Chapter - I

INTRODUCTION

1.1 THE CONTEXT

Mountain regions occupy about one fourth of the Earth's terrestrial surface (Kapos *et al.* 2000), they are home to approximately one tenth of the global population, and provide goods and services to more than half of humanity and are in the nearby environs of approximately one fourth of the global population (Messerli & Ives 1997). Accordingly, they received particular attention at the highest level during the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro "Earth Summit" with the inclusion of Chapter 13: "Managing Fragile Ecosystems - Mountain Sustainable Development" in Agenda 21. "Chapter 13" of this document focuses on mountain regions, and states, "Mountain environments are essential to the survival of the global ecosystems, many of them are experiencing degradation in terms of accelerated soil erosion, landslides, and rapid loss of habitat and genetic diversity, hence, proper management of mountain resources and socio-economic development of the people deserves immediate action" (Becker & Bugmann 2001). Unfortunately the capacity of mountain ecosystems to provide continued resources is threatened due to increasing stress of human impact at global level in general and Himalayan region in particular.

The human impact on the global environment has received wide attention in past. Marsh (1864) recognized the deleterious consequences of human activities on the earth's landscape. More recently, Thomas (1956) lent further credence to the notion that one of the most obvious global changes in the last three centuries has been the direct human modification and conversion of land cover. Land-use changes are cumulatively transforming land-cover at an accelerating pace (Turner *et al.* 1994; Houghton 1994). These changes in terrestrial ecosystems are closely linked with the issue of the sustainability of socio-economic development since they affect essential parts of our natural capital, such as climate, soils, vegetation, water resources and biodiversity (Mather & Sodsyuk 1991).

Land cover transformation is significant to a range of themes and issues central to the study of global environmental change. The alterations and its effect on the surface of the earth hold major implications for sustainable development and livelihood systems and also contribute to changes in the biogeochemical cycles of the elements affecting the atmospheric levels of greenhouse and other trace gases.

The land-use change from forest to other usage has been quite conspicuous in the last few decades in the Hindu-Kush Himalayan region (Singh & Singh 1992). It has been envisaged that carbon balance and hydrological cycle have been disrupted. The consequences of land-use transformation from forest to agriculture, in the developing countries of the tropics has aroused international concern for human poverty, loss of plant and animal species, erosion of landscape, siltation of water courses, and flooding (Turner *et al.* 1990). The reduction of original forest cover already amounts to at least 21% in Asia and Australia (Jackson 1983; Rubinoff 1983). These changes have contributed to manifold and massive alterations of fundamental biochemical cycles (e.g., carbon cycle) and have been a major contributory source to increased CO_2 concentration in the atmosphere in the region (Clark 1982; Houghton 1990).

The historical conversion of natural systems to agriculture and other human uses of the land have resulted in a net release of CO_2 to the atmosphere (Houghton *et al.* 1985; Houghton *et al.* 1987; Houghton & Skole 1990). The impact of human land-use on the global carbon cycle through changes in terrestrial vegetation, is a major research concern in understanding the control of global carbon cycle, and therefore, future climatic changes by land and ocean (Houghton *et al.* 1983; Siegenthaler & Oeschger 1987). The global mobilization of carbon from soils and vegetation, estimated at 2-2.8 x 10^{15} g C in 1989 (Houghton 1990), mainly results from changes in land-use in the tropics and represents 25-35% of carbon mobilization from fossil fuels.

Deforestation is still one of the most important sources of CO_2 emissions into the atmosphere. Deforestation accounts for substantial release of carbon, one third of which could be due to oxidation of soil carbon in tropics occasioned by changes in land-use pattern (Singh *et al.* 1991). Deforestation has occurred since the evolution of early settlements and the start of agriculture but over the last decades its rate has accelerated. The resulting net flux from such changes in land-use is difficult to establish because most deforested plots are abandoned after a shorter or longer period of intensive use. This dynamics make the determination of carbon fluxes more complex because during forest re-growth carbon is sequestered again. Carbon dynamics also depend on the dynamics of abandonment, which are complex and depend on a multitude of socio-economic conditions and possibilities for land-use, including suitability for agriculture. The evaluation of carbon dynamics under such land-use change thus requires a detailed description of activities both in time and space. Historic and current land-cover and its land-use have to be portrayed and changes have to be adequately monitored.

