Chapter - V

HYDROLOGICAL ANALYSES

5.1 INTRODUCTION

The Himalayan massif is a relatively young and geo-morphologically unstable region. It is a major contributor of run-off and sediment in the principal rivers of South Asia. Conventional wisdom holds that widespread deforestation and population pressure have exacerbated erosion and led to increased down-stream flood hazards. The Himalayan Mountain range is the source of the major river systems of India. Because of the accelerated silting of these rivers and catastrophic floods in the adjoining plains, the soil loss from Himalaya has attracted considerable attention in recent years.

Eighty per cent of the sediments delivered to the World's oceans each year come from Asian rivers and amongst these the Himalayan Rivers are the major contributors (Stoddart 1969). The Himalaya contributes 500-1000 t km^{-2} yr^{-1} of sediment (Milliman & Meade 1983) and Sikkim in the eastern Himalaya as also shows similar value of 794 t km^{-2} yr^{-1} (Sharma *et al.* 2001). It is estimated that the river Brahmputra alone carries a suspended load of 800 million tones, the average sediment-yield from its catchments being of the order of 26000 ha meters (Raina *et al.* 1980). River systems are also the major means of transport of dissolved materials, including inorganic nutrients and contaminants, which depend on riverine geochemical and hydrological processes. It is estimated that current rates of erosion are five times as great as the rates prevailing in the geological past (Singh *et al.* 1983). Mass wastage and spectacular landslides have occurred owing to tectonic stresses (Raina *et al*, 1980) and road construction, but they form a class among themselves.

The problem of erosion is still more acute in the high-sesmicity areas, which are geo-dynamically sensitive thrust areas.

The rapidly increasing population is seen to be fuelling the expansion of agricultural land on steep and marginal slopes, thereby increasing the destruction of forest cover to make way for agricultural terraces and this has resulted in land degradation. To meet the increasing needs of forest products for fuel and fodder, such change in land–use was expected to lead a dramatic environmental degradation with important consequences for soil erosion, reduced productivity, and deterioration of fragile natural ecosystems (Danida 1988). Soil erosion is a major environmental and agricultural problem worldwide. Although erosion has occurred throughout the history of agriculture, it has intensified in recent years. The loss of soil degrades arable land and eventually renders it unproductive. Worldwide, about 12×10^6 ha of arable land are destroyed and abandoned annually because of unsustainable farming practices and only about 1.5×10^9 ha of the land are cultivated (Pimental *et al.* 1995).

Hydrologically linked ecosystems interact through the flow of nutrients through water. Nutrients discharged from uplands pass through low lands on their way to the sea. Understanding the dynamics of such nutrient flows requires knowledge of the effect of land-use on nutrient discharge and of the effects of uphill ecosystems on downhill ecosystems. Therefore, information on the hydrological cycle in the hills is very important for considering management strategies at a watershed level. The relationship between land-use/cover change and soil erosion and hydro-ecological process is a key element in understanding the little known local, regional and global biospheric disruptions. Unfortunately, there were no such hydrological studies of carbon flow through different land-uses for the Himalayan region. In this chapter investigation was undertaken to understand the different hydrological processes involving carbon flow in a hilly watershed. The present chapter was divided to consider the following (i) stream discharge and carbon loss; (ii) sediment concentration; (iii) precipitation and overland flow; (iv) soil erosion and carbon loss and (v) precipitation pathways and carbon flow. The land-use change and hydrology of these on micro-watersheds and total watershed have been analyzed to determine the effect of land-use on sediment and carbon flux from the system.

5.2 MATERIALS AND METHODS

5.2.1 Stream Discharge and Sediment Concentration

Precipitation was recorded on a monthly basis since 1999 in a non-recording rain gauge located in sub-tropical and temperate belts of the watershed area. The collectors were located at elevations ranging from below 1000 m to 1900 m a.s.l.

Stream flow grab samples were taken at six locations i.e., Pockcheykhola, Chemcheykhola, Sombareykhola, Tirikhola, Rangrangkhola and at the outlet of the watershed at Rinjikhola. Samples were taken after rainfall events or at least every two weeks between events and the data pooled into seasonal values, viz., summer, rainy and winter between 1999 and 2000. The year 1999 had a normal monsoon season but 2000 was marked by a failure of the rains and droughts. Stream sampling sites for Pockcheykhola, Chemcheykhola and Sombareykhola were predominantly occupied by agriculture with agroforestry and the other two were dominated by agriculture, agroforestry and forest land-uses. Out flow from the main outlet were also collected on these dates. Total suspended sediment content of each stream flow sample was determined by filtering the sediment from collected water samples.

5.2.2 Overland Flow and Soil Loss

Overland flow and soil loss were estimated from 27 experimental plots under different land-use during 1999 and 2000 on three monsoon (pre-monsoon, mid-monsoon and post-monsoon) seasons. Three rainfall events were considered for each monsoon period totaling 18 events during two years of study. These were estimated using natural shallow surface run-off channels and artificially delineated plots (Pandey *et al.* 1983; Singh *et al.* 1983; Rai & Sharma 1998). The delineated plot size was 10x3 m^2 for estimations of overland flow and soil loss, and three plots were laid in each type of land-use/cover practice. These plots were delineated with aluminum sheets (inserted in soil for about 6 cm and remaining 15 cm exposed in air) from all sides to prevent water likely to enter from adjacent areas. The plots were selected with 25 to 30° slope in all the land-uses as majority of the area in the watershed fall in this slope category. The overland flow and soil loss along the slope were estimated from the collecting tank after each rainfall event. Soil samples were collected from surroundings of each of the delineated plots in replicates up to 30 cm depth and samples were mixed together for a representative composite parent soil. These samples were collected just before the rainy season at the time of plot delineation. The eroded soil was sampled in the form of bed-load sediments and suspended clay materials from the collecting tank. The suspended clay material was separated by filtration through whatman filter paper size 41 from the sample water. The soils for carbon analyses comprised of both bed-load sediment and suspended clay materials for eroded soils. Total organic carbon of the soil was estimated following modified Walkley-Black method (Anderson & Ingram 1989).

