# Chapter – IV

# LAND-USE/LAND-COVER DYNAMICS, BIOMASS STATUS AND COMMUNITY DEPENDENCE

## 4.1 INTRODUCTION

Land is the most important natural resource which embodies soil, water, vegetation and other productive resources upon which all terrestrial biosystems are dependent. The science of land-use/cover change comprised of identifying and quantifying changes in the landscape, requiring and understanding of that existed (or currently exist) in the landscape, how the landscape will look in near future (prognostic component), and socio-economic forces that drive changes. In the recent time advancement of the technological inputs has made land-cover change monitoring platforms more complex. There has been a new earth observation system, satellites with very fine resolution that has helped new opportunities to advance the frontier of land-use/cover change researches. Over the years there has been frequent concern of land resource degradation due to increasing human and bovine population that leads to put high pressure on certain resources and thus changes land-use/cover, leading to loss of soil fertility and depletion of forest resources (Milas 1984; Toit 1985; Pimental *et al.* 1986; Soule 1986; Whitlow 1988). Other factors contributing to resource degradation include the breakdown of traditional resource management systems (Swift 1976; Sinclairs & Fryxell 1985; Rai *et al.* 1994), inequality in access to natural resources (Repetto & Holmes 1983; Baker 1984; Whitlow 1988) and commercialization (Owen 1976; Singh *et al.* 1984).

Land-cover change stemming from human land-uses represents a major source and a main element of global environmental change. Land-use/cover changes contribute to globally systematic changes because of greenhouse gas accumulation in the troposphere and stratospheric ozone depletion (Turner *et al.* 1993). The quest for fast economic development and expanding agricultural activities has increased the exploitative pressure on the forests in the Himalaya (Singh *et al.* 1984). Himalayan forest loss is recognized as a regional and global problem, a little is known about the link between resource use and effects on forest fragmentation and loss. Knowledge of the dynamics and patterns of land-use/cover and forest fragmentation inventories are needed for the long-term sustainability of human-forest interactions and for developing management policies that protect and enhance Himalayan forests. Information on forest composition and association, biotic pressure and type of species surviving and the extent of biomass removal can help to rejuvenate depleting forest through silvicultural practices and community involvement (Ramakrishnan & Toky 1981; Singh & Singh 1987 and Sundriyal & Sharma 1996).

Forest constitutes about 42% of the total area of the Sikkim State. Records show that the area under closed canopy was only about 14% (Sudhakar *et al.* 1998). The forests of the State have suffered a serious set back during recent years due to tremendous pressure arising out of ever increasing demand for fuel wood, fodder and timber coupled with diversion of forest lands to non-forest uses in the name of developmental processes. A rapid depletion of forest resources has led to environmental degradation and economic deterioration all too widely in the Himalaya, where the majority of people are living just at or below the subsistence level (Thapa & Weber 1990). There is a vital need for protecting and scientifically managing the valuable land resources of the Himalayan region.

A better understanding of land-use and land-cover dynamics is of crucial importance to the study of carbon dynamics because changes in land- cover are caused by land-uses, which, in turn, are governed by human driving forces. Therefore, comprehensive information on the spatial and temporal distribution of land-use and land-cover categories and the pattern of their change is a prerequisite for understanding the optimum utilization and management of land resources on watershed basis because watershed approach in the Himalayan region has become acceptable in undertaking land improvement measures. Land, water and vegetation are the most important natural resources of mountain regions and these are much more degraded today than they were in the past. Considering the above issues, this chapter examines the overall pattern of land-use and land-cover change in a watershed focusing; (a) land-use/cover pattern; (b) land-use/cover change detection; (c) biomass, productivity and litter production and (d) fuel, fodder and timber extraction.

## 4.2 MATERIALS AND METHODS

### 4.2.1 Land-use/cover

The potential of satellite data as a basis for generating valuable information for land-use/land-cover is by now widely recognized, although initial efforts were made since mid seventies for application of different interpretation techniques in land-use/cover mapping (Anderson *et al.* 1976; Colwell 1983).

The land-use/cover pattern of the Mamlay watershed was analyzed based on a combination of surveys carried out in phases, using a combination of conventional and remote sensing techniques. The first phase consisted of collection of conventional data and their evaluation.

The second phase involved collection of satellite imageries IRS-1A, LISS-II of 1988 and IRS-1C, LISS-III of 2001, Geocoded FCC of bands 2, 3, 4 in the scale of 1:50000 in conjunctions with the survey of India topographical map on 1:50000 scale. Preparation of land-use/cover map is based on visual interpretation of satellite imageries by employing a photo interpretation key, tone, texture, pattern, shape, size, shadow, site, and association (Anonymous 1989). Interpreted details from the imageries were transferred to a base map 1:50000 scales having micro-watershed boundaries prepared from a topographical map. Each forest type was subdivided on the basis of crown-cover into three classes ≤20% (degraded), 21-40% (open) and ≥ 40% (dense). Both the visual interpretation and ground truth survey were employed for the extraction of various land-use/cover features.

Ground check studies were carried out for each theme to verify image interpretations. A traverse survey was undertaken from Gangtok to Mamlay watershed via Damthang and Namchi. On the way, observations were taken for the field features at several places. These were correlated with the satellite imagery information. Based on the ground truth data, modifications were effected and the classified features as well as their boundaries redefined. Image interpreted maps were finalized based on the ground truth and collateral data/information. This information is transferred to the base map and final thematic maps were prepared. Information on various features derived from satellite and collateral data were integrated and analyzed. Areas of different land-use and forest types under each crown class were estimated by using digital planimeter to complete the watershed land-use/land-cover statistics.

The only limitation encountered during this interpretation was the shadow effect of the hills. This is quite usual phenomenon in case of the satellite imageries of the Himalaya. Because of the total data acquisition time of the IRS satellite, which is 10.25 AM, the western and north-eastern slopes of the watershed are shadowed to some extent. This was overcome with the field verifications of the doubtful features of the shadow zone and modified suitably in the final interpretations.

