	Rainfall in mm	Evaporation loss mm	Evaporation loss as % of rainfall	Runoff mm	Run-off as % of rainfall
January	16.54	9.7	79.75		-70.05	
February	18.59	16.4	89.63		-73.23	
March	22.62	43.2	109.06		-65.86	
April	26.31	96.7	136.50		-39.80	
May	25.48	285.9	122.85	42.97	163.05	57.03
June	27.83	784.9	134.19	17.10	650.71	82.90
July	27.92	996.8	134.62	13.51	862.18	86.49
August	28.63	730.1	138.04	18.91	592.06	81.09
September	27.71	557.9	132.84	23.81	425.06	76.19
October	26.41	175.9	127.34	72.39	48.56	27.61
November	21.62	29.8	104.24		-74.44	
December	18.67	6.8	90.02		-83.22	

Marionbari

Months	Temp. in C	Rainfall in mm	Evaporation loss mm	Evaporation loss as % of rainfall	Runoff mm	Run-off as % of rainfall
January	16.01	16.8	77.19		-60.39	
February	18.28	25.2	88.14		-62.94	
March	22.17	58.9	106.89		-47.99	
April	25.09	118.6	120.97		-2.37	
May	27.18	404.9	131.05	32.37	273.85	67.63
June	27.32	998.2	131.73	13.20	866.47	86.80
July	27.45	1256.9	132.35	10.53	1124.55	89.47
August	28.04	768.4	135.20	17.59	633.20	82.41
September	27.15	402.5	130.91	32.52	271.59	67.48
October	26.03	234.9	125.51	53.43	109.39	46.57
November	21.28	40.7	102.60		-61.90	
December	17.89	9.8	86.26		-76.46	

Ambootia

Months	Temp. in C	Rainfall in mm	Evaporation loss mm	Evaporation loss as % of rainfall	Runoff mm	Run-off as % of rainfall
January	12.86	19.45	62.01		-42.56	
February	14.92	28.4	71.94		-43.54	
March	18.92	32.06	91.22		-59.16	
April	21.67	251.7	104.48	41.51	147.22	58.49
May	23.78	423.8	114.66	27.05	309.14	72.95
June	23.81	801.6	114.80	14.32	686.80	85.68
July	24.03	1026.3	115.86	11.29	910.44	88.71
August	25.03	682.2	120.68	17.69	561.52	82.31
September	23.92	433.4	115.33	26.61	318.07	73.39
October	22.71	180.2	109.50	25.84	70.70	39.23
November	16.82	31.8	81.10		-49.30	
December	14.8	11.6	71.36		-59.76	

Chamong

Months	Temp C	Rainfall in mm	Evaporation loss mm	Evaporation loss as % of rainfall	Runoff mm	Run-off as % of rainfall
January	10.26	15.2	49.47		-34.27	
February	11.07	39.6	53.38		-13.78	
March	13.82	49.2	66.63		-17.43	
April	17.34	125.5	83.61	66.62	41.89	33.38
May	18.75	203.6	90.41	44.40	113.19	55.60
June	20.5	624.8	98.84	15.82	525.96	84.18
July	21.15	933.7	101.98	10.92	831.72	89.08
August	21.38	550.2	103.09	18.74	447.11	81.26
September	19.05	295.5	91.85	31.08	203.65	68.92
October	18.32	97.5	88.33	90.60	9.17	9.40
November	14.64	19.7	70.59		-50.89	
December	11.94	7.3	57.57		-50.27	

Mahaldiram

Months	Temp C	Rainfall in mm	Evaporation loss mm	Evaporation loss as % of rainfall	Runoff mm	Run-off as % of rainfall
January	9.05	12.16	43.64		-31.48	
February	10.22	39.66	49.28		-9.62	
March	12.79	59.42	61.67		-2.25	
April	16.03	106.54	77.29	72.55	29.25	27.45
May	17.91	289.59	86.35	29.82	203.24	70.18
June	19.21	933.26	92.62	9.92	840.64	90.08
July	20.09	1050.89	96.87	9.22	954.02	90.78
August	20.5	773.56	98.84	12.78	674.72	87.22
September	18.03	651.39	86.93	13.35	564.46	86.65
October	17.31	118.39	83.46	70.50	34.93	29.50
November	13.71	18.99	66.10		-47.11	
December	10.88	6.56	52.46		-45.90	

Appendix 9a.
COMPUTATION OF DATA OBTAINED FROM THE (20 X 20 mts). QUADRETS FOR TREES AND UNDER-TREES IN THE TWO FOREST TYPES.