Total area of each sub-divided land-use in the watershed was calculated, and overland flow and soil loss from each of the land-use were estimated. The run-off water samples were analyzed for soluble carbon (Anderson & Ingram 1989).

5.2.3 Precipitation Partitioning Pathways

Partitioning of incident precipitation into throughfall, stemflow, canopy interception; floor leachate and floor interception was made. Trees were marked for stemflow measurement in each of the sites, temperate natural forest dense, temperate natural forest open, sub-tropical natural forest, cardamom based agroforestry and mandarin orange based agroforestry systems. Stemflow was collected by attaching aluminum collars to five trees of different diameter classes in each stand. Stemflow was sampled over almost the whole range of size classes for the dominant tree species in each plot. Within each plot five throughfall collectors and five floor leachate collectors were established. Throughfall, stemflow, and forest floor leachate volumes were measured frequently to prevent over flowing. The floor leachate collectors were covered by 2 mm mesh nylon net on the top on which rested the litter, carefully removed from the bottom of the collectors. Floor leachate collectors were inserted into the soil such that the rim of the container was horizontal and level with the surface of the litter. Throughfall collectors rested on the soil surface such that their upper rims were also horizontal and about 20 cm above the surface. All throughfall and floor leachate collectors were set out in a random pattern and measurements were made at different times during the rainy season. Following each sampling, all throughfall and floor leachate collectors were randomly relocated. This technique is likely to produce more accurate estimates of annual volumes than fixed collectors (Kimmins 1973). Throughfall and floor leachate volumes were calculated considering the width of the upper rim of collecting vessels and converted to mm. Average stemflow volumes per tree for each species for a sampling period was calculated. These volumes were then multiplied by number of trees present to obtain the total stemflow volume for each plot and then converted to mm. Canopy interception was calculated by subtracting throughfall and stemflow value from incident precipitation. Forest floor interception was derived from the difference of the forest floor leachate with the added value of throughfall and stemflow.

Throughfall, stemflow, and floor leachate samples were determined in the field on bimonthly basis in different stands of forest and agroforestry and brought to the laboratory and processed for soluble carbon analyses following Anderson & Ingram (1993).

5.2.4 Statistical Analysis

All statistical analyses were conducted within the framework provided by the statistical analysis system (Systat 1996). The 0.05 level of probability was used as the criteria for accepting or rejecting null hypotheses pertaining to all data sets.

5.3 RESULTS

5.3.1 Stream Discharge and Carbon Loss

The Mamlay watershed is a part of the catchment of the Rangit River, the second largest river of the Sikkim Himalaya. The drainage network of the watershed is dendritic type and the texture is fine in the upper part of the watershed. The outlet for the watershed is the Rinjikhola which feeds the River Rangit, a main tributary of the River Tista. The watershed has a total area of 30.14 km^2 and the total stream length is 82.6 km. The drainage density of the watershed is very high, having a value of 2.74. The total number of channels are 80, 18 and 7 in the first, second and third order streams, respectively. The bifurcation ratio (ratio between the number of streams of a particular order and that of the streams of the next higher order) of the first order stream was 4.44 and the second order stream 1.14.

All the streams attain significant sizes during the rainy season. Seasonal streams dry up by January-May in the watershed. The highest discharge of 4143 l s^{-1} was recorded in the rainy season in 1999 followed by 4137 l s^{-1} in 2000 and the lowest of 850 l s^{-1} and 840 l s^{-1} in summer season, in the respective years, in the Rinjikhola, the outlet of the watershed (Fig. 5.1). For the different streams the discharge was in order Pockcheykhola > Sombareykhola > Chemcheykhola > Tirikhola > Rangrangkhola and the significant variation was observed only in rainy season. The discharge in various streams showed high seasonality and direct relationship with precipitation. Most of the precipitation was received in the monsoon and consequently discharge was highest in this season. Analysis of variance showed that streams, season and stream×season varied significantly ($P<0.0001$).

Across the micro-watersheds and total watershed, the carbon loss through runoff and sediment was analyzed. Organic carbon loss through sediments ranged from 0.014 to 136 t yr^{-1} in micro-watershed, while the annual loss from the outlet of the watershed was 833 t yr^{-1} (Table 5.1). The loss of soluble carbon through runoff water ranged between 0.96 to 814 t yr^{-1} for the micro-watersheds and was about 2025 t yr^{-1} at the watershed outlet. Streamflow concentrations of soluble carbon showed the most distinct seasonal trend. On seasonal basis highest loss was recorded during rainy season (Table 5.2) and it varied significantly ($P<0.0001$). All the streams showed highest concentration in the rainy season. On micro-watershed wise, mean yearly stream water soluble carbon concentration for the two years study period was recorded highest at Pockcheykhola (814 t yr-1) compared to mean concentration values with other micro-watersheds.

