Abstract  There have been growing concerns in Nepal and other South Asian less developed countries (LDCs) with the acceleration of global environment changes due to continuing increases in greenhouse gas emissions and accelerated deforestation rates. Available literature on forestry’s dilemmas reveals that, except for the extreme temperature, moisture, and nutrient deficient situations, vegetation can (a) efficiently conserve elevated atmospheric carbon; (b) use the absorbed carbon in biomass production through the process of photosynthesis; and (c) if properly managed, can help to boost gross and net primary productivity of an ecosystem while mitigating global climate change. Within Nepal, conservationists, scientists, and administrators have expressed growing concerns about the rapid deterioration of the Himalayan environment because of deforestation, landslide increases, and large-scale downstream flooding. These processes are frequently linked together into a wide-ranging cause-and-effect drama of the Himalayan Degradation. Effective management of forest resources is considered one of the solutions to ameliorating environmental and land degradations. Recent Nepal’s government statistics show that Nepal’s total forest area has increased from 29 to 44%; however, forests are constantly facing new socio-environmental pressures from the growing population and from bulldozer-based development. Further complicating this issue, the statistics on Nepal’s forests have been disputed by various scholars. Nonetheless, through a set of policies, Nepal has been actively involved in the REDD+ (Reducing Emissions from Deforestation and Degradation, Plus Related Pro-forest Activities) programs since 2009 involving local communities to conserve and manage existing forests and creating new forest on non-forested lands through afforestation programs. If applied effectively, the full range of REDD+ activities can turn forests from a source of global warming emissions into a counteracting “sink.” REDD+’s incentives in the form of carbon fund allocations and can act as a development catalyzer, involving many communities in greening the denuded lands of Nepal while also generating employment opportunities at local grass-root levels. Government agencies, many private organizations, religious institutions, and over 22,266 community forestry user groups have been involved in the management of Nepal’s forests, and their activities are contributing to the reduction of carbon emissions through forest conservation as well as deriving economic benefits to local communities.
Though mountainous Nepal contributes merely 0.027% of the total global greenhouse gas emissions, it unwillingly exports top fertile soils along the rivers flowing down steep to very steep gradients. Sedimentation from Nepal’s Himalayan region often clogs rivers and canals along the Indo-Gangetic belt and causes massive floods in the Indian state of Bihar before draining into the Bay of Bengal. Participatory natural resource management and the ecosystem services concept proposed in this chapter—which have been instrumental across many South Asian, European, and North American countries in claiming degraded lands and mutually benefitting the upstream and downstream communities—could be instrumental in the restoration and management of degraded ecosystems in various parts of Nepal. We propose such a concept to solve the ongoing problems of land degradation of the Churia Range of Nepal. We have divided the entire Churia and corresponding Tarai-Madhesh regions into 91 watersheds and recast them as the operational service providing units (SPUs) for handling this deforestation dilemma. There are several sub-SPUs within SPUs, serving local communities. It is hoped that with the delineation of SPUs and sub-SPUs, it will be possible to make individual households living within the watersheds responsible for managing their lands and forest resources of their territories and creating an environment of communalism where both upstream and downstream communities will benefit in this “win-win” environmental scenario. The woodlots and vegetated areas that the households living within SPU and sub-SPUs manage will provide a wide range of ecosystem services to the downstream communities. In turn, the upstream communities will benefit from the downstream communities and REDD+’s incentives programs while also ameliorating the global climate from carbon sequestration. The upstream communities benefit from grant money or development funds granted from the government. The government might increase nominal revenue on the farmlands of downstream communities for the regulated ecosystem services from upstream communities. Revenues paid to the government by the downstream communities can be redirected as the government grants money to upstream communities to further improve the ecosystem services to the downstream communities. Properly identifying, assessing, and valuing natural resources and ecosystem services within SPUs and sub-SPUs will help in the management of natural resources in various ways. One such approach proposed here is the prioritization of SPU’s management options by assessing the trade-offs in ecosystem services and developing resilient communities who will eventually contribute to the sustainable management of available resources while contributing to the mitigation of global climate changes. Different computer-based models along with this chapter will help local communities to assess their benefits from each SPU or sub-SPU and change their course of actions in the future.

