Land-Use Change Induced Watershed Carbon Flux and Climate Change

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Integrated landuse management in Sikkim, India

Globally, land-use changes are cumulatively transforming land cover at an accelerating rate. In mountain ecosystems such changes are closely linked to the issue of sustainable socioeconomic development, since they affect essential elements of natural capital such as climate, soils, vegetation, water resources, and biodiversity.

Land transformation may result in a wide variety of changes, many of which can be significant on the global scale – including greenhouse gases and potential global warming, loss of biodiversity and loss of soil resources, and the regional impacts contributing to climate change. In the mountains, watersheds can be considered as functional units of natural resource management for sustainable development. Understanding the dynamics of watershed functions includes physical characteristics such as hydro-ecological linkages between land uses, resource dimensions, and socioeconomic conditions. Socio-economic demands and natural resource use are interactive (Rai and Sharma 1998; Sharma et al. 1998). Increasing stresses on natural resource use and their impacts at the watershed level can also result in cumulative impacts at the regional level. Carbon is an important indicator for studying the mechanisms of change in watershed functioning as a result of changing land-use in mountain areas.

Of the estimated eight billion tons of carbon dioxide injected annually into the air by human activity, three-fourths come from the burning of fossil fuel and the remainder from land-use change and cultivation of land

Forests store 150-280 tons of carbon in one hectare of forests in the Sikkim watershed

for agriculture (Odum 1971). Over the last three centuries, the total global area of forests and woodlands has decreased by 12 trillion sq km, grasslands and pastures have declined by 5.6 trillion sq km, and croplands have increased by 12 trillion sq km (Richards 1990). Such large-scale change has consequences on regional and global climate, more prominently through modification of global carbon, nitrogen, and water cycles, and increased rates of extinction of biological resources. Changes, in terms of both the conversion of land for cultivation and the intensification of agriculture on land already cultivated, have accelerated globally.

Most prime agricultural lands, with the exception of some areas in the tropics, are already cultivated, and any major increases in food production are likely to come from the application of fertilisers, pesticides, herbicides, and irrigation. Irrigation of cropland has expanded 24-fold over the past three centuries, with most of that increase taking place in the last century. This practice has led to increased carbon (methane) emissions, while the increasing frequency of land tillage worldwide has affected soil carbon. The major global initiatives on this issue are the International Geosphere-Biosphere Programme and the Human Dimensions Programme's Science Agenda on Land-use/cover Change.

Carbon dynamics depend on land-use change and consequent impact on ecosystem components. The evaluation of carbon dynamics thus requires a detailed description of land-use patterns and change in both time and space. Soil is the largest pool of terrestrial carbon in the biosphere, storing some 1,500 peta grammes ($x10^{15}$) of carbon in the upper metre of mineral soils, about 2.5 times more than the carbon contained in terrestrial vegetation. Globally, soils constitute one of the five principal carbon pools; others are oceans, biomass, the atmosphere, and fossil fuels. The conversion of forests to agriculture and other uses has resulted in net release of carbon dioxide to the atmosphere. Studies have shown that the carbon content of soils declines with agricultural use. Improved land-use management with greater carbon sink potential is an essential prerequisite for carbon sequestration. Application of improved management practices is projected to sequester between 400 and 800 metric tons of carbon per year worldwide. Carbon dioxide emissions through respiration, from both vegetation and from decomposition of organic matter, increase with global warming. Soils are sources and sinks of carbon as a result of both changes in carbon content per soil unit (via assimilation and decomposition) and of the erosion and deposition of soil. The export rate of dissolved organic carbon by river water is equally important in global carbon budgets and flux.

Land-use transition in the Himalaya has been driven by both global environmental change and the market economy. The major driving forces are economic, policy, institutional, technological, and demographic factors. The visible land-use transitions are urbanisation, sedentarisation, forest conversion to other uses, agricultural intensification, habitat modification, migration, and population dynamics, and loss in biodiversity. Such large-scale land-use transitions have changed the carbon dynamics in the Himalayan region.

Mamlay Watershed in Sikkim in the Eastern Himalaya is a good example of a populated middle hill (300-2,600masl) watershed where land-use change and its consequences on carbon dynamics were studied. During a 13-year period more than 34% of the land use changed in this 3,014ha watershed. The changes were conspicuous in conversion of forests to agricultural land (28% converted) and degradation of forests from dense to open canopy (6% changed) conditions. A similar trend in land-use change has been reported from all over the middle hills of the Himalaya. However, in the case of Nepal much of the lost forests were regenerated from community forestry initiatives. Carbon dynamics within a land use implies soil, vegetation, humus, litter, soluble carbon in precipitation partitioning, soil erosion, overland flow, loss through discharge in river systems, microbial biomass in soils, and respiration and harvest fluxes. This clearly shows that carbon cuts across all ecosystem components entailing its qualification as a good indicator for understanding watershed functioning and processes.

The land-use change over 13 years (1988-2001) in the Mamlay watershed resulted in a net release of 305×10^3 tons of carbon into the atmosphere (see Table 2). The reduction of forest biomass contributed 119×10^3 tons of carbon by vegetation and 186×10^3 tons of carbon by soil, translating into a release of about eight tons of carbon from a hectare of land every year in the watershed. The stock of carbon in vegetation and soils in the watershed amounted to 624×10^3 tons in 2001. Using a similar rate of forest conversion in the Sikkim State of India and the Indian part of the Himalaya, carbon release into the atmosphere was projected at 22×10^5 and 520×10^5 tons of carbon annually, respectively. Such trends have to be reversed through integrated watershed management approaches and efforts to do so are being carried out in the region by implementing investment projects. The development and resource management scenarios have to be driven by lessons learned from regional watershed research

Land-use change from forests to	Area (ha)	Total carbon release ($\times 10^3$ ton)
Degraded forests	447	169
Agricultural land	486	110
Wastelands	113	26
Total	1046	305
Total watershed area: 3014 ha		

Source: Sharma (2003)

Land-use change and carbon release into the atmosphere from Mamlay Watershed from 1988 to 2001, in Sikkim in the Eastern Himalaya

initiatives such as the People and Resource Dynamics Project (PARDYP) of ICIMOD and other global initiatives such as the next generation of watershed management projects and programmes (FAO 2006).

Land-use transformation and management of mountain watersheds are key issues of concern for the global carbon balance. The global scientific community and initiatives like the Intergovernmental Panel on Climate Change (IPCC) and the United Nations' Framework Convention on Climate Change (UNFCCC) should study mountain watersheds to understand, manage, and develop strategies for responsive adaptations to climate change. Responses should be socioculturally sensitive and economically viable, considering sustainability as one of the pillars of development.

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