5.3.2 Sediment Concentration

The sediment concentration varied distinctly with seasons in different streams and the outlet of the watershed. The sediment concentration during 1999 and 2000 ranged from 9-61 mg l^{-1} in winter, 8-59 mg l^{-1} in summer, and 14-399 mg l^{-1} in the rainy season (Fig. 5.2). Analysis of variance showed significant variation between streams and seasons and its interaction was also significant ($P<0.0001$).

The highest sediment concentration in the rainy season was mainly because of high precipitation and extensive agricultural practices followed in this season. Seasonal and yearly soil loss value was recorded in stream waters of the micro-watersheds and total watershed for the two year period 1999-2000 are presented in Table 5.3. The soil loss from different micro-watersheds ranged from 0.001-7.48 t ha^{-1} in 1999 and 0.001-6.62 t ha^{-1} in 2000. The soil loss rate from the total watershed ranged between 6 to 7 t ha^{-1} yr^{-1} during the two years of the study. The total soil loss from the watershed with an area of 30.14 km^2 is significant, ranging from 18295 t yr^{-1} in 1999 to 21953 t yr^{-1} in 2000.

5.3.3 Precipitation and Overland Flow

Precipitation was recorded at two locations representing different slope and aspects in the watershed covering sub-tropical and temperate belts for the period of two years from 1999-2000. The average annual precipitation for the two years period was 2992 mm in temperate belt and 1295 mm in sub-tropical belt of the watershed.

Overland flow (percentage of rainfall during rainy season) was recorded to be highest in open cropped area sub-tropical (10.86%) and lowest in cardamom based agroforestry (2.80%) (Table 5.4). Usually the non-forested sites had a greater overland flow of water compared with adjacent forested and agroforestry sites. Overland flow was a function of the size of the rain-shower. Nevertheless, the magnitude of overland flow was too small to play a significant role in the wider context of flooding. The overland flows involve subsurface systems and that most of the water is transmitted to streams by lateral down slope flow within the soil.

5.3.4 Soil Erosion and Carbon Loss

In most areas, raindrop splash and sheet erosion are the dominant forms of erosion. Erosion is intensified on sloping land, where more than half of the soil contained in the splashes is carried downhill. The sediment movement from the temperate natural forest dense was 16 kg ha^{-1} during the monsoon period and this is 17 times lower than the values recorded from open cropped area of the sub-tropical belt (Table 5.4). There is a dramatic rise in sediment output from the landslide and newly constructed road sites consequent to the formation of channels. Erosion increased dramatically on steep cropland. Soil loss was recorded highest in open cropped area sub-tropical (525 kg ha^{-1}) when compared to forests and agroforestry systems.

Total organic carbon concentration in parent soil and eroded soil was estimated during the rainy season in different land-use/covers and the values are presented in Figure 5.3. Concentration of total organic carbon content was higher in eroded soil than the parent soil. Total organic carbon content in the parent soil upto 30 cm depth ranged from 10 to 26 mg g^{-1}, highest being recorded in temperate natural forest dense and very little variation was observed in other land-use/covers. But the highest organic carbon concentration in eroded soil was recorded in wasteland area temperate (40.8 mg g^{-1}) and lowest from temperate natural forest dense (32.2 mg g^{-1}). An ANOVA test on organic carbon concentration between eroded and parent soils and between land-uses shared a statistically significant variation ($P < 0.0001$).

5.3.5 Precipitation Pathways and Carbon Flow

Incident precipitation is initially partitioned into throughfall, stemflow and interception by a forest canopy. Some of the throughfall and stemflow reaching the forest floor is intercepted by the litter, the remainder flows into the mineral soil as forest floor leachate. Partitioning of incident precipitation into various pathways in temperate natural forest dense, temperate natural forest open, sub-tropical natural forest open, large cardamom based agroforestry system and mandarin orange based agroforestry system of the watershed were analyzed. The quantities of water moving through these pathways are given in Table 5.5. In temperate natural forest dense, precipitation partitioned into 77.71% throughfall, 9.92% stemflow and 11.40% intercepted by canopy. About 45% of the water was collected as leachate and the floor interception was 55%. In the case of temperate natural forest open, 52.71% canopy interception was recorded. In the large cardamom based agroforestry system, throughfall was recorded 54.58% of total precipitation, canopy interception was 40% and stemflow was just 5%. In the sub-tropical natural forest, throughfall was about 55.67%, canopy interception was 42% and the stemflow was negligible that amounted 0.23%. The floor leachate was 38% and the remaining 62% was recorded to be the floor interception. Stemflow in the mandarin agroforestry system was higher (5%) than that recorded from sub-tropical natural forest open. The total amount of water on the floor partitioned as 70% as leachate and remaining as floor interception in the mandarin based agroforestry system (Table 5.5).

In temperate natural forest open a significant reduction in throughfall ($P<0.05$) was observed in open canopy and cardamom agroforestry stand probably because of less rainfall intercept by these than dense forest stand. Higher canopy interception was recorded in open forest stand but canopy interception in between open forest stand and cardamom agroforestry stand did not vary significantly ($P>0.05$) because of similar canopy coverage (Table 5.5). Floor leachate also did not vary significantly. In floor interception significant reduction was observed ($P<0.05$) due to more floor litter and herbaceous biomass. No significant variation was observed in throughfall, stemflow, canopy interception, floor leachate and floor interception between subtropical natural forest and mandarin based agroforestry system (all $P>0.05$) because of sparse canopy coverage (Table 5.5).