### 4.2.2 Biomass, Productivity and Litter Production

A set of sample sites for each forest and agroforestry system comprising sub-tropical to temperate belts was selected from the map and these sites were marked on the ground. On each site, woody biomass standing state, woody biomass production, stand density and basal area were analyzed on 20x30 m quadrats. Sample consisted of 15 randomly placed permanent quadrats. Within each quadrat, each tree >10 cm DBH was identified, marked at 1.3 m for measurement of annual increment. Litter production and agronomic yield (in case of agroforestry systems) were estimated in the above quadrat. The volume of standing tree woody biomass in different forests and agroforestry systems were computed as product of volume and specific wood density (Ruark *et al.* 1987; Sundriyal *et al.* 1994a and Sundriyal & Sharma 1996), using species-specific regression equations developed by Sundriyal *et al.* (1994a) and Sundriyal & Sharma (1996). This was further confirmed with the measurement of fallen tree (cut by villagers and forest department) volume and biomass. Estimation of woody biomass of tree was extrapolated for each plot using the above relationship. Allometric relationships of tree component biomass on DBH developed by Sharma (1995) for *A. nepalensis, Albizia stipulata, Citrus reticulata* and mixed tree species for temperate and subtropical belts of the study area were used. The component weight data of each tree in the sample plots were extrapolated using the allometric relationship and then expanded to stand values. Mean annual increments of aboveground and belowground component of the individuals in the sample quadart were obtained by DBH increment measurement. The net change in the component biomass over one year period yielded annual biomass accumulation and the sum of the different components gave net production of tree strata. Monthly sampling of forest floor herbaceous biomass was done using 50×50 cm quadrat in replicates.

Litter production was studied in these sample plots. Monthly tree litterfall was recorded in each of the plots over a 2-year period (1999 and 2000), using three litter traps representing 1 $m^2$ collecting area in each plot. Accumulated litter on the floor was randomly sampled in triplicate from each stand and extrapolated to stand values. In the sample plots of large cardamom agroforestry total numbers of understory cardamom bushes were recorded. Average number of tillers per bush was calculated using data of 20 bushes for each plot. Total tillers for the plots were extrapolated using average number of tillers per bush and total number of bush per plot. About 200 tillers from each plot were harvested and height, leaf dry weight, pseudo-stem dry weight and bush root/rhizome dry weight measured for calculating mean values. The cardamom tillers that have fruited in any year are slashed after the harvest as a management practice because it does not fruit again. Therefore, the cardamom crop residue at the time of harvest was estimated for its annual contribution to the floor. Similarly, the above-ground crop residue in the mandarin based agroforestry system was estimated at the time of harvest of each crop.

### 4.2.3 Fuel wood, Fodder and Timber

Villagers were interrogated about the uses they made of different tree species, i.e., house construction, for agricultural field implements, volume of timber needed for house construction and amount of fodder collected from the forest and agroforestry area. The fuel wood, fodder and timber use and extraction of species by different communities were based on a detailed primary survey in randomly selected 100 households during the study period. To provide proportionate representation to every socio-economic segment, the community households were stratified on the basis of the size of land holding, income status, ethnicity and caste reflecting social status. Community wise fuel wood fodder and timber consumption per day, supply of fuelwood, fodder and timber from different sources, time taken for collection and distance covered were collected through questionnaire survey.

The questionnaire is the most widely adopted method for gathering data on collection and consumption quantities of fuel wood and fodder. The wide use of questionnaires is probably due to the limitation of time, resources and logistic facilities (Uma Shanker *et al.* 1998). Although extensively used, the questionnaire method generates highly biased data, because most of the respondents do not give accurate information due to lack of interest, inadequate knowledge of the subject, and intentional distortion of information. Inadequate knowledge of quantities might also lead to incorrect reporting (Malhotra *et al.* 1991). However, the questionnaire method is useful for a rapid assessment and to collect qualitative information such as the name of species used for fuel wood and fodder. To avoid the biases, estimation of the actual quantity of fuel wood and fodder requirement/consumption by each household was worked out on the basis of personal observation over a period of 24 hours by adopting a weight survey method. Simultaneously observations were also made in each sample to quantify fuel wood and fodder use for various tasks such as cooking, water heating and other purposes. During the survey the interviewer visited each sample household and requested the head person of the family to monitor the amount of fuel wood and fodder that would be burnt during that particular day. The wood and fodder was weighed using spring balance and then left in the kitchen (35 kg wood bundle and 50 kg fodder leaves) of each household with instruction to use wood and fodder only from bundle. On the next day, interviewer returned to each sample household, the remaining wood and fodder leaves were weighed again and deducted from the original bundle to calculate the actual consumption per day. Time spent for collection was noted when the members of the households went to the forests.

Participatory Rural Appraisal (PRA) techniques were also used to collect information of preferred species for fuel wood and fodder consumption. People's responses to the resource pressure faced by them, were considered the most accurate indicators of fuel wood and fodder shortage and were used to examine the severity of the problem.

## 4.3 RESULTS

### 4.3.1 Land-use Pattern

The land-use/cover pattern of the Mamlay watershed varies considerably depending upon the ecological conditions, altitude, lithology and slope aspect. Apart from these factors, technological and institutional influences also affected the land-use/cover pattern. The land-use/cover data generated through satellite imagery has been classified into four major classes of level I category i.e., (i) forests (ii) agroforestry (iii) agricultural land, and (iv) wasteland, and further sub-division has led to 9 sub-classes at level II. The spatial distribution pattern of the land-use/cover map of the watershed as interpreted from the imageries for the year 1988 and 2001 are shown in Figure 4.1 and 4.2 and area of different land-use types are given in Table 4.1, 4.2 and 4.3.