Based on the results obtained for Central Himalaya and assuming the same conditions, total net release of carbon in the entire Indian Himalayan forests has been assessed by Singh *et al.* (1985). It is cleared that, because of over exploitation, the Himalayan forests have become a net source of CO_2 to the atmosphere. Most of these forests when unexploited can constitute an effective net sink of CO_2 (Singh *et al.* 1985). Besides this, tropical forests contain as much as 40% of the carbon stored as terrestrial biomass (Phillips *et al.* 1998) and account for 30 to 50% of terrestrial productivity. Therefore a small perturbation in this biome could result in a significant change in the global carbon cycle.

The impact of humans on natural vegetation as the processes of logging and timber removal or conversion of forest to other land-uses has long-term consequences on secondary vegetation, involve gross disruptions of nutrient cycles and water balances (Turner *et al.* 1997). The extent of which these practices result in losses of soil and nutrients affecting subsequent re-growth of vegetation, depends upon the severity of disturbances and the degree to which the differences between the depletion of the capital and plant demands is made up by weathering and or atmospheric inputs (Anderson & Spensor 1991).

Soil erosion is a major environmental threat to the sustainability and the productive capacity of agriculture. During the last forty years, nearly one third of the World's arable land has been lost by erosion and continues to be lost at a rate of more than 10 million hectare per year (Pimental *et al.* 1995). Rivers carry multiple forms of carbon especially in soluble form. This transport has been particularly studied in the 1980s for many major world rivers within the SCOPE-Carbon Programme (Degens *et al.* 1991). Rai & Sharma (1998a) made a study on hydrology and nutrient flux in different land-uses in the Sikkim Himalaya. The importance of hydro-ecological linkages in different land-uses in a watershed has been discussed in greater details (Rai & Sharma 1996). This demonstrates that the changes in land-use/cover may trigger changes in the hydrological cycle which in turn would have significant implications for land-uses.

The importance of land-use/cover change and its role in carbon cycle is duly recognized by the International Geosphere Biosphere Programme (IGBP) and the International Human Dimension Programme (IHDP) on Global Environmental Change (GEC). The IGBP also has a focus on these issues through the programme on Biospheric Aspects of Hydrological Cycle (BAHC), Global Change and Terrestrial Ecosystem (GCTE) and Land-Use/Land Cover Change (LUCC). In order to address the consequences of global change in mountains around the world, an initiative for collaborative research on global change and mountain regions - the Mountain Research Initiative (MRI) - was developed and officially launched in July 2001. It will involve close collaboration between these organizations.

The pace, magnitude and spatial reach of human alterations of the Earth's land surface are unprecedented. To understand recent changes and generate scenarios on future modifications of the Earth System, the scientific community needs quantitative, spatially explicit data on how land cover has been changed by human use over the last 300 years and how it will be changed in the next 50-100 years.

1.2 IMPORTANCE

A large scale land transformation in the past few decades in the Himalayan region may have altered the hydrological cycle and carbon balance of the terrestrial ecosystems. The land-use change from forest to agriculture has been quite conspicuous over the last 40 years in a watershed of Sikkim (Rai *et al.* 1994). The land transformations may have caused tremendous loss of carbon to atmosphere and to streams, which could have both regional and global concerns in terms of climate change. These carbon loss and carbon dynamics in relation to hydro-ecological linkages have not been quantified in understanding functioning of watershed's. Land-use change is expected to cause enormous loss of valuable nutrients from the natural systems. It is also envisaged that the hydro-ecological linkages are distorted in the process of land-use transformation. Such changes in the Himalayan watersheds draw research attention towards understanding the mechanisms of change in the ecosystem processes. Carbon is the most appropriate indicator for studying the mechanisms of change in the ecosystem functioning in a series of land-use transformation from natural forest to plantation forest to different types of agroforestry systems and to open agriculture.

In view of limited information available on watersheds of the Himalaya in general and eastern Himalaya in particular, this work was undertaken to study carbon dynamics in relation to land-use/cover change and hydro-ecological linkages on a watershed level with implications at regional and global biospheric disruptions. The study has been planned with following hypotheses and objectives.

