Chapter – III

THE STUDY AREA, CLIMATE AND SITE CHARACTERISTICS

The Himalaya is the youngest, tallest and most fragile mountain system of the world, covering an area of approximately 5, 91,000 km^2. Extending for about 2,500 km from east to west, the Himalayan Arc covers more than 10° of latitudinal expanse, i.e. 27° to 38° N. Altitude varies greatly, and tropical and alpine communities may occur within a distance of 300 to 500 km.

The Himalaya has been formed as a result of northward movement of the Indian Plate striking against the Tibetan Plateau and came into existence in the Tertiary-Quaternary period. Since, the Indian Plate continued pushing northward, the Himalaya is still growing and thus its landscape is being reshaped time and again. An "incipient altitudinal zonation" of vegetation was established during the mid-Miocene in the Himalaya, when it was not that high (around 2200-2400 m) as it is today. Wet tropical forests on the lower slopes, wet temperate forests on the higher slopes, and wet sub-tropical types between the two, constituted the vegetation pattern in present time. Owing to its varied topography and climate, the Himalaya supports a variety of forests up to the timber line. However, one's perception of the dense and undisturbed forests in inaccessible valleys and ridges is shattered upon entering the Himalaya, whereas the fact remains that in most parts the forests are degraded and interspersed with deforested open 'blanks' and village settlements. The Hindu Kush Himalayan terrain is inhabited by about 150 million people with a multiple ethnic composition which further has an impact on its ecosystem making it more fragile.

The Himalaya constitutes a unique geographical and geological entity comprising diverse social, cultural and environmental set-up. It extends from the Indus Trench below Naga Parbat (8125 m) in the west to the Tsangpo (Bramhaputra) gorge below Namcha Barwa (7756 m) in the east, covering the political administrative regions of Afghanistan, Pakistan, India, Nepal, Bhutan, Myanmar, Tibet and China. Although it covers only 18% of India's geographical area, the Himalaya accounts for more than 50% of the country's forest cover and 40% of the species endemic to the Indian subcontinent (Myers 1990; Khoshoo 1992).

Generally three broad geographical divisions are recognized for the Indian Himalaya, viz., the western Himalaya that include Jammu & Kashmir and Himachal Pradesh; the central Himalaya consisting of Kumaon and Garhwal regions; and the eastern Himalaya extending from Sikkim to Arunachal Pradesh. Physiographically and geologically, four distinctive terrains are recognized in the Himalaya. From south to north, these are: Outer Himalaya, Lesser Himalaya, Higher Himalaya and Tethys Himalaya. The western and eastern flanks of the Himalaya are different in climate and vegetation. The western Himalayan ranges are much wider and colder with drier climate and vegetation is cold and drought resistant. In contrast, eastern ranges are among the wettest regions having rich diversity of vegetation. It is so because the highly precipitous hilly terrain of the eastern Himalayan amphitheatre happens to be at a closer proximity to the Bay of Bengal to receive more rainfall than the central and western Himalaya.

3.1 THE SIKKIM HIMALAYA

Sikkim or Sukhim (means New House), a small hilly state (27° 3' 47" to 28° 7' 34" N and 88° 03' 40" to 88° 57' 19" E) of India in the eastern Himalayan biogeographic zone that harbors largest number of endemics and endangered species in the Indian subcontinent, is recognized as one of the biodiversity 'Hot Spot' of global significance (Khoshoo 1992). The State is exceptionally rich in biodiversity. It extends approximately 114 km from north to south and 64 km from east to west. The State is bounded in the north by the Tibetan Autonomous Region of the People's Republic of China, in the east by Bhutan and the Chumbi Valley of Tibetan Autonomous Region of the People's Republic of China, in the west by Nepal and in the south lies Darjeeling Gorkha Hill Council of West Bengal State (Fig. 3.1). The entire Sikkim Himalaya constitutes a mountainous terrain spreading over 7096 km^2 and is a quite well-known in terms of its resplendent flora and faunal aggregation. It beholds one of the most magnificent ranges of snow clad mountains popularly known as the Khangchendzonga (8598 m) groups. The elevation of the State ranges between 300-8598 m above mean sea level.

Administratively the State is divided into four districts, viz., North, South, East and West and is a cornucopia of four major ethnic groups', viz., Lepchas, Nepalese, Bhutias and Limbus. The Lepchas are the aboriginal of Sikkim and are predominantly Buddhists. The Bhutias are the people of Tibetan origin. The people of Nepalese origin have migrated to Sikkim in large number from middle of the nineteenth century. The majority of the population is Nepalis (67%) who are Hindus by religion, followed by Buddhists (29%) and others (4%). The main livelihood option in the State is agriculture which earns about 47% of its GDP from this sector. There are 447 villages, out of which 440 are inhabited. A total of 540493 populations were recorded in 2001 with an average density of 76 persons km^{-2}. The rich natural and cultural heritage of Sikkim makes this small Himalayan State an attractive destination for international and domestic tourists (Rai & Sundriyal 1997).