#### *4.3.1.1 Forests*

Forest is the most important land cover on higher steep slopes and ridges. The forest land includes temperate natural forest dense, temperate natural forest open and sub-tropical natural forest open (Plate 1a & b). The total forest land in the watershed accounts for 69% and 49% of the total areas of the watershed in 1988 and 2001, respectively (Table 4.1). The spatial distribution pattern shows that the northern, western and eastern parts of the watershed area are dominated by dense mixed and open mixed forests. Some forest blanks are also found in the reserved forest categories, this indicates the high human and livestock pressure in the area. Micro-watershed wise, Pockcheykhola and Sombareykhola were dominated by temperate natural forest dense and open, whereas Tirikhola by subtropical natural forest open in both the assessment years (Table 4.2 and 4.3). Figure 4.1 and 4.2 reveals that the Pockcheykhola, Sombareykhola, and Chemcheykhola micro-watersheds were dominated by forest at the ridge tops, agroforestry in the middle and agriculture in the valley areas.

#### *4.3.1.2 Agroforestry systems*

The agroforestry practices in the watershed are traditional and promising for higher economic returns. Two types of agroforestry systems are very common in the watershed, i.e., (i) large cardamom based and (ii) mandarin orange based (Plate 2a & b). About 4% areas came under agroforestry practices in 1988 and 2001, respectively (Table 4.1). Sombareykhola micro-watershed is dominated (3%) by large cardamom based agroforestry system whereas Tirikhola and Rangrangkhola by mandarin based agroforestry system (Table 4.2 and 4.3) in both the years.

### *4.3.1.3 Agricultural land*

This class includes built-up land, rainfed and irrigated land. About 14.39% and 30.53% area was under this category in 1988 and 2001 respectively. The land-use/cover pattern in the watershed as a whole showed about 2% area under built-up land in both the years. This includes only cluster settlements. In the Mamlay watershed, the distribution pattern of settlements is scattered ($R_n$= 1.19 and Di= 54%). So, it is very difficult to demarcate the whole built-up land area through satellite imageries because of limitations of resolution. The low lands along the river bed, commonly known as *khet*, are irrigated and paddy cultivation is the common practice in this land. The whole watershed had only about 2% of its area under irrigation in both the assessment years. Rainfed known as *pakho* cultivation (Plate 3a) covered about 12 and 28% area in 1988 and 2001, respectively. This land is suitable for cultivation of mainly maize, ginger and pulses (Plate 3b).

The dominant land-use/cover in each of the micro-watersheds has been also worked out in the watershed. The highest agricultural coverage was recorded in Chemcheykhola (4.17%), followed by Tirikhola (3.96%) and Pockcheykhola (3.11%) of the total watershed area in 1988, while in 2001, the highest coverage was observed in Tirikhola (13.11%), followed by Chemcheykhola (8.58%) and Rangrangkhola (3.69%) respectively (Table 4.2 and 4.3). The spatial distribution pattern of the agricultural land revealed that the central and north-western part of the watershed were under intensive agricultural practices (Fig. 4.1 and 4.2).

Four types of crop rotations are found in the watershed viz., maize-pulse/maize-potato/maize-ginger-pulse, these are practiced in rainfed conditions and one type (maize-paddy-fallow) in irrigated areas of the watershed. The maize-pulse crop combination is quite common and maize is harvested much earlier than pulses. Potatoes are becoming more popular as a cash crop. They are usually grown in triple cropping rotations after monsoon maize and relay-cropped with pulses or ginger. The intensity of cropping varies from farm to farm and from household to household due to differences in socio-economic conditions, particularly inputs and products, dependence on land and tenurial system etc.

#### *4.3.1.4 Wastelands*

This category of land cover includes rock outcrops, landslides, forest blanks, degraded forests and scrublands. The wasteland covered about 11 and 15% of the total area of the watershed in 1988 and 2001, respectively (Table 4.1). In 2001 about 9 ha area was under landslides whereas no landslides were observed in 1988. Micro-watershed wise, Chemcheykhola, Pockcheykhola and Sombareykhola were dominated by wasteland area temperate, while Tirikhola by wasteland area subtropical in both the assessment years (Table 4.2 and 4.3).

The surface water bodies include river, streams and springs. Owing to vegetation cover over the major drainage channels of the watershed, satellite imagery does not show a clear response for these channels in terms of the spectral signature of the water bodies. This is compounded by the fact that during the acquisition of image, the season was such that the channels were dry to a great extent. Therefore, in terms of land-use/cover interpretation, it was not possible to quantify the surface water bodies of the watershed.

### 4.3.2 Land-use/cover Change

The land-use/cover change detection was generated by the multi-date satellite data. Monitoring of land-use/cover reflected that changes were greater in extent over the span of 13 years in the land under different categories. Table 4.1 is a summary of changes in land-use between 1988 and 2001. The most dramatic changes are the increase in agricultural area and decrease in forest cover area. The open cropped area sub-tropical increased by more than 166% for the thirteen years period, while wasteland subtropical increased by about 117%. The total forests cover comprising temperate dense mixed, open mixed, and sub-tropical open mixed forest decreased by 28% during 1988-2001 (Table 4.1). Micro-watershed wise, major land-use/cover changes were observed in Tirikhola, Chemcheykhola and Pockcheykhola (Table 4.4). Figures 4.1 and 4.2 reflect the conversion of dense mixed forest to open mixed forest to degraded forest and dense mixed forest with agroforestry to open mixed forest with agroforestry and further to open cropped area. Ground-truth verification supports the finding that the depletion of closed forest or its conversion into other categories is the result of maximum anthropogenic pressure on the limited forest resources.

### 4.3.3 Biomass, Productivity and Litter Production in Different Land-Uses/Cover

Basal tree-trunk cover, total biomass (above-ground and below-ground), productivity, floor litter, annual litter production and humus content for different types of forest and agroforestry systems are given in Tables 4.5 and 4.6. Mean basal tree-trunk cover among different forest and agroforestry types ranged from 2 $m^2$ $ha^{-1}$ (mandarin based agroforestry systems) to 50 $m^2$ $ha^{-1}$ (temperate natural forest dense) (Table 4.5). The pattern of biomass (aboveground+belowground) was similar to that of basal cover. The total biomass varied from 12 t $ha^{-1}$ in mandarin based agroforestry system to 448 t $ha^{-1}$ in temperate natural forest dense (Table 4.5). The total biomass of large cardamom based agroforestry system was 103 t $ha^{-1}$, while it was 22 t $ha^{-1}$ in open cropped area temperate. The total biomass was 22 times higher in temperate natural forest dense than open cropped area. Of the total biomass, over 95% is contributed by aboveground component in forest ecosystems, up to 98% in mandarin based agroforestry and 52% in cardamom based agroforestry systems.