1.3 HYPOTHESES AND OBJECTIVES

Hypothesis-I

The land-use transformation from forest to agriculture and wasteland causes tremendous loss of carbon from the land-cover systems to the atmosphere and streams that disrupts the hydrological cycle and also contributes to climate change in a regional scale.

Objectives to test hypothesis-I

- Dynamic monitoring and systematic analysis of land-use/land-cover change.
- Investigate the hydrological parameters such as overland flow, soil erosion, carbon loss through soil erosion, and sediment concentration in stream water and discharge on land-use/cover basis.
- Study the biogeochemical cycling of carbon i.e. carbon flux between compartments along with carbon fixation, loss through respiration, harvest flux, land cover change loss and agricultural loss and sequestration.

Hypothesis-II

Carbon is the most appropriate indicator for studying the mechanisms of change in ecosystem functioning in a series of land-use transformation.

Objectives to test Hypothesis-II

- Study the land-use sustenance taking the soil carbon level as an indicator.
- Quantify the carbon budget in various ecological compartments and also in humus and litter components in different land-uses.
- Correlate the hydrological processes with ecological dimensions and ultimately develop a mathematical model to quantify ecological linkages especially in relation to carbon dynamics.

1.4 APPROACH

In recent years, high growth rate of human and livestock population has enormously increased the food demand and pressure on natural resources. This has put tremendous pressure on certain land-uses e.g., forests are getting converted to more agricultural lands disrupting support forest system for maintaining agricultural fertility; conversion of pasture land to wastelands and degradation of close canopy forest to open and scrublands has major leading factors for imbalancing hydrological and biogeochemical cycles at a regional and global scale. It is understood that factors leading to unsustainability in mountain system need corrective measures through identification of various resources, their utilization pattern, consequences and quantification of the extent of the problems.

A conceptual frame was developed to understand the main linkages between physical environment, land-use systems and human driving force (Fig 1.1). These linkages related to land-use/cover change are visible at watershed levels but impacts are directly felt at villages and households. It has greater ecological implications at regional and climatic zone levels. Land-use system components such as biodiversity, production systems, practices and soil-water systems are directly impacted by the human driving force, while at the process level it is the alterations of physical environment that has profound impacts. However, at the land-use system, components and processes are inter-effected. These land-use/cover changes at the watersheds show resilience by adjusting and interplaying between components and processes of land-use system as affected by changing physical environment and human driving force (Fig 1.1). This conceptual frame of interactions has been conceived to guide the study approach followed in this thesis.

Varied human driving forces (e.g., population or development), mediated by the socio-economic setting (e.g., market economy, resource institutions) and influences by the existing environmental conditions lead to an intended land-use of an existing land cover through the manipulation of the biophysical conditions of the land. This type of information is necessary to understand properly the land-use/cover change and the carbon input levels and change in physical environment, which control the turnover rate of soil organic matter. This type of conceptual model helps to design and monitor the long term dynamics of carbon and nutrients in natural and managed ecosystems.

It is therefore imperative to study such conversion at least at a watershed level that could be managed properly, since watershed is regarded as a functional unit for analysis of natural resource base and development planning in the hills. It is expected that the results would be replicated partially or fully in other watersheds of the mountain region. This will also help in policy decisions and management of land-uses in the Hindu-Kush Himalayan region.

1.5 DESIGN OF THE THESIS

The present study has been divided into eight chapters dealing with varied but interrelated aspects. Chapter one deals with an introductory outline of the land-use and carbon dynamics, hypotheses, objectives and approaches. Chapter two introduces the review of literature indicating the chronological development and changing content of the land-use/cover. Since not much study has been carried out on the topic in the Indian context, more attention is paid to review studies carried out in other countries. In addition, attempt has been made here to review IGBP initiatives on carbon challenge. The third chapter is devoted to describe the study area, climate and site characteristics. Land-use pattern, land-use/cover change detection, biomass status and community dependence has been examined in the fourth chapter. It is followed by hydrological analyses (chapter fifth). Carbon budget has been discussed in chapter six and carbon flux in chapter seven. Carbon dynamics and models on land-use/cover basis have been described in chapter eight. The end of the study is marked by a summary of basic elements and references.■