**Keywords**  Nepal · Government of Nepal · Forest Department · Forest · Community forestry user groups (CFUGs) · Churia · Tarai-Madhesh · Watershed · Imagery · Service providing units (SPUs) · Sub-SPU · Prioritizing
8.1 Introduction

Global climate change has impacted rainfall patterns resulting in intense rainfall for short periods and prolonged dry periods (UNIPCC 2007). These changes are expected to have far-reaching consequences on forested ecosystems and human livelihoods, within them. Nepal’s varied hydroclimate faces abrupt climate changes because of its complex topography ranging from 62 to 8805 m within a latitudinal distance of 1.3–1.5° (~140–250 km). Simply put, Nepal’s climate varies from tropical in the South, to alpine–arctic in the North, all within a short distance, and with major altitudinal variations. Rapid changes in the hydroclimate within a short span results in varied vegetation compositions and phenology across various pocket areas. This chapter explains how a forested ecosystem, if managed properly, can act as a mitigating factor for rapid climate change. It could also act as a development catalyzer through carbon fund contribution in a seismically sensitive Nepal territory facing destructive cycles of land degradation caused by extensive erosions on hill slopes in the North to riverine and floodplain siltation in the southern plains.

Plants have adaptive capabilities to their changing climatic conditions, such as the variations in temperature, atmospheric CO₂ concentration, and precipitation, to become better suited to their ecosystems (Streck et al. 2008). However, plant productivity and the carbon cycle are likely to be altered by these contemporary climatic variations (McGuire and Joice 2005; Hawkins et al. 2008). For example, too high temperatures and severe drought may decrease plant productivity, whereas elevated CO₂ inputs may increase plant productivity, if there are no other limiting factors. Climate change (in temperatures and rainfall amounts), plant productivity, and the carbon cycle are intrinsically interrelated. A forested ecosystem becomes instrumental in transferring the atmospheric and soil carbon into food products by converting carbon dioxide (CO₂) into carbohydrate (C₆H₁₂O₆) in the presence of solar radiation and water—a process called the photosynthesis (Ajtay et al. 1979; Garnaut 2008). Almost half of the atmospheric carbon is utilized by plants during the photosynthesis process (Hawkins et al. 2008). The ability of plants to utilize atmospheric carbon through the photosynthetic process turns a forested ecosystem into carbon sink (Houghton 2004). By absorbing atmospheric carbon, a forested ecosystem can ameliorate the environment in various ways (BJ 2016): (a) acting as a physical barrier to natural disasters, such as floods, and as protection from intense solar radiation, landslides, and windstorms; (b) binding soil particles, protecting the soil from erosion, storing atmospheric carbon in the soil, and protecting the land from degradation; (c) offering regulatory services in conserving and recharging water through evapotranspiration during drought periods; (d) providing building materials needed for the construction of infrastructures; (e) delivering various kinds of foods; and (f) supporting climate mitigation by reducing greenhouse gases (GHG) through enhanced carbon sequestration.

The above accounts suggest there are significant causal relationships among forest productivity, elevated CO₂ in the atmosphere, precipitation and temperature, and various soil nutrients. Therefore, a thorough understanding of the causal
interrelationship among elevated CO$_2$, temperature, precipitation, and forested ecosystem requires in-depth knowledge of biogeography and bionomics. Biogeography involves the past and present distribution of various species in relation to the physical environment and how the physical environment affects species and shapes their distribution across space (Guisan and Zimmermann 2000). It has strong ties to biology, ecology, evolution studies, climatology, and soil science. Biogeography dictates that species distribution changes with (a) the latitude and gradients (Carpenter, 2005; Colwell et al., 2004; Lomolino, 2001; McCain and Grytnes, 2010); (b) the changes in temperature, moisture, and energy levels (Körner 2007); (c) topography (Hofer et al. 2008); (d) land use and geographic factors (Bhattarai et al. 2009); (e) aspect and slope (Sanders and Rahbek, 2012); (e) elevation gradients (Bhattarai and Vetaas 2003); (f) fragmentation of the natural forests (Maitima et al. 2009; Tilman et al. 1997); (g) the nutrient cycling processes such as organic carbon in the soil (Maitima et al. 2009); and (h) available nitrogen level in the soil (Li et al. 2006).

Bionomics, on the other hand, not only bridges across ecology and economics but also psychology, anthropology, archaeology, and history. It also helps us to understand how humans have interacted with their environment in the past, how they are today, and how they might interact with it in the future. Bionomics addresses the causal relationships between everything outside and inside the market and it brings both endogenous and exogenous factors together. It helps to explain the limits of the environment, what it can create, and how we can remain within a safe operating space. Bionomics explains how biotic components exist in relation to one another and to their environments; following Darwin’s theory of natural selection (Largent 1999).

With a detailed understanding of the theoretical concepts related to how an ecosystem functions and what trees might contribute, the services offered by an ecosystem can be identified in subjective terms. Later in this chapter, a conceptual framework of ecosystem service will be presented, using the southern part of the Churia and Tarai regions as its spatial context. This case study is chosen because both Churia and Tarai areas have been contested by different communities, and a lot of resources have been poured into linking Churia’s conservation with the sustainable development of the Tarai region since the early