The productivity of forest and agroforestry systems were estimated and presented in Table 4.5. Highest (16.93 t $ha^{-1}$ $yr^{-1}$) net primary productivity was estimated in temperate natural forest dense and lowest (6.93 t $ha^{-1}$ $yr^{-1}$) in mandarin based agroforestry system.

The floor litter biomass was measured in different forests and agroforestry systems. The floor litter biomass was recorded maximum (13 t $ha^{-1}$) in temperate natural forest dense and the mandarin based agroforestry system had the minimum (3.8 t $ha^{-1}$) (Table 4.6). The annual litter production was recorded highest in temperate natural forest dense (4.57 t ha-$^{1}$ $yr^{-1}$) and lowest in subtropical natural forest open (2.82 t $ha^{-1}$ $yr^{-1}$).

The humus content was measured in temperate natural forest dense, temperate natural forest open, subtropical natural forest and cardamom based agroforestry system only, as mandarin based agroforestry contained no differential humus. It followed the similar trend as floor litter biomass with highest value recorded in temperate natural forest dense (6.7 t $ha^{-1}$) and the lowest in subtropical natural forest open (3.3 t $ha^{-1}$) (Table 4.6).

### 4.3.4 Fuel wood, Fodder and Timber Utilization

Field checks, interviews and detailed households survey in the watershed revealed that a large number of woody species are utilized for fuel, fodder and timber for house construction and in making agricultural implements (Plate 4a, b, c & d). Most of these species are collected from the forest and agroforestry systems. Each household on an average is composed of 6 persons and consists of 4 cattle. Fuel wood consumption per house hold is as much as 21 kg per day, through a minimum of 4000 kg (range 4000-5800kg) of dry firewood annually (Table 4.7). Annual consumption of firewood was greater for cooking (69%) followed by animal food preparation (9%), water heating (7%), house warming (6.7%), local wine /beer preparation (6%) and use for festivals (2%).

Each family maintains four animals consisting of cattle, pig and goat. Fodder is collected mainly from the forest (65%) and from agricultural fields (35%). Average fodder collection per household varies from 5000-6500 kg $yr^{-1}$ (mean 5700 kg per household $yr^{-1}$) from the forest area (Table 4.7). Most of the tree sprouts as well as ground herbaceous vegetation are removed for fodder purposes. In addition, unpalatable species and leaf litter are used for animal bedding.

Family fragmentation every 20-25 years leads mostly to construction of many new houses and almost all houses are made of wood (Plate 4b). Generally a space of two rooms needs 3-6 $m^3$ wood, depending upon the socio-economic condition of the farmers, and thus a huge amount of wood is collected each year. Field observations revealed that a tree of 50-90 cm and 90-125 cm CBH produces about 0.3-0.4 and 0.8-1.0 $m^3$ wood respectively. Generally large timber poles are harvested for making ceilings, doors, windows and beams. Medium size poles are used in making furniture and repairs, whereas small size poles for making cattle sheds or temporary huts (Table 4.7).

## 4.4 DISCUSSION

Human and livestock population pressure on the limited land resources has increased in recent years. This has resulted from the construction of road, fuel, fodder and timber extraction, encroachment into forests and more land utilization for agricultural expansion. Increased pressure on forests has brought tremendous changes in the pattern of land-use including reduction in forest cover. The expansion of agricultural land can be mainly attributed to fragmentation of upland farm families, which has led to expansion of the agricultural area. A bulk of settled agriculture fields in the watershed occurs on sloping terraces along the steep hill sides. Slopes of some agricultural land exceed 40° but most of them fall in between 20 to 35° (Rai *et al.* 1994).

The overall pattern of the forest and agroforestry revealed that all sites are under increasing biotic pressure from the neighboring villages. The forest stand shows high species diversity. Similarly, the density and basal area of the forest is towards the top of the range for most studied Himalayan and other forests (Saxena & Singh 1982; Ralhan *et al.* 1982; Sargent *et al.* 1985; Upreti *et al.* 1985; Singh & Singh 1987; Sundriyal *et al.* 1994a; Sundriyal & Sharma 1996). Now there are trends/evidences of indiscriminate cutting and mismanagement during recent years which has resulted in more damage of some species than others.

The biomass and productivity potential of the studied forest and agroforestry system is within the comparable range of values published for Himalayan and other forests and agroforestry (Singh & Ramakrishnan 1982; Shukla & Ramakrishnan 1984; Sharma & Ambasht 1991; Sundriyal *et al.* 1994a; Sundriyal & Sharma 1996; Sharma *et al.* 1997). Amount of biomass at different locations varied due to differences in species composition. Greater biomass was mainly due to the presence of canopy trees of larger girth classes, viz., *Castanopsis tribuloides, Quercus lamellosa, Symingtonia populnea* and *Nyssa sessiliflora* etc.

The forest and agroforestry systems has been meeting and satisfying the material needs of the majority of the population of the watershed, but now evidence of decline in species number and composition are emerging and it is apparent that local subsistence needs are causing much of the degeneration in the forests. Indiscrimate cutting by people, selective felling by Forest Department, plantation of exotic species like *Cryptomeria japonica*, and use of enormous amounts of wood in house construction and large scale cardamom curing are the most common causes of forest destruction. Field visits revealed that the cutting process is highly irregular in both space and time and a huge amount of wood is wasted. Nearly 40-50% and 20-30% is wasted in the processes of timber and fuel collection, respectively. Generally, smaller dry and dead, and fallen logs and branches are not collected and trees of smaller girth classes are preferred due to easy extraction.