The State has a good drainage network. The entire State is drained by the Tista and the Great Rangit through its numerous tributaries and innumerable sub-tributaries. The most important tributaries include the Zemu Chhu, the Rangyong Chhu, the Lachung Chhu, Ranthong Chhu, and the Ramam Chhu. The combined course of the Ramam and the Great Rangit marks the southern boundary of the State. The entire State is divided into two catchments, i.e., the Tista and the Rangit catchment. Further, the Rangit catchment comprises 51 micro-watersheds, including the Mamlay Watershed, which has been selected as the study area of the present work.

3.2 THE MAMLAY WATERSHED

The Mamlay Watershed is situated in the South District of Sikkim, which is the most populated zone. It extends from 27°10' 8" to 27° 14' 16" N and 88° 19' 53" to 88° 24' 43" E, embracing an area of 30.14 km^2. It has an elevational range of 300-2650 m above mean sea level, encompassing nine revenue blocks including 34 settlements (Fig 3.1).The population of the watershed was 4522 in 1991 census with an average density of 200 persons km^{-2}. There are five perennial streams (Tirikhola, Rangrangkhola, Sombareykhola, Pockcheykhola and Chemcheykhola) forming five micro-watersheds. All these streams finally merge into Rinjikhola, which is the outlet of the Mamlay Watershed. It has a dendritic pattern where each micro-watershed has a mosaic distribution of land-use practices.

3.2.1 Topography

The watershed area under study lies entirely in the mountainous zone. The area is characterized by varied lithology and folded structure. The elevation of the watershed varies from 300 m near Rangit River in the west to more than 2650 m near Tendong peak in the north-east ridges.

The topography progressively becomes rugged from the Rangit River to the Tendong peak.

Physiographically, the watershed has been divided into three geomorphic divisions viz., (i) Lower hill slope (<1000 m), (ii) Middle hill slope (1000-2000 m) and (iii) Upper hill slope (>2000 m) based on geology, land use and natural vegetation cover. Some landslips and gullies are also observed. The vegetation changed remarkably with variation in micro-climate in a gradient of altitude. About 50% area of the watershed is under the middle hill slope, 40% in the lower hill slope, and just 10% in the upper hill slope. Medium to dense natural forest covers are found in the sub-tropical and temperate belts. A major portion of the watershed faces the east-west direction.

3.2.2 Geology

The Mamlay Watershed falls under the Lesser Himalayan Zone. Four major litho-tectonic units exist in Sikkim Himalaya, viz., the Gondwana Group, Buxa Group, Daling Group and Darjeeling Group. The Precambrian high-grade crystalline rocks of Darjeeling Group are thrusted over the Daling Group of rocks of Late Precambrian to Middle Palaeozoic age along the Main Central Thrust (MCT). These rocks are exposed in large part of Sikkim; whereas, the rocks of Buxa and Gondwana groups are mostly exposed in a tectonic window, known as "Rangit Window" that exists in South Sikkim.

In Mamlay Watershed area, which falls in the Rangit Window, mostly the rocks of Buxa and Gondwana groups are exposed, though a few exposure of Daling Group are also present mostly along the periphery of the Window (Fig. 3.2). Apparently, the rocks of Daling Group form nearly NNE-SSW trending large-scale and elongated domal structure that overlie the sediments of Gondwana Group with a thrust (Gangopadhyay & Roy 1979).

The Gondwana sediments are represented by pebble slate, inter-bedded sandstone and carbonaceous shale, slaty-shale and thin layers of coal. Sahni & Srivastava (1956) have described marine fossils, mainly bivalve and brachiopods, such as *Eurydesma*, *Ambikella*, *Spirifer*, *Syringothyris*, etc., from Kamrang and Wak in South Sikkim. Further, well-preserved plant fossils, viz., *Glossopteris*, *Phyllotheca*, *Vertebraria*, etc., are also known to occur in the slaty-shales of the Gondwana sediments exposed in the Rangit Window (Singh & Bajpai 1990). These fossils indicate a Permian age to the Gondwana sediments. The Buxa Group is predominantly represented by variegated colour limestone and slate, impure carbonate phyllites and quartzite. It shows good organo-sedimentary structures. Sinha & Roy (1972) has reported algal stromatolites from the rocks of Buxa Group in the Rangit Window. The Gondwana and Buxa Groups of rocks are surrounded by typical greenish phyllites, quartzites and low-grade schists and gneisses of Daling metamorphites.