Soluble carbon flow was analysed in throughfall, stemflow and floor leachate in different forest and agroforestry stands in sub-tropical and temperate belts of the watershed (Table 5.6). The soluble carbon concentration in throughfall was highest in cardamom based agroforestry system (34.43±4.89 mg l^{-1}) and lowest in sub-tropical natural forest (25.27±4.31 mg l^{-1}). In stemflow water also, soluble carbon was recorded highest (54.13±7.91 mg l^{-1}) in cardamom based agroforestry system, while soluble carbon in floor leachate was recorded highest (51.40±4.70 mg l^{-1}) in sub-tropical natural forest open (Table 5.6).

5.4 DISCUSSION

The drainage texture is fine on the higher elevation and gradually becomes coarse at the valley. Fine drainage texture is vulnerable for high rates of erosion under extensive cultivation. In the Mamlay watershed all high hill areas are located under forest cover where fine drainage texture is prevalent experiencing minimum soil erosion. Because of the fine texture and dense forest, this zone has high underground water potential. In spite of coarse drainage texture, erosion was greatest in the middle hills because of dense population and extensive cultivation. The discharge in various streams showed high seasonality and direct relationship with precipitation. About 90% of annual precipitation was received in the monsoon and the discharge was highest in this period. Many streams dried completely during the summer season mainly in the mid hills because of deforestation and extensive human activities. This belt is located between two major thrusts of the watershed where water percolates from upper thrust and appears in the lower thrust through sub-surface flow. Sediment concentration also showed seasonality similar to discharge. The sediment concentration in different seasons at all streams showed direct relationship with precipitation. The highest sediment concentration in rainy season was attributed to (i) high rainfall during this period, (ii) steep slopes and (iii) extensive cultivation of the soil practices in this season. The soil loss rate from the total watershed ranged from 6 to 7 t ha^{-1} yr^{-1} during the two years of study. Rawat & Rawat (1994) reported about 2 t ha^{-1} yr^{-1} soil loss in a normal rainfall year from a watershed in the Central Himalaya where the rainfall is comparatively low. The two year average of the annual sediment flux from the watershed was 667 t km^{-2} yr^{-1}. This is within the range of 500-1000 t km^{-2} yr^{-1} reported for the Himalayan region by Milliman & Meade (1983). Soil loss as high as 3005 t km^{-2} yr^{-1}, was recorded in an agro-ecosystem less than 5 years of shifting cultivation (Toky & Ramakrishnan 1981).

Mean annual estimates of organic carbon export via stream flow differ somewhat with micro-watersheds. Carbon in soluble form was lost more through runoff than sediment movement. The higher concentration values at stream water are related to the mean annual discharge.

Rainfall was distributed seasonally and more than 90% was received during May to October. The overland flow in the open cropped area was highest because of intensive cultivation and steep aspect of the land. It takes between 200 and 1000 years to form 2.5 cm of top soil under cropland conditions, and even longer under forest conditions (Pimental *et al.* 1995). About 80% of the World's agricultural land suffers moderate to severe erosion, and 10% suffers slight to moderate erosion (Speth 1994). Croplands are most susceptible to erosion because their soil is repeatedly tilled and left without a protective cover of vegetation. A survey of agricultural fields on unterraced slopes showed more than 60% pebbles/stones. Participatory inventory with farmers also revealed high soil erosion problem and the indicators as observed by farmers were exposure of red soil and stones of deeper soil profile. The overland flow decreased in mandarin orange based agroforestry as a result of protection by trees. In the sub-tropical forest relatively high amount of overland flow was recorded because of high biotic pressure. Prior to the year of experimentation this forest was totally in degraded condition and devoid of ground vegetation and understory species. This has contributed to greater overland flow and soil loss. Overland flow and soil loss from the wasteland was low compared to open cropped area as it was not disturbed and was covered by ground vegetation. Similar observations on fallow lands were also made in shifting agriculture system in North-Eastern India by Toky & Ramakrishnan (1981). According to an estimate made by Shah (1982) nearly 85% of all agricultural land already suffers from severe erosion problems. The overland flow and the soil loss in large cardamom based agroforestry system were lower because of good tree canopy and under-story thick large cardamom bush coverage. Temperate natural forest dense showed relatively lower overland flow and soil loss. In the Central Himalaya, comparatively less overland flow was recorded from the temperate forest but the soil loss was more than the temperate forest of the present study (Pandey *et al.* 1983; Singh *et al.* 1983; Negi *et al.* 1998). The high overland flow in the present study located in the eastern Himalaya was the consequence of higher rain intensity and more annual precipitation. In spite of more overland flow in the temperate natural forest in the present study, soil loss was less than the Central Himalaya because of complete ground vegetation, thicker forest floor litter and more stratification of the forest. Large cardamom based agroforestry is a traditional practice of the region and is regarded to be profitable and sustainable farming system. The less overland flow values in temperate natural forest and large cardamom based agroforestry indicate that the catchment areas under these land-uses encourage high infiltration and subsurface flow. Bren & Turner (1979) and Bren (1980) studied the surface runoff on steep forested infiltrating slopes in Australia and reported that overland flow was very low (0.005% of the rainfall). The hydrological response of a forested hill slope to rain is often dominated by the lateral down slope movement of water within the soil system. Overland flow may be a rare occurrence on such forested watershed.