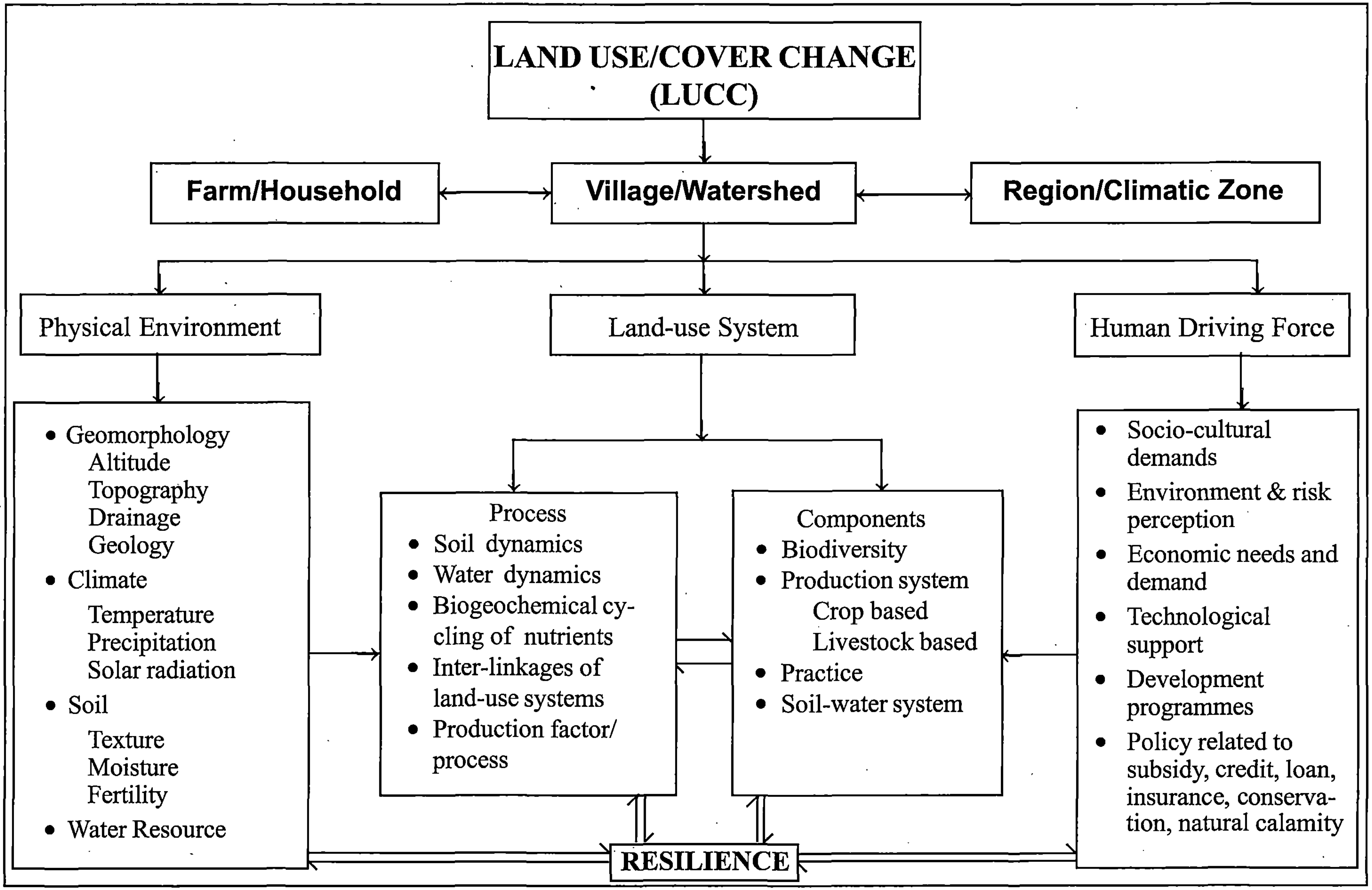

Fig. 1.1 Conceptual frame showing components and processes of land-use system which are influenced by physical environment and human driving force at a watershed level.