Abbreviations Used: QR= Quadrat represented; TC= Total count; RD= Relative density; RF= Relative frequency; IV= Importance value.

Name of the plant species	Natural forest					Dhupi plantation				
	QR	TN	RD	RF	IV	QR	TN	RD	RF	IV
Acer campbellii	26	32	4.827	86.67	91.49	5	9	1.837	16.67	18.5
Acer thomsonii Miq.	6	18	2.715	20	22.71	-	-	-	-	-
Albizia myriophylla Benth.	5	11	1.659	16.67	18.33	-	-	-	-	-
Alcimandra cathcarthii (Hook.f. et Thoms.) ex Dandy	23	27	4.072	76.67	80.74	-	-	-	-	-
Alnus nepaulensis D.Don	13	32	4.827	43.33	48.16	6	21	4.286	20	24.29
Aralia armata Seemann	9	13	1.961	30	31.96	11	13	2.653	36.67	39.32
Beilschmiedia roxburgiana Hook.f.	5	15	2.262	16.67	18.93	-	-	-	-	-
Brassaiopsis hainla (Hamilt.)Seeman	21	24	3.62	70	73.62	7	12	2.449	23.33	25.78
Brassaiopsis mitis Clarke	2	7	1.056	6.667	7.722	-	-	-	-	-
Machilus villosa.	2	11	1.659	6.667	8.326	-	-	-	-	-
Rhododendron falconeri	2	3	0.452	6.667	7.119	-	-	-	-	-
Castanopsis hystrix	19	28	4.223	63.33	67.56	5	9	1.837	16.67	18.5
Cinnamomium obtusifolium Nees.	18	21	3.167	60	63.17	-	-	-	-	-
Cryptomeria japonica (L.f.) D.Don	3	5	0.754	10	10.75	30	362	73.88	100	173.9
Ilex dipyrena	3	3	0.452	10	10.45	-	-	-	-	-
Symplocus *phyllocalyx*	6	9	1.357	20	21.36	-	-	-	-	-
Dillenia pentagyna L.	1	2	0.302	3.333	3.635	-	-	-	-	-
Duabanga grandiflora (DC) Walpers	2	4	0.603	6.667	7.27	-	-	-	-	-
Eurya japonica	19	23	3.469	63.33	66.8	-	-	-	-	-
Elaeocarpus lancefolius Roxb.	3	5	0.754	10	10.75	-	-	-	-	-
Elaeocarpus sikkimensis Mast.	3	4	0.603	10	10.6	-	-	-	-	-
Engelhardia spicata Lesch.ex Blume	19	29	4.374	63.33	67.71	7	13	2.653	23.33	25.99
Erythrina arboreum	3	11	1.659	10	11.66	7	13	2.653	23.33	25.99
Eurya acuminata DC.	26	32	4.827	86.67	91.49	1	1	0.204	3.333	3.537
Exbucklandia poplunea (Griff.)R.W.Brown	3	10	1.508	10	11.51	-	-	-	-	-
Ficus hookeriana Corner	5	9	1.357	16.67	18.02	-	-	-	-	-
Ficus nemoralis.	2	2	0.302	6.667	6.968	-	-	-	-	-
Lagerostroemia reginae Roxb	3	4	0.603	10	10.6	-	-	-	-	-
Eriobotrya petiolata	19	21	3.167	63.33	66.5	2	9	1.837	6.667	8.503
Machilus edulis King ex Hook.f.	2	3	0.452	6.667	7.119	-	-	-	-	-
Macropanax dispermus (Blume) Kuntze	2	5	0.754	6.667	7.421	-	-	-	-	-
Maesa chisia Buch. & Ham.ex D.Don	6	11	1.659	20	21.66	-	-	-	-	-
Magnolia campbellii Hook.f. et Thoms.	1	1	0.151	3.333	3.484	3	5	1.02	10	11.02
Quercus lineata	7	14	2.112	23.33	25.44	-	-	-	-	-
Michelia velutina DC.	11	16	2.413	36.67	39.08	2	2	0.408	6.667	7.075
Lithocarpus pachyphylla	2	6	0.905	6.667	7.572	-	-	-	-	-
Leucoceptrum cannum	2	9	1.357	6.667	8.024	-	-	-	-	-
Pentapanax fragrans	5	16	2.413	16.67	19.08	-	-	-	-	-
Prunus ceracoides D.Don	13	21	3.167	43.33	46.5	2	7	1.429	6.667	8.095
Rhododendron grande	5	9	1.357	16.67	18.02	-	-	-	-	-
Rhododendron arboreum Smith	6	9	1.357	20	21.36	1	3	0.612	3.333	3.946
Rhus succendanea Hook. F.	17	19	2.866	56.67	59.53	-	-	-	-	-
Saurauia napaulensis DC.	3	5	0.754	10	10.75	-	-	-	-	-
Schefflera venulosa (Wight et Arn.)Harms	4	9	1.357	13.33	14.69	-	-	-	-	-
Schima wallichii (DC) Korthals	7	11	1.659	23.33	24.99	3	7	1.429	10	11.43
Symplocus theafolia D.Don.	21	37	5.581	70	75.58	1	1	0.204	3.333	3.537
Cinnamomum impressinervum.	2	3	0.452	6.667	7.119	-	-	-	-	-
Tetradium fraxinifolia (Hook.) Hartley	27	31	4.68	90	94.7	-	-	-	-	-
Zanthoxylum acanthopodium DC.	5	13	1.961	16.67	18.63	-	-	-	-	-
Total		663					487			