Several metallic and non-metallic minerals are known to occur in the area, of which coal and dolomite are the most dominant and important. Besides these, sporadic occurrences of sulphide mineralization are also present.

During the early period of the geological history, deep water marine sediments exhibiting considerable facies variation were deposited in the major part of the area and were later subjected to repeat fold, fault and thrust movements. It bears the evidences of several persistent thrusts in the Rangit Window, viz., the Sikkip Thrust and the Tendong Thrust (Fig. 3.2).

3.3 CLIMATE

The climatic data for the present study was collected at the Jaubari village (2000 m) and Kamrang village (800 m) covering temperate and subtropical belts respectively of the watershed during 1999 and 2000. The climate of the area is typically monsoonic having the three main seasons: winter (November-February), spring (March-May) and rainy (June-October) and rainfall varies from area to area, and over 80% of the rain occurs through June to September.

3.3.1 Rainfall

The rainfall in the watershed varies rapidly with elevation. The watershed experiences high rainfall in the temperate region and has shadowed rainfall in the valleys which fall in the sub-tropical region. Monthly rainfall data were collected from both the regions in two consecutive years (1999 and 2000). The mean annual rainfall was much higher at the temperate site 2992 mm, while it was 1295 mm at the sub-tropical site during the same period. At both the sites low rainfall was received between November to February while fairly good rainfall was received every month from March to October and highest was recorded in the month of August in both the sites (Fig. 3.3). In the sub-tropical site very little rainfall was recorded between November to April except February.

3.3.2 Temperature

The temperature was measured at Jaubari in the temperate zone and Kamrang in the sub-tropical zone of the watershed and it was observed that the temperate zone experiences a mean monthly maximum temperature of 18^0 C while the mean monthly minimum temperature reaches up to 11^0 C. The record shows that the temperate zone of the watershed experienced a temperature as high as 21^0 C in June whereas it scaled as low as 5^0 C in the month of January. The sub-tropical zone of the watershed on the other hand experienced a mean monthly maximum temperature of 30^0 C and a mean monthly minimum temperature of 15^0 C (Fig. 3.3). Air temperature was distinctly much lower in the temperate site than the sub-tropical site.

3.3.3 Evaporation

Daily evaporation was measured at temperate and sub-tropical belts of the watershed and data were pooled on monthly basis. Mean monthly measured value ranged from 2 to 10 mm in temperate belt and 3 to 12 mm in sub-tropical belt. The highest monthly evaporation was recorded in July and lowest in December at both the belts (Fig. 3.4).

3.3.4 Relative Humidity

The relative humidity of temperate and subtropical belts was recorded during 1999-2000. Mean monthly relative humidity ranged between 66-77% in temperate belt and 73-88% in subtropical belt. Rainy season had the highest relative humidity followed by winter and short summer season.

3.3.5 Photosynthetically Active Radiation

Photosynthetically active radiation (PAR) was recorded during 10.30 to 12.00 hours in temperate and subtropical belts of the watershed. Minimum and maximum value of PAR in a month varied widely in all the months in both the belts. Mean PAR ranged from 68 to 1168 μ mol m^{-2} s^{-1}, which was lower during winter and rainy seasons, but peaked during spring season.

3.4 SITE CHARACTERISTICS

Twenty seven sites from nine dominant land-use/cover types were selected for the study covering slope, aspect and altitude i.e., three forest types (temperate natural dense mixed forest, temperate natural open mixed forest, and sub-tropical natural open forest), two agroforestry system types (large cardamom based agroforestry systems and mandarin orange based agroforestry systems), two agricultural area types (open cropped area temperate and open cropped area sub-tropical) and two wastelands types (wasteland area temperate and wasteland area sub-tropical) (Table 3.1). All sites were located within a geographic distance of more than 3 km in a designated watershed area. Though the species composition varied with sites, *Castanopsis tribuloides* and *Quercus lamellosa* dominated at most of the sites. Other dominating canopy species were *Alnus nepalensis, Quercus lineata, Juglans regia, Cryptomeria japonica, Michelia excelsa* and *Symingtonia populnea* at temperate natural forest dense and open, whereas *Schima wallichii, Castanopsis indica, Castanopsis tribuloides*, and *Shorea robusta* in sub-tropical natural forest. Large cardamom based agroforestry were dominated by *Alnus nepalensis*, *Bellschmedia sp., Nyssa sp., Erythrina sp.*, and in mandarin agroforestry systems, *Citrus reticulata* and *Albizia stipulata* etc. were the dominating species. The dominating subcanopy species in temperate forests were *Eurya acuminata, Symplocos theaefolia, S. sumuntia, Leucosceptrum canum* etc.