Soil and organic carbon losses from open cropped area was more than 90% of total watershed indicating that agriculture practice without agroforestry in such unterraced sloping land and in high rainfall areas are highly vulnerable. Therefore, strong agroforestry based agriculture such as mandarin, cardamom and horti-agri-silvi system is recommended in the watershed for conservation of soil, water and nutrients in such a fragile upland farming system. Reliable and proven soil conservation technologies include ridge planting, no-till cultivation, crop rotations, strip cropping, grass-strips, mulches, living mulches, terracing, contour planting, cover crops and windbreaks (Pimental *et al.* 1995). Although the specific processes vary, all conservation methods reduce erosion rates by maintaining a protective vegetative cover over the soil, which is often accompanied by a reduction in the frequency of ploughing. Ridge planting, for example, reduces the need for frequent tillage and also leaves vegetative cover on the soil surface year round, and crop rotations ensure that some part of the land is continually covered with vegetation. Each conservation method may be used separately or in combination to control soil erosion. To determine the most advantageous combination of appropriate conservation technologies, the soil type, specific crop and climate (rainfall, temperature and wind intensity), as well as the socioeconomic conditions of the people living in a particular site must be considered.

The implementation of appropriate soil and water conservation practices has the potential to reduce erosion rates from 2 to 1000 fold and water loss from 1.3 to 21.7 fold. Conservation technologies also significantly reduce organic carbon loss. By substantially decreasing soil and nutrient loss, conservation technologies preserve the soils fertility and enable the land to sustain higher crop yields. In many instances, the use of conservation technologies may actually increase yields (Faeth 1993; Sharma *et al.* 2001).

Organic carbon content was high in temperate natural forest dense as a result of humus accumulation and high organic matter input. The organic carbon of the cropped area was also high which has resulted from application of organic manure in the system. Organic carbon loss could be more in the cropped area because of the high soil loss. The higher loss of organic carbon through soil erosion in the sub-tropical forest compared to temperate natural forest dense and temperate natural forest open is mainly attributed to higher soil loss in the sub-tropical forest. Nutrient discharge from watersheds increases as percentage of cropland increases (Jordan *et al.*1986; Omernik 1976; Likens & Borman 1974) and high carbon loss from the open cropped area in the present study is consistent to this finding. However, the amounts of nutrients released by croplands differ greatly even among lands with the same crop. This is partly due to the variety of farming methods. Carbon release by forests is generally thought to be related to age and amount of disturbance. Young or highly disturbed forests release the most nutrients, old forest release less and intermediate aged forests release the least (Bormann & Likens 1979). Soil type may also influence organic carbon discharge. Dillon & Kirchner (1975) found that watersheds with soils of sedimentary origin, like the present watershed, discharge more nutrient than those with soils of igneous origin. The ranking of land-use vulnerable to soil erosion with respect to loss of organic carbon was open cropped area> mandarin orange based agroforestry>sub-tropical natural forest> wasteland> cardamom based agroforestry>temperate natural forest dense. In the crop fields of the Himalayan catchments which are highly vulnerable to erosion, a large amount of manure input is required to off set the carbon losses. This can be appreciated by the fact that for a potato crop field of Poland it was reported that particulate input of only 263 g C m^{-2} resulted in an increase of 103 g C m^{-2} (Melillo 1985), while in the maize field in Central Himalaya, similar amount of organic matter input could not even off set the decline in the carbon status of the soil (Singh & Singh 1992), where deforestation leads to an agricultural land-use, higher rates of erosion will be maintained indefinitely (Rapp 1975) unless practices of soil conservation are especially followed (Doran 1980).

The throughfall, stemflow, and canopy interception results are similar to that of forests of the Central Himalaya (Pathak *et al.* 1983; Negi *et al.* 1998; Jain *et al.* 2000). Throughfall in the temperate natural forest dense was highest as a result of more canopy coverage and broad leaf nature of natural forest species than the mixed open forest. Throughfall of similar magnitude has been reported by Henderson *et al* (1977). Stemflow was more in open forest because of *Cryptomeria japonica* dominating which has conical canopy architecture and stream lining of water through stemflow. Our data on canopy interception corroborate that broad-leaved forest intercepts less rainfall than do coniferous species. Pathak *et al* (1983) reported positive relationship of interception with canopy cover in the Oak forest of the Central Himalaya. Waring *et al* (1980) argued that the surface area of the forest is an important determinant in interception processes. Floor interception of precipitation was directly related with the floor litter composition and quantity. Broad-leaved litter composition showed higher floor interception and relatively smaller floor leachate. Precipitation partitioning was studied only in systems where there was tree cover. Comparisons between forest types and agroforestry systems showed that totality of canopy and floor interception is very important determinant for water availability with respect to floor leachate. Forests showed more floor interception as result of thick litter layer. Mandarin orange based agroforestry have smaller floor interception and showed fairly high soil erosion indicating inverse relationship.