Appendix 9 b.

COMPUTATION OF DATA OBTAINED FROM THE (5 X 5 mts). QUADRETS FOR SHRUBS, TREE SEEDLINGS AND CLIMBERS IN THE TWO FOREST TYPES.

Abbreviations used: QR= Quadrat represented; TC= Total count; RD= Relative density; RF= Relative frequency; IV= Importance value.

Name of the plant species	Natural forest					Dhupi plantation				
	QR	TC	RD	RF	IV	QR	TC	RD	RF	IV
Aconogonum molle (D.Don.) Hara	47	78	5.09	78.3	83.4	3	11	1.61	5	6.61
Aristolochia roxburghiana Hook.f. et	6	11	0.72	10	10.7	-	-	-	-	-
Artemesia indica Willd.	22	58	3.79	36.7	40.5	33	62	9.05	55	64.1
Arundinaria maling	6	29	1.89	10	11.9	21	31	4.53	35	39.5
Boehmerria macrophylla D.Don	32	67	4.37	53.3	57.7	37	71	10.4	61.7	72.1
Calamus erectus Roxb.	14	19	1.24	23.3	24.5	2	6	0.88	3.33	4.21
Cestrum aurenticum	14	37	2.42	23.3	25.7	17	31	4.53	28.3	32.8
Cestrum fasiculatum	7	21	1.37	11.7	13.1	5	7	1.02	8.33	9.35
Cestrum nocturnum	6	31	2.02	10	12	-	-	-	-	-
Clematis montana	14	30	1.96	23.3	25.3	2	9	1.31	3.33	4.64
Clematis smilicinifolia Wall.	4	7	0.46	6.67	7.13	1	1	0.15	1.67	1.82
Crotolaria mucronata Desvaux	12	31	2.02	20	22	-	-	-	-	-
Crotolaria tetragona Andrews	6	16	1.04	10	11	-	-	-	-	-
Datura stramonium L.	6	11	0.72	10	10.7	-	-	-	-	-
Dichroa fabrifuge.	27	78	5.09	45	50.1	40	62	9.05	66.7	75.8
Discorea bulbifera L.	10	21	1.37	16.7	18.1	-	-	-	-	-
Discorea deltoidea Wall.	14	22	1.44	23.3	24.7	-	-	-	-	-
Egdaria darjeelengsis.	9	52	3.39	15	18.4	-	-	-	-	-
Esoltzia blanda Benth.	5	14	0.91	8.33	9.24	-	-	-	-	-
Eupatorium adenophorum Sprengel	36	37	2.42	60	62.4	49	74	10.8	81.7	92.5
Girardina palmata (Forsk.)Gaudichaud	48	83	5.42	80	85.4	21	68	9.93	35	44.9
Gleichenia glauca	6	23	1.5	10	11.5	3	19	2.77	15	17.8
Hoelbolia pentaphylla	12	16	1.04	20	21	-	-	-	-	-
Mahonia acanthifolia	11	21	1.37	18.3	19.7	4	11	1.61	6.67	8.28