Altitudes, slope, soil pH, soil moisture, and dominant tree species of the sites are given in Table (3.1). Soil texture of different forest and agroforestry types are also outlined in Table 3.1, which is either sandy loam, silty loam, or clay loam varying at different physiographic divisions and land-use/cover types of the watershed. The texture of the open cropped area in temperate and subtropical field soils was sandy loam. Soil temperature of different land-use/cover was recorded seasonally. The higher soil temperature was observed in rainy season in comparison to spring and winter seasons. On land-use/cover basis, highest soil temperature was recorded in open cropped and wasteland areas of sub-tropical belt and lowest in forest and agroforestry systems of the temperate belt.

Most soils are acidic (pH ranged from 5.02 to 6.43) due to cations accumulation in biomass causing anionic disbalance in soil and anion leaching loss due to heavy rainfall. Average soil moisture levels ranged from 17% in subtropical wasteland to 34% in temperate natural forest dense.

3.4.1 Bulk Density

The bulk density of the soil horizon (0-100 cm) in different land-use/covers varied distinctly with higher values in temperate natural forest dense and lower in open cropped area subtropical (Table 3.2). The bulk density in the lower depths of all the land-use/covers showed higher values indicating the most compact soil in this horizon. Bulk density varied significantly ($P<0.0001$) within land-use and soil depths. Interactions between the land-use and depths were also significant ($P<0.0001$).

3.4.2 Soil Nutrient Status

In order to assess the effect of change in land-use/covers on soil fertility, the nutrient levels of soil at two depths (0-15 cm and 15-30 cm) from different land-use/covers were estimated following standard methods (Anderson & Ingram 1993).

3.4.2.1 Organic carbon

Organic carbon concentrations of both the soil depths varied significantly (*P*<0.0001) between land-use and depths. Interactions between land-use and depth were significant (*P*<0.01) (Table 3.3). Pairwise mean difference probabilities showed significant differences between temperate natural forest dense with other land-use (*P*<0.05). Mean difference between subtropical natural forest open, mandarin based agroforestry system, open cropped area subtropical and wasteland area subtropical showed no significant difference (*P*>0.05) (Table 3.3). Between the depths also the mean differences was significant (*P*<0.05). At higher soil depth percentage of organic carbon was smaller than the surface layer.

3.4.2.2 Total nitrogen

Soil total-N varied significantly between land-use, seasons and depths. Interaction between land-use and depth were also significant (Table 3.3). Pairwise mean difference probabilities were significantly higher in temperate natural forest dense than other land-uses (*P*<0.05). Pairwise mean differences between other land-uses were not significantly different (*P*>0.0.5). Between the seasons, differences were significant for winter with rainy and spring with rainy (*P*<0.05). Soil total-N was always higher in 0-15 cm depth compared to 15-30 cm depth in all the land-uses.

3.4.2.3 Total phosphorus

The range of total-P concentration was 0.02-0.12% in the 0-15 cm and 0.01-0.09% in 15-30 cm soil depths in different seasons and land-use/covers. Highest values were recorded in winter and lowest in spring season. Significant variation was obtained between land-use and depths. Interaction between land-use and depth (*P*<0.005), were significant.

Pairwise mean difference probabilities showed significantly higher value in subtropical natural forest open with other land-uses ($P<0.05$) (Table 3.3).■

Table 3.1 Site characteristics of different land-use/cover selected for study

Land-use/cover	Altitude (m)	Slope (^{0})	Soil texture	Soil pH	Moisture (%)	Dominant tree species/crops
Temperate natural forest dense	1900-2650	30-52	Sandy loam	5.10±0.10	33.5±5.2	*Alnus nepalensis, Juglans regia, Quercus lamillosa, Michellia lanuginosa*
Temperate natural forest open	1700-2200	35-42	Sandy loam	5.02±0.07	30.3±5.1	*Cryptomeria japonica, Alnus nepalensis, Beilschmedia sp., Nyssa sp., Erythrina sp.*
Subtropical natural forest open	800-1000	30-35	Silty loam	5.16±0.05	20.2±4.1	*Schima wallichii, Castanopsis indica, C. tribuloides, Shorea robusta*
Cardamom based agroforestry	1000-2000	25-30	Silty/clay loam	5.44±0.04	28.9±3.4	*Alnus nepalensis, Beilschmedia sp., Nyssa sp., Erythrina sp.*
Mandarin based agroforestry	400-1600	20-25	Silty loam	6.11±0.18	16.6±3.3	*Citrus reticulata*
Open cropped area temperate	1000-2000	25-30	Sandy loam	6.43±0.04	27.8±4.2	Maize
Open cropped area subtropical	300-1000	20-25	Sandy loam	6.02±0.10	17.1±3.1	Maize, Pulses, Rice
Wasteland area temperate	1000-2000	25-30	Sandy silt	5.21±0.05	26.4±3.7	
Wasteland area subtropical	300-1000	20-25	Sandy soil	5.90±0.16	16.5±3.8	