In the partitioning of precipitation the soluble carbon on the leaf surface, stem bark, and floor litter are mobilized. Our study shows different levels of mobility of soluble carbon in different pathways of partitioning. Soluble carbon loss through floor leachate was highest in cardamom based agroforestry system. Soluble carbon loss through floor leachate was almost similar from different land-uses except for temperate natural forest open that showed relatively lower value. This may be because of slow decomposition rates in temperate natural forest open.■

Table 5.1 Carbon loss (tons) through sediment in different streams water of Mamlay watershed

Season	Micro-watersheds					Total watershed
	Pokchey khola	Chemchey khola	Tiri khola	Sombaray khola	Rangrang khola	Rinji khola*
Winter	1.2	1.6	3.9	0.2	0.003	17.8
Summer	0.4	0.7	1.1	0.0003	0.00	3.0
Rainy	45	28	131	34	0.014	812
Total ($t\ yr^{-1}$)	46.6	30.3	136	34.2	0.0143	833

*Watershed outlet

ANOVA: Streams $F_{4,30} = 427.65$, $P<0.0001$; Season $F_{2,30} = 1769.40$, $P<0.0001$; Streams x Season $F_{8,30} = 382.901$, $P<0.0001$.

Table 5.2 Soluble carbon (tons) loss through different streams water of Mamlay watershed

Season	Micro-watersheds					Total watershed
	Pokchey khola	Chemchey khola	Tiri khola	Sombaray khola	Rangrang khola	Rinji khola*
Winter	74	77	74	14	0.06	51
Summer	7	14	16	0.2	0.00	148
Rainy	733	559	388	401	0.9	1826
Total (t yr^{-1})	814	650	478	415	0.96	2025

*Watershed outlet

ANOVA: Streams $F_{4,30} = 5650.89$, $P<0.0001$; Season $F_{2,30} = 46064.92$, $P<0.0001$; Streams x Season $F_{8,30} = 3980.46$, $P<0.0001$.

Table 5.3 Seasonal and yearly soil loss (tons) estimated using discharge and sediment concentration of micro and total watershed

Parameter		Micro-watersheds					Total Watershed
		Pokchey khola	Chemchey khola	Tiri khola	Sombaray khola	Rangrang khola	Rinji khola*
Area (ha)		788	717	509	635	365	3014
1999	Winter	48	47	284	10	0.03	744
	Summer	13	30	33	0.01	0.00	87
	Rainy	1235	854	3491	977	0.44	17464
	Total	1296	931	3808	987	0.47	18295
	Soil loss (t ha^{-1})	1.64	1.30	7.48	1.55	0.001	6.07
2000	Winter	33	43	98	7	0.01	500
	Summer	10	19	28	0.01	0.00	83
	Rainy	1118	793	3242	948	0.4	21370
	Total	1161	855	3368	955	0.41	21953
	Soil loss (t ha^{-1})	1.47	1.19	6.62	1.50	0.001	7.28

*Watershed outlet

Table 5.4 Overland flow (% of rainfall) and soil loss (kg ha $^{-1}$) in different land-use/cover of Mamlay watershed

Land-use	Overland flow	Soil loss
Temperate natural forest dense	2.57	16
Temperate natural forest open	3.92	22
Subtropical natural forest open	4.56	27
Cardamom based agroforestry system	2.80	18
Mandarin based agroforestry system	4.77	31
Open cropped area temperate	10.25	480
Open cropped area subtropical	10.86	525
Wasteland area temperate	3.78	24
Wasteland area subtropical	3.90	25

ANOVA: Overland flow – Land-use $F_{8, 18} = 104.14$, $P<0.0001$; Soil loss – Land-use $F_{8, 18} = 1131.52$, $P<0.0001$.

Table 5.5 Partitioning of incident precipitation into various pathways in different land-use/cover of Mamlay watershed (n=6). Values in parentheses are ± se. Means with same superscript in each row are not significantly different to each other at $P<0.05$ (Tukey's honestly significant test)

Parameters	Land-use				
	Temperate region			Subtropical region	
	Temperate natural forest dense	Temperate natural forest open	Cardamom based agroforestry system	Subtropical natural forest open	Mandarin based agroforestry system
Throughfall (mm)	2355^{c} (96)	974^{a} (48)	1633^{b} (54)	721^{a} (26)	746^{a} (50)
Stemflow (mm)	297^{c} (19)	441^{d} (26)	162^{b} (13)	32^{a} (7)	68^{a} (5)
Canopy interception (mm)	341^{a} (76)	1577^{b} (22)	1197^{b} (67)	541^{a} (19)	481^{a} (55)
Floor leachate (mm)	1195^{b} (105)	1226^{b} (71)	1215^{b} (68)	290^{a} (36)	573^{a} (26)
Floor interception (mm)	1456^{c} (31)	189^{a} (49)	580 (135)	464^{a} (54)	241^{a} (29)

Table 5.6 Carbon content (mg l^{-1}) in throughfall, stemflow and floor leachate in forests and agroforestry land-uses of Mamlay watershed

Land-use	Throughfall	Stemflow	Floor leachate
Temperate natural forest	27.42±3.42	37.43±3.02	24.57±3.68
Subtropical natural forest open	25.27±4.31	29.60±8.86	51.40±4.70
Cardamom based agroforestry system	34.43±4.89	54.13±7.91	36.93±5.45
Mandarin based agroforestry system	27.03±7.60	48.20±4.58	20.27±4.85