Interviews with the residents of the watershed revealed that previously the forest had a good number of individuals of *Michelia excelsa, M. lanuginosa, Juglans regia, Cedrela toona*, and various other timber trees. The most significant extraction of these species was done after 1970 due to construction of more luxurious house throughout the State. In Sikkim as well as in the Mamlay watershed it has been observed that the rate of immigration into the area was high during 1971-1991. Most of the immigrants were traditionally cultivators (personal observation). The growth of population in the watershed was at an average rate of 2.84% per year over the period of 1981-1991 and the forest cover decreased at an alarming rate of upto 2.80% per annum, which is excessively high. A similar trend was observed in the Central Himalayan region at 1.5% per year (Shah 1982; Singh *et al.* 1984). Thus the family fragmentation and population pressure is continually taking place within the watershed, which indicates that the man-land ratio is likely to further decline in the near future. Considering all these factors, it can be said that this natural forest stand is at severe risk of reduction which may lead to the disappearance of many species in the near future.

Lack of effective land-use planning and uncontrolled population growth has contributed to the present deplorable state of affairs. In general, the area shows increasing environmental degradation and resource depletion, while very little conservation efforts are being made to reverse the trend. These results indicate that a sustainable land-use/cover management plan is urgently needed for the area.■

**Table 4.1** Area under different land-use/cover and change detection of the Mamlay watershed based on remote sensing data, 1988-2001

| Land-use/cover | Year | | | | Variation | |
|---|---|---|---|---|---|---|
| | 1988 | | 2001 | | (1988 - 2001) | |
| | (ha) | (%) | (ha) | (%) | (ha) | (%) |
| **Forest** | | | | | | |
| Temperate natural forest dense | 606.81 | 20.13 | 160.00 | 5.32 | -446.81 | -73.63 |
| Temperate natural forest open | 815.09 | 27.04 | 982.24 | 32.59 | 167.15 | 20.51 |
| Sub-tropical natural forest open | 681.54 | 22.61 | 362.25 | 12.03 | -319.29 | -46.85 |
| **Agroforestry** | | | | | | |
| Cardamom based agroforestry | 114.78 | 3.81 | 114.78 | 3.81 | -- | -- |
| Mandarin based agroforestry | 17.42 | 0.58 | 17.42 | 0.58 | -- | -- |
| **Agriculture*** | | | | | | |
| Open cropped area temperate | 243.89 | 8.09 | 413.62 | 13.72 | 169.73 | 69.59 |
| Open cropped area sub-tropical | 189.96 | 6.30 | 506.33 | 16.81 | 316.37 | 166.55 |
| **Wasteland**** | | | | | | |
| Wasteland area temperate | 341.99 | 11.35 | 451.92 | 14.99 | 109.93 | 32.14 |
| Wasteland area sub-tropical | 2.5 | 0.08 | 5.42 | 0.18 | 2.92 | 116.80 |
| **Total** | 3014 | 100 | 3014 | 100 | | |

* Irrigated area, rainfed area and built-up area

**Degraded forest, scrub land, forest blanks, rock out crops, land slides

-- denotes no change

**Table 4.2** Area under different land-use/cover on micro-watershed level of the Mamlay watershed based on remote sensing data, 1988

| Land-use/cover | Micro-watersheds | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pockcheykhola | | Chemcheykhola | | Tirikhola | | Sombareykhola | | Rangrangkhola | |
| | (ha) | (%) | (ha) | (%) | (ha) | (%) | (ha) | (%) | (ha) | (%) |
| Temperate natural forest dense | 372.13 | 12.35 | 43.13 | 1.43 | 0.00 | 0.00 | 189.97 | 6.30 | 1.58 | 0.05 |
| Temperate natural forest open | 245.70 | 8.15 | 375.04 | 12.44 | 0.00 | 0.00 | 194.35 | 6.45 | 0.00 | 0.00 |
| Sub-tropical natural forest open | 0.00 | 0.00 | 14.94 | 0.50 | 381.85 | 12.67 | 0.00 | 0.00 | 284.75 | 9.45 |
| Cardamom based agroforestry | 11.74 | 0.39 | 4.24 | 0.14 | 0.00 | 0.00 | 98.80 | 3.28 | 0.00 | 0.00 |
| Mandarin based agroforestry | 0.00 | 0.00 | 3.94 | 0.13 | 7.96 | 0.26 | 0.00 | 0.00 | 5.52 | 0.18 |
| Open cropped area temperate | 93.88 | 3.11 | 125.63 | 4.17 | 0.00 | 0.00 | 24.38 | 0.81 | 0.00 | 0.00 |
| Open cropped area sub-tropical | 0.00 | 0.00 | 0.00 | 0.00 | 119.32 | 3.96 | 0.00 | 0.00 | 70.64 | 2.34 |
| Wasteland area temperate | 64.38 | 2.14 | 150.11 | 4.98 | 0.00 | 0.00 | 127.50 | 4.23 | 0.00 | 0.00 |
| Wasteland area sub-tropical | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.50 | 0.08 |
| Total | 788 | 26.11 | 717 | 23.79 | 509 | 16.89 | 635 | 21.07 | 365 | 12.11 |

0.00 = not present

**Table 4.3** Area under different land-use/cover on micro-watershed level of the Mamlay watershed based on remote sensing data, 2001