Table 3.2 Bulk density (g cm^{-3}) of different land-use/cover with depth

Land-use/cover	Depths (cm)						
	0-15	15-30	30-45	45-60	60-75	75-90	90-100
Temperate natural forest dense	1.31	1.33	1.37	1.40	1.47	1.55	1.60
Temperate natural forest open	1.14	1.16	1.17	1.28	1.31	1.35	1.37
Subtropical natural forest open	0.64	0.67	0.72	0.78	0.80	0.84	0.93
Cardamom based agroforestry system	0.86	0.87	0.89	0.95	0.97	1.03	1.07
Mandarin based agroforestry system	0.84	0.86	1.10	1.33	1.39	1.40	1.41
Open cropped area temperate	0.57	0.60	0.86	0.89	0.90	0.92	1.00
Open cropped area subtropical	0.46	0.51	0.67	0.70	0.71	0.83	1.07
Wasteland area temperate	0.62	0.64	0.78	0.83	0.87	0.88	0.92
Wasteland area subtropical	0.72	0.76	0.92	0.95	1.10	1.11	1.18

ANOVA: Land-use, $F_{8,\,126}$= 804.82, P<0.0001; Depth $F_{6,\,126}$= 319.70, P<0.0001; Land-use x Depth $F_{48,\,126}$= 9.46, P<0.0001.

Table 3.3 Soil nutrient status (%) in different land-use/cover. Means in each column with different letters denotes significant difference at (P<0.05, n=3) (Tukey's honestly significant difference test)

Land-use/cover	Organic carbon	Total nitrogen	Total phosphorus
Temperate natural forest dense	2.770^{f}	0.254^{b}	0.076^{a}
Temperate natural forest open	2.290^{e}	0.219^{a}	0.060^{a}
Subtropical natural forest open	1.256^{a}	0.207^{a}	0.160^{b}
Cardamom based agroforestry system	1.871^{c}	0.212^{a}	0.067^{a}
Mandarin based agroforestry system	1.401^{a}	0.172^{a}	0.067^{a}
Open cropped area temperate	1.988^{d}	0.182^{a}	0.069^{a}
Open cropped area subtropical	1.182^{a}	0.180^{a}	0.066^{a}
Wasteland area temperate	1.617^{b}	0.178^{a}	0.042^{a}
Wasteland area subtropical	0.968^{a}	0.134^{a}	0.043^{a}