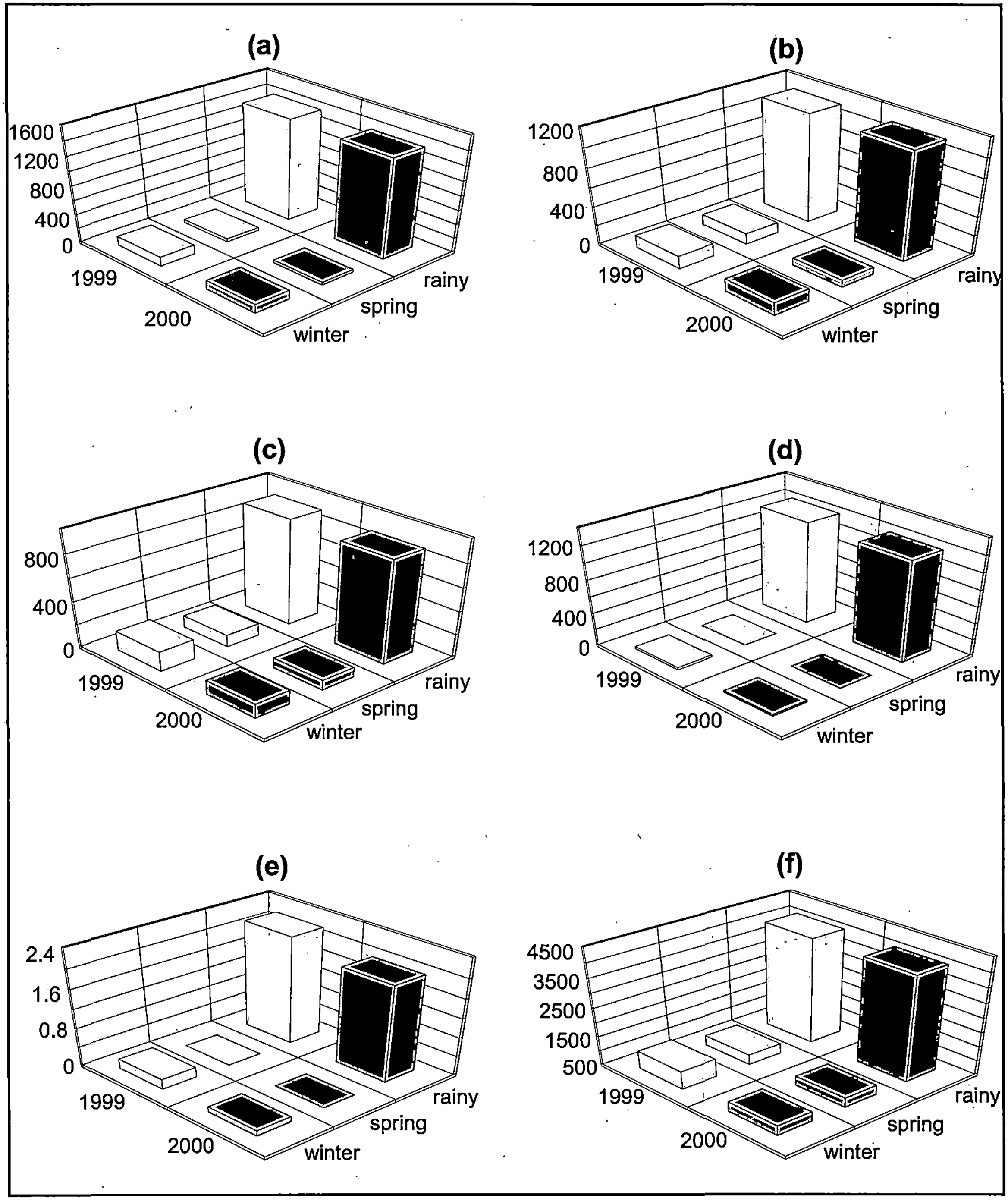

Fig. 5.1 Seasonal stream discharge (ls^{-1}) for 2 years in different streams and the outlet; **(a)** Pokcheykhola, **(b)** Chemcheykhola, **(c)** Tirikhola, **(d)** Sombareykhola, **(e)** Rangrangkhola and **(f)** Rinjikhola (watershed outlet).

ANOVA: Discharge-streams $F_{4,60}$=15213, P<0.0001; year $F_{1,60}$=69.71, P<0.0001; season $F_{2,60}$=150076, P<0.0001; streams x year $F_{4\ 60}$=12.18, P<0.0001; stream x season $F_{8,60}$=11040, P<0.0001; year x season $F_{2,\ 60}$=0.229, NS; stream x year x season $F_{8,\ 60}$= 7.14, P<0.0001; LSD (0.05) = 3.66.