| Land-use/cover | Micro-watersheds | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pockcheykhola | | Chemcheykhola | | Tirikhola | | Sombareykhola | | Rangrangkhola | |
| | (ha) | (%) | (ha) | (%) | (ha) | (%) | (ha) | (%) | (ha) | (%) |
| Temperate natural forest dense | 92.50 | 3.07 | 5.00 | 0.17 | 0.00 | 0.00 | 62.50 | 2.07 | 0.00 | 0.00 |
| Temperate natural forest open | 498.76 | 16.55 | 195.78 | 6.50 | 0.00 | 0.00 | 287.70 | 9.58 | 0.00 | 0.00 |
| Sub-tropical natural forest open | 0.00 | 0.00 | 14.94 | 0.50 | 103.50 | 3.43 | 0.00 | 0.00 | 243.81 | 8.09 |
| Cardamom based agroforestry | 11.74 | 0.39 | 4.24 | 0.14 | 0.00 | 0.00 | 98.80 | 3.28 | 0.00 | 0.00 |
| Mandarin based agroforestry | 0.00 | 0.00 | 3.94 | 0.13 | 7.96 | 0.26 | 0.00 | 0.00 | 5.52 | 0.18 |
| Open cropped area temperate | 102.50 | 3.40 | 258.62 | 8.58 | 0.00 | 0.00 | 52.5 | 1.74 | 0.00 | 0.00 |
| Open cropped area sub-tropical | 0.00 | 0.00 | 0.00 | 0.00 | 395.04 | 13.11 | 0.00 | 0.00 | 111.29 | 3.69 |
| Wasteland area temperate | 82.50 | 2.74 | 234.48 | 7.78 | 0.00 | 0.00 | 132.50 | 4.40 | 0.00 | 0.00 |
| Wasteland area sub-tropical | 0.00 | 0.00 | 0.00 | 0.00 | 2.50 | 0.08 | 0.00 | 0.00 | 4.37 | 0.14 |
| Total | 788 | 26.11 | 717 | 23.79 | 509 | 16.89 | 635 | 21.07 | 365 | 12.11 |

0.00 = not present

**Table 4.4** Land-use/cover change detection on micro-watershed level of the Mamlay watershed based on remote sensing data, 1988-2001

| Land-use/cover | Micro-watersheds | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pockcheykhola | | Chemcheykhola | | Tirikhola | | Sombareykhola | | Rangrangkhola | |
| | (ha) | (%) | (ha) | (%) | (ha) | (%) | (ha) | (%) | (ha) | (%) |
| Temperate natural forest dense | -279.63 | -75.43 | -38.13 | -88.41 | 0.00 | 0.00 | -127.47 | -67.10 | 0.00 | 0.00 |
| Temperate natural forest open | 253.06 | 102.99 | -179.26 | -47.79 | 0.00 | 0.00 | 94.35 | 48.55 | 0.00 | 0.00 |
| Sub-tropical natural forest open | 0.00 | 0.00 | -- | -- | -278.35 | -72.89 | 0.00 | 0.00 | -40.94 | -14.38 |
| Cardamom based agroforestry | 0.00 | 0.00 | -- | -- | 0.00 | 0.00 | -- | -- | 0.00 | 0.00 |
| Mandarin based agroforestry | 0.00 | 0.00 | -- | -- | -- | -- | 0.00 | 0.00 | -- | -- |
| Open cropped area temperate | 8.62 | 9.18 | 132.99 | 105.86 | 0.00 | 0.00 | 28.12 | 115.34 | 0.00 | 0.00 |
| Open cropped area sub-tropical | 0.00 | 0.00 | 0.00 | 0.00 | 275.72 | 231.08 | 0.00 | 0.00 | 40.65 | 57.55 |
| Wasteland area temperate | 18.12 | 28.14 | 84.37 | 56.21 | 0.00 | 0.00 | 5.00 | 3.92 | 0.00 | 0.00 |
| Wasteland area sub-tropical | 0.00 | 0.00 | 0.00 | 0.00 | 2.50 | 250.00 | 0.00 | 0.00 | 1.87 | 74.80 |

0.00 = not present;

-- = no change

**Table 4.5** Estimation of density, basal area, biomass and productivity in different land-use/cover of the Mamlay watershed

| Land-use/cover | Components | Density (trees $ha^{-1}$) | Basal area ($m^2$ $ha^{-1}$) | Biomass (t $ha^{-1}$) | Productivity (t $ha^{-1}$ $yr^{-1}$) | Removal (t $ha^{-1}$ $yr^{-1}$) |
|---|---|---|---|---|---|---|
| Temperate natural forest dense | Tree | 422 | 50 | | | 3.15 |
| | Bole + Branch | | | 425.94 | 10.37 | |
| | Leaf + Twig | | | 2.07 | 4.57* | |
| | Root | | | 19.49 | 0.74 | |
| | Tree Total | | | 447.50 | 15.68 | |
| | Herbaceous | | | | | 1.95 |
| | Aboveground Biomass | | | 0.69 | 1.00 | |
| | Belowground Biomass | | | 0.17 | 0.25 | |
| | Herbaceous Total | | | 0.86 | 1.25 | |
| | Stand Total | | | 448.36 | 16.93 | 5.10 |
| Temperate natural forest open | Tree | 239 | 31 | | | 2.75 |
| | Bole + Branch | | | 188.70 | 7.39 | |
| | Leaf + Twig | | | 1.73 | 3.31* | |
| | Root | | | 10.05 | 0.42 | |
| | Tree Total | | | 200.48 | 11.12 | |
| | Herbaceous | | | | | 2.03 |
| | Aboveground Biomass | | | 1.00 | 1.06 | |
| | Belowground Biomass | | | 0.25 | 0.27 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Herbaceous Total | | | 1.25 | 1.33 | |
| | Stand Total | | | 201.73 | 12.45 | 4.78 |
| Sub-tropical natural forest open | Tree | 189 | 10 | | | 4.35 |
| | Bole + Branch | | | 184.45 | 6.63 | |
| | Leaf + Twig | | | 0.60 | 2.82* | |
| | Root | | | 2.85 | 0.05 | |
| | Tree Total | | | 187.90 | 9.50 | |
| | Herbaceous | | | | | 2.45 |
| | Aboveground Biomass | | | 0.82 | 0.90 | |
| | Belowground Biomass | | | 0.20 | 0.23 | |
| | Herbaceous Total | | | 1.02 | 1.13 | |
| | Stand Total | | | 188.92 | 10.63 | 6.80 |
| Cardamom based agroforestry system | *Alnus* + Mix Tree | 330 | 42 | | | |
| | Branch | | | 13.64 | 1.13 | |
| | Bole | | | 35.07 | 2.23 | |
| | Leaf +Twig | | | 5.63 | 3.69* | |
| | Root | | | 12.76 | 1.35 | |
| | Catkin | | | 0.50 | 0.53 | |
| | Tree Total | | | 67.60 | 8.93 | |
| | Cardamom | | | | | |
| | Leaf | | | 2.33 | 0.42 | |