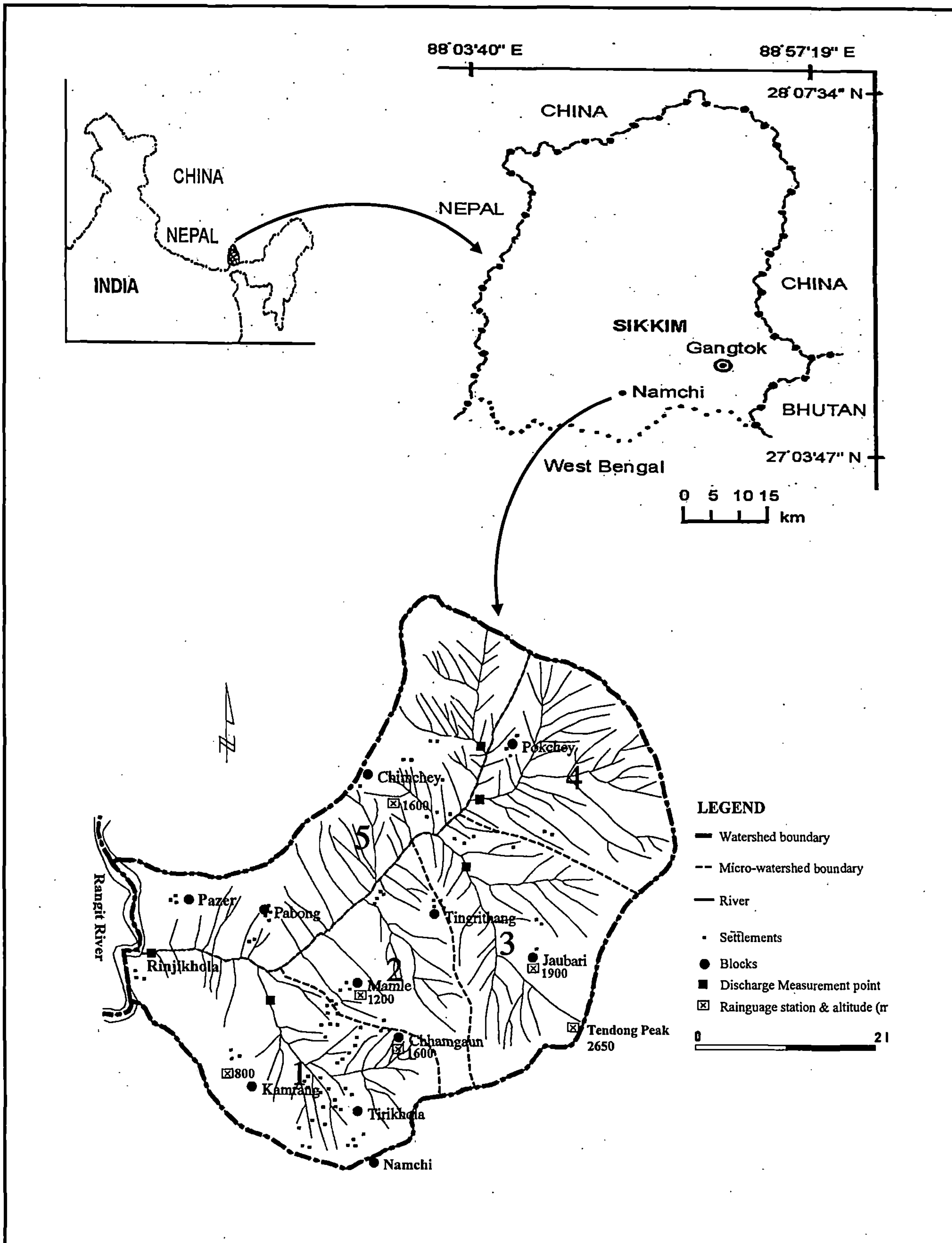

Fig. 3.1 Location map of Mamlay Watershed showing drainage pattern and settlements