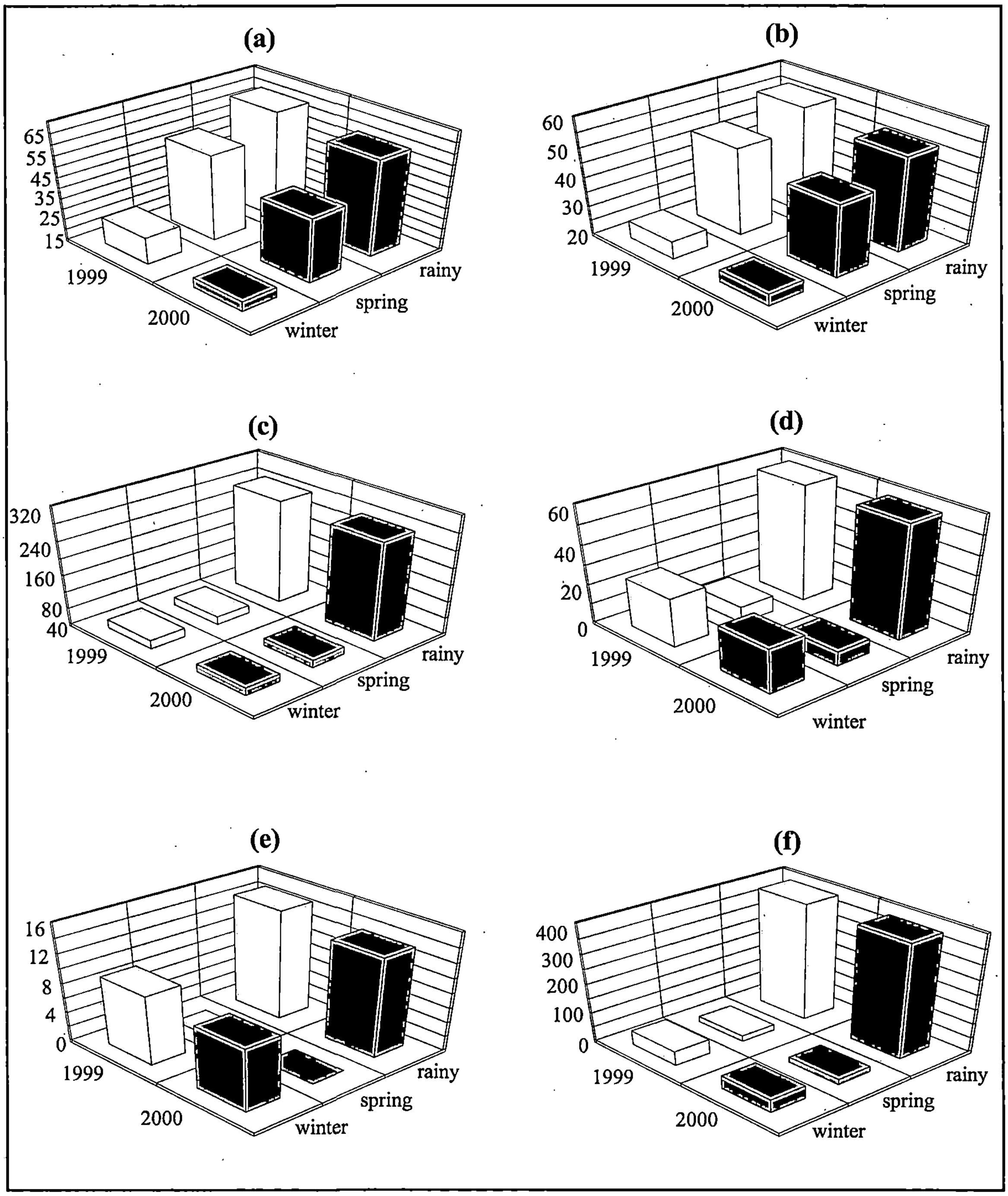

Fig. 5.2 Seasonal sediment concentration (mg l^{-1}) for 2 years in different streams and the outlet; **(a)** Pokcheykhola, **(b)** Chemcheykhola, **(c)** Tirikhola, **(d)** Sombareykhola, **(e)** Rangrangkhola and **(f)** Rinjikhola (watershed outlet). ANOVA: Sediment concentration-streams $F_{4,60}$=3733, P<0.0001; year $F_{1,60}$=25.98, P<0.0001; season $F_{2,60}$=3675, P<0.0001; streams x year $F_{4,60}$=3.15, P<0.05; stream x season $F_{8,60}$=1480, P<0.0001; year x season $F_{2,60}$=0.48, NS; stream x year x season $F_{8,60}$=1.31, NS.

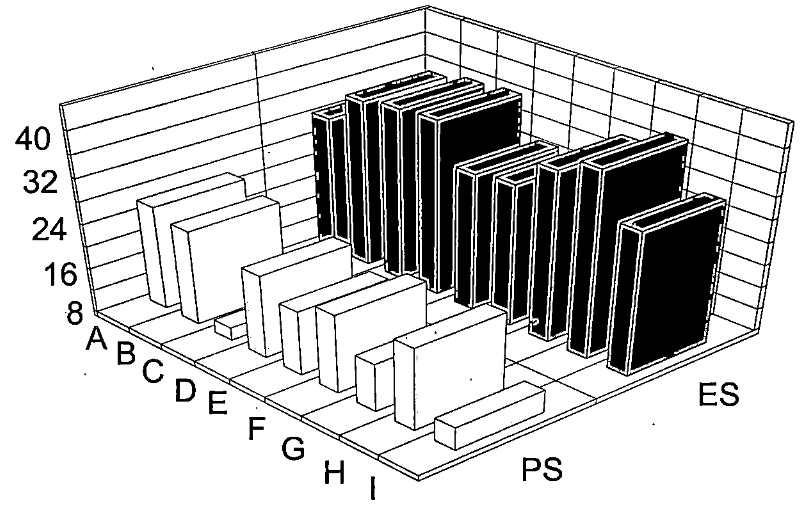

Fig 5.3 Organic carbon (mg g^{-1}) in parent soil (PS) and eroded soil (ES) in different land-use/cover, A=Temperate natural forest dense, B = Temperate natural forest open, C = Subtropical natural forest open, D = Cardamom based agroforestry system, E = Mandarin based agroforestry system, F = Open cropped area temperate, G = Open cropped area sub-tropical, H = Wasteland temperate and I = Wasteland subtropical.
ANOVA: Organic carbon – Land-use $F_{8,36}$ = 311.53, $P<0.0001$; soil type $F_{1,36}$ = 19039, $P<0.0001$; Land-use x soil type F_{836} = 316.41, $P<0.0001$. LSD (0.05) = 0.299