| | | | | | |
|---|---|---|---|---|---|
| | Pseudostem | | | 6.98 | 1.25 |
| | Capsule | | | 0.31 | 0.18 |
| | Root/Rhizome | | | 25.30 | 2.01 |
| | Cardamom Total | | | 34.92 | 3.86 |
| | Stand Total | | | 102.52 | 12.79 |
| Mandarin based agroforestry system | Mandarin + Mix Tree | 128 | 2 | | |
| | Branch | | | 1.15 | 0.11 |
| | Bole | | | 3.99 | 0.41 |
| | Leaf + Twig | | | 0.46 | 1.08* |
| | Root | | | 1.56 | 0.17 |
| | Orange Fruit | | | 0.65 | 0.65 |
| | Tree Total | | | 7.81 | 2.42 |
| | Crops | | | | |
| | Aboveground Residue | | | 2.12 | 2.12 |
| | Belowground Residue | | | 0.79 | 0.79 |
| | Agronomic Yield | | | 1.60 | 1.60 |
| | Crop Total | | | 4.51 | 4.51 |
| | Stand Total | | | 12.32 | 6.93 |
| Open cropped area temperate | Crops | | | | |
| | Aboveground residue | | | 4.84 | 4.84 |
| | Belowground Residue | | | 1.57 | 1.57 |

| | | | |
|---|---|---|---|
| | Agronomic Yield | 3.57 | 3.57 |
| | Crop Total | 9.98 | 9.98 |
| | Weed | 11.85 | - |
| | Stand Total | 21.83 | 9.98 |
| Open cropped area sub-tropical | Crops | | |
| | Aboveground Residue | 4.77 | 4.77 |
| | Belowground Residue | 1.19 | 1.19 |
| | Agronomic Yield | 1.23 | 1.23 |
| | Crop Total | 7.19 | 7.19 |
| | Weed | 12.05 | - |
| | Stand Total | 19.24 | 7.19 |

* Tree leaf and twig production estimated on standing trees was corrected using annual litterfall data

- not measured

**Table 4.6** Annual litter production, floor litter and humus content of different land-use/cover

| Land-use/cover | Annual litter production (t ha$^{-1}$ yr$^{-1}$) | Floor litter (t ha$^{-1}$) | Humus content (t ha$^{-1}$) |
|---|---|---|---|
| Temperate natural forest dense | 4.57 | 13.00 | 6.70 |
| Temperate natural forest open | 3.31 | 8.30 | 4.10 |
| Sub-tropical natural forest open | 2.82 | 7.50 | 3.30 |
| Cardamom based agroforestry system | 4.11 | 11.70 | 5.90 |
| Mandarin based agroforestry system | 3.2 | 3.80 | - |

**Table 4.7** Per household consumption of fuel wood, fodder and timber in the Mamlay watershed.

| | |
|---|---|
| **Fuel wood consumption** | |
| Daily requirement per household | 15-21 kg |
| Annual requirement per household* | 4000-5800 kg |
| **Fodder collection** | |
| From forest** | 5700 kg household$^{-1}$ year$^{-1}$ |
| From agricultural fields** | 2630 kg ha$^{-1}$ |
| **Timber (on per household basis)** | |
| ***Small size poles (bamboo)*** | |
| Purpose | cattleshed, baskets, mats, minor repairs |
| No. of poles required | 100+ |
| Average size of poles (CBH***) | <30 CM |
| Time interval of need | 5 - 7 years |
| ***Medium size pole*** | |
| Purpose | house repairs, furniture etc. |
| Wood volume required | 2.5 – 4.2 m$^3$ |
| Time interval of need | 15 – 20 years |
| No. of trees required | 20-40 |
| Average size (CBH) | 30-90 cm |
| ***Large size poles*** | |
| Purpose | new house construction |
| Wood volume required | 5 - 7 m$^3$ |
| No. of trees required | 7 – 10 |
| Average size (CBH) | 90 – 125 cm |
| Time interval of need | 20 – 30 years |

*large cardamom growers use an additional 70 to 80 kg of fuel wood (dry weight) for curing per 100 kg of cardamom.