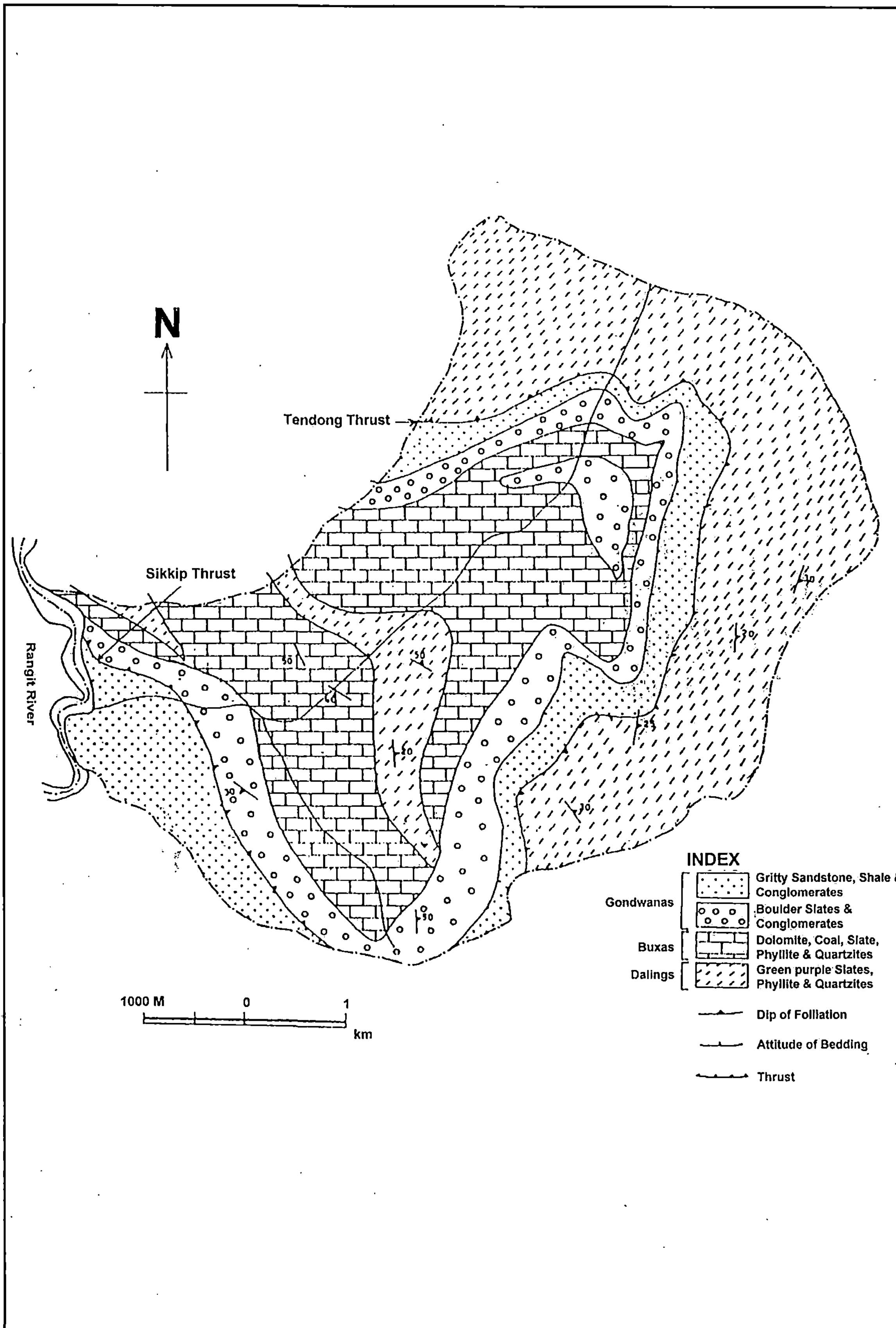

Fig. 3.2 Geological map of Mamlay watershed.

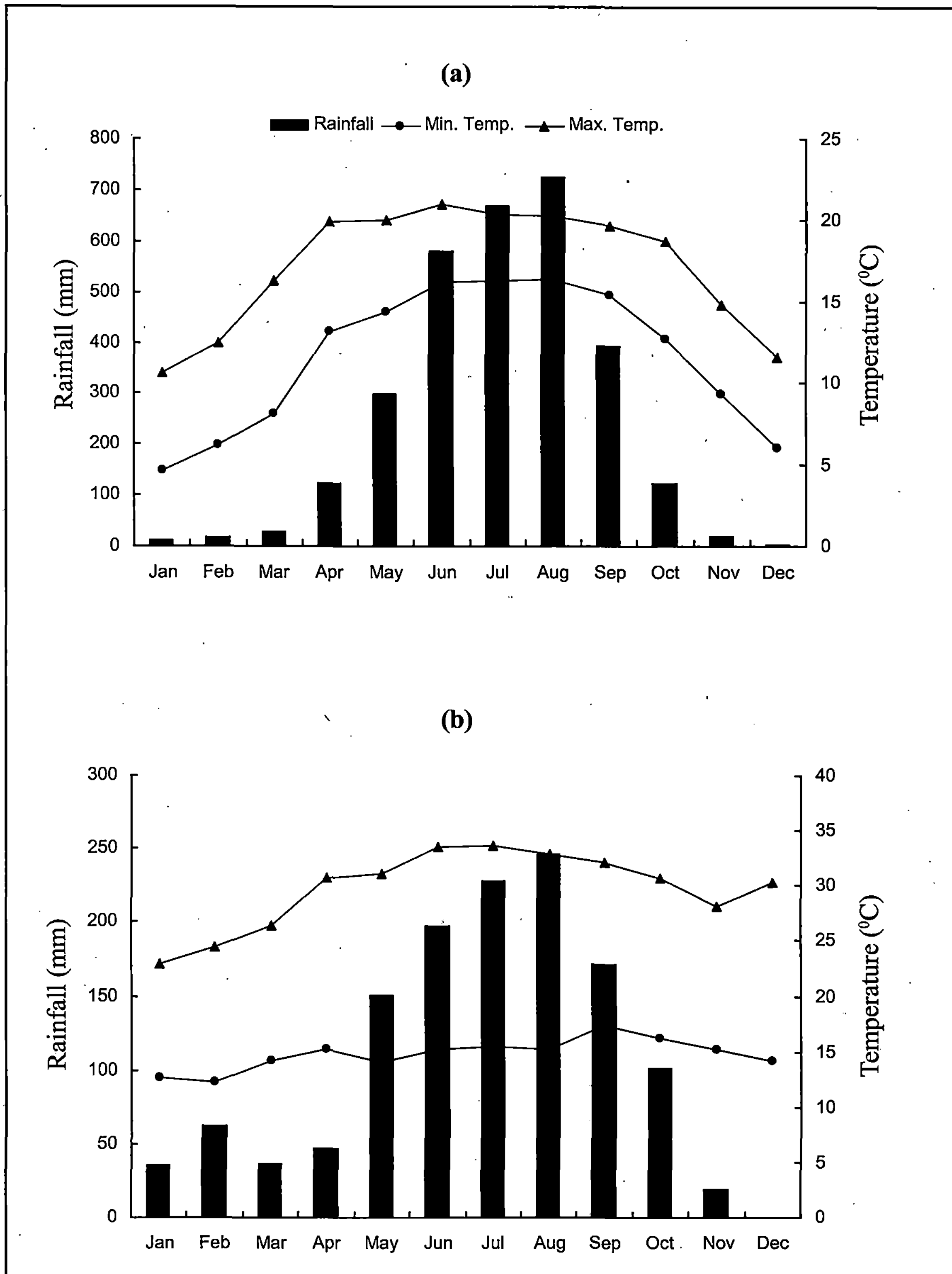

Fig. 3.3 Mean monthly rainfall (mm) and temperature (^{0}C) in **(a)** temperate belt and **(b)** subtropical belt of the Mamlay watershed recorded during 1999 and 2000 (n = 6).