Mahonia sikkimensis	6	17	1.11	10	11.1	2	3	0.44	3.33	3.77
Osbeckia nepalensis Hook.	49	54	3.52	81.7	85.2	17	68	9.93	28.3	38.2
Piper attenuatum Ham.	10	27	1.76	16.7	18.5	-	-	-	-	-
Plectranthus incanus Link.	7	26	1.7	11.7	13.4	3	3	0.44	5	5.44
Polygonum chinensis	5	17	1.11	8.33	9.44	2	9	1.31	3.33	4.64
Rubus ellipticus	5	18	1.17	8.33	9.5	2	5	0.73	3.33	4.06
Rubus paniculatus	17	26	1.7	28.3	30	2	7	1.02	3.33	4.35
Sambucus Hookeri Rehder	4	9	0.59	6.67	7.26	-	-	-	-	-
Sechium edule (Jacq.) Swartz	15	25	1.63	25	26.6	11	19	2.77	18.3	21.1
Solanum nigrum L.	24	51	3.33	40	43.3	-	-	-	-	-
Strobilanthes pectinatus Graham	9	48	3.13	15	18.1	-	-	-	-	-
Thysanolaena maxima (Roxb.)Kuntz.	4	13	0.85	6.67	7.52	-	-	-	-	-
Urtica dioica L.	44	61	3.98	73.3	77.3	1	4	0.58	1.67	2.25
Viburnum coraceanum Blume	8	31	2.02	13.3	15.3	-	-	-	-	-
Viburnum erubescence.	40	59	3.85	66.7	70.6	8	23	3.36	13.3	16.7
Tree seedlings	-	-	-	-	-	-	-	-	-	-
Aralia armata Seemann	2	3	0.2	3.33	3.53			0	0	0
Brassaiopsis mitis Clarke	8	9	0.59	13.3	13.9	3	2	0.29	5	5.29
Castanopsis hytrix	11	22	1.44	18.3	19.7			0	0	0
Cryptomeria japonica (L.f.) D.Don	24	58	3.79	40	43.8	48	54	7.88	80	87.9
Rhus succedeana	3	7	0.46	5	5.46	10	13	1.9	16.7	18.6
Machilus edulis King ex Hook.f.	11	32	2.09	18.3	20.4	-	-	-	-	-
Magnolia campbelli Hook.f. et Thoms.	7	11	0.72	11.7	12.4	-	-	-	-	-
Rhododendron arboreum	5	13	0.85	8.33	9.18	1	2	0.29	1.67	1.96
Quercus lamellosa	7	17	1.11	11.7	12.8	1	3	0.44	1.67	2.11
Erythrina arborescence	17	23	1.5	28.3	29.8	5	7	1.02	8.33	9.35
Tetractum fraxinifolia (Hook.) Hartley	10	15	0.98	16.7	17.7	-	-	-	-	-
Total		1505					685			

Appendix 9c.

COMPUTATION OF DATA OBTAINED FROM THE (1 X 1 mts). QUADRETS FOR HERBS IN THE TWO FOREST TYPES.

Abbreviations used: QR= Quadrat represented; TC= Total count; RD= Relative density; RF= Relative frequency; IV= Importance value.