** on dry weight basis (fresh weight-dry weight ratio is 3:1)

*** CBH is pole's circumference at breast height

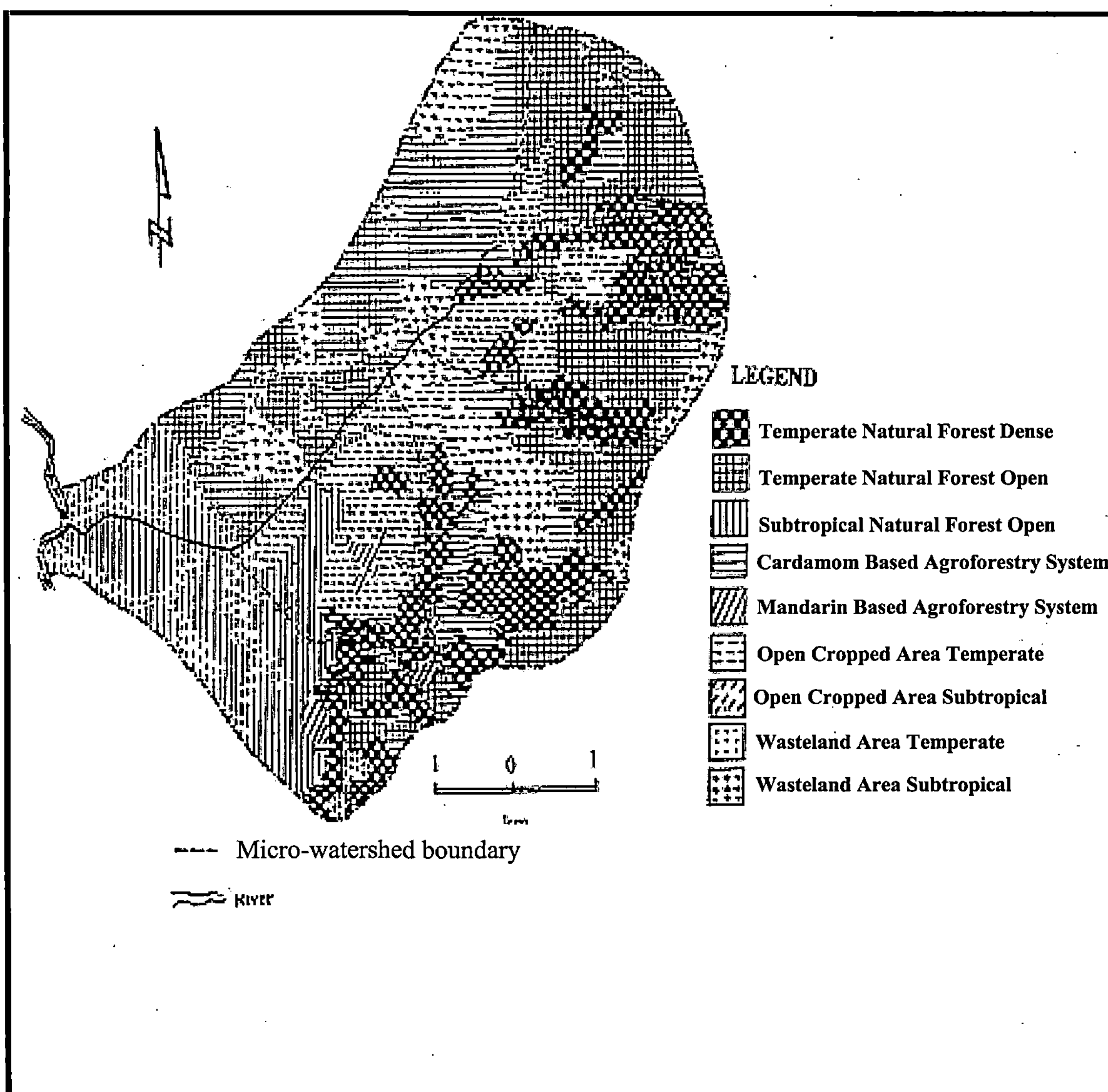


**Fig. 4.1** Land-use/cover map of the Mamlay watershed, 1988

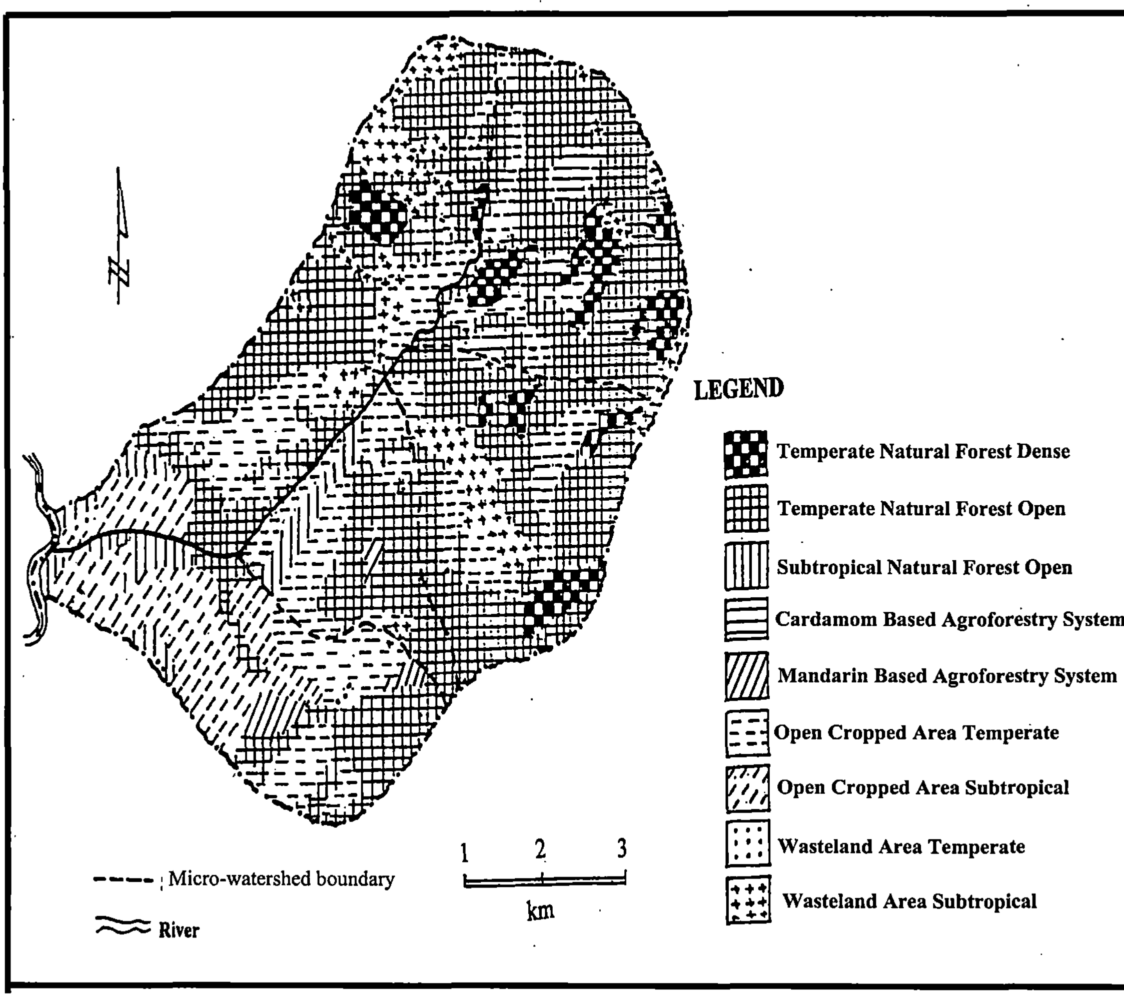


**Figure 4.2** Land –use/cover map of the Mamlay watershed 2001