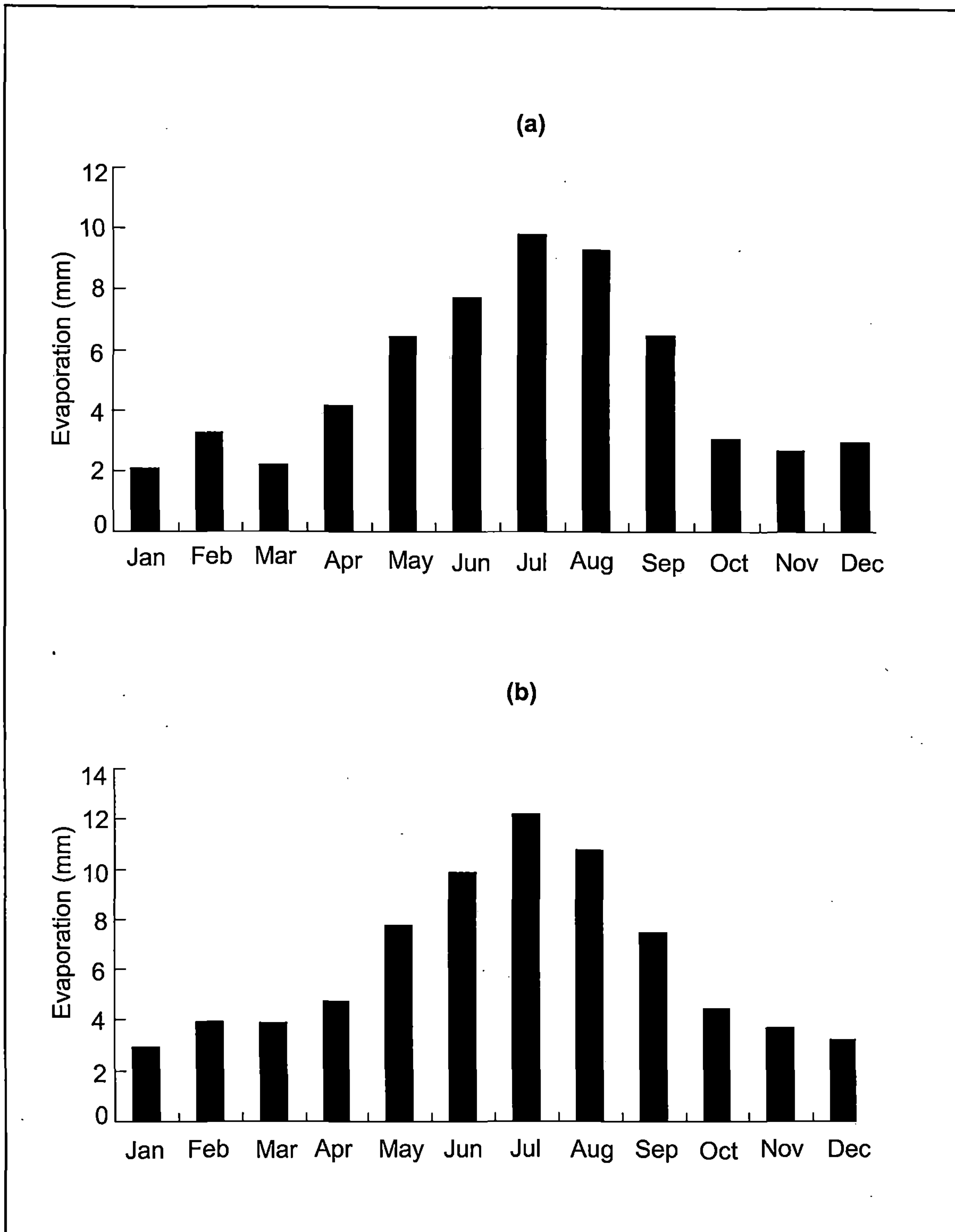

Fig. 3.4 Mean monthly evaporation (mm) in **(a)** temperate belt and **(b)** sub-tropical belt of the Mamlay watershed recorded during 1999 and 2000 (n = 6).