Name of the plant species	Natural forest					Dhupi plantation				
	QR	TN	RD	RF	IV	QR	TN	RD	RF	IV
Amaranthus lividus	12	49	2.69	20	22.7	8	21	2.4	13.3	15.7
Anaphalis contorta	48	56	3.07	80	83.1	7	34	3.89	11.7	15.6
Astilbe rivularis	11	15	0.82	18.3	19.2	-	-	-	-	-
Begonia picta	13	19	1.04	21.7	22.7	3	7	0.8	5	5.8
Calaminthe umbrosa	9	74	4.06	15	19.1	7	32	3.66	11.7	15.4
Campanula colorata	12	17	0.93	20	20.9	-	-	-	-	-
Cardamine hirsuta	32	64	3.51	53.3	56.8	4	14	1.6	6.67	8.27
Carex	14	54	2.96	23.3	26.3	28	44	5.03	46.7	51.7
Cautleya spicata	3	19	1.04	5	6.04	-	-	-	-	-
Cyanotis barbarata	21	56	3.07	35	38.1	3	19	2.17	5	7.17
Cynodon dactylon	13	71	3.9	21.7	25.6	32	51	5.83	53.3	59.1
Cyperus macrocarpa	11	32	1.76	18.3	20.1	2	11	1.26	3.33	4.59
Cyperus	6	24	1.32	10	11.3	3	12	1.37	5	6.37
Drymaria cordata	18	61	3.35	30	33.3	4	31	3.54	6.67	10.2
Dryopteris chrysocoma	4	26	1.43	6.67	8.09	7	39	4.46	11.7	16.2
Elsoltzia strobilifera	4	28	1.54	6.67	8.2	7	43	4.91	11.7	16.6
Eragrotis	30	54	2.96	50	53	9	29	3.31	15	18.3
Fagopyrum cymosum	7	78	4.28	11.7	15.9	3	11	1.26	5	6.26
Galinsoga parviflora	8	71	3.9	13.3	17.2	4	23	2.63	6.67	9.3
Galium mullago	3	12	0.66	5	5.66	-	-	-	-	-
Gallium rotundifolia	5	18	0.99	8.33	9.32	-	-	-	-	-
Globba hookeri	39	82	4.5	65	69.5	7	16	1.83	11.7	13.5
Gnaphalium affine	7	39	2.14	11.7	13.8	3	27	3.09	5	8.09
Gynura angulosa	4	13	0.71	6.67	7.38	2	7	0.8	3.33	4.13
Hedyotis scandens	6	19	1.04	10	11	-	-	-	-	-
Houttuynia cordata	5	31	1.7	8.33	10	-	-	-	-	-
Hydrocotyle japonica	49	84	4.61	81.7	86.3	13	22	2.51	21.7	24.2
Impatiens bicornuta	5	41	2.25	8.33	10.6	5	33	3.77	8.33	12.1
Impatiens racemosa	7	22	1.21	11.7	12.9	-	-	-	-	-
Inula cappa	3	11	0.6	5	5.6	2	4	0.46	3.33	3.79
Lindenbergia grandiflora	32	67	3.68	53.3	57	7	38	4.34	11.7	16
Oxalis corniculata	38	74	4.06	63.3	67.4	6	32	3.66	10	13.7
Panicum	14	65	3.57	23.3	26.9	10	58	6.63	16.7	23.3
Paspalum	11	43	2.36	18.3	20.7	7	33	3.77	11.7	15.5
Plantago mejor	4	31	1.7	6.67	8.37	3	11	1.26	5	6.26
Polygonum runcinatum	7	33	1.81	11.7	13.5	9	31	3.54	15	18.5
Pouzolzia hirta	9	52	2.85	15	17.9	3	21	2.4	5	7.4
Prunella vulgaris	49	101	5.54	81.7	87.2	9	56	6.4	15	21.4
Pteris	4	11	0.6	6.67	7.27	11	33	3.77	18.3	22.1
Rubus calycinus	3	16	0.88	5	5.88	-	-	-	-	-
Sanicula chinensis	5	11	0.6	8.33	8.94	-	-	-	-	-
Viola diffusa	50	78	4.28	83.3	87.6	3	32	3.66	5	8.66
Total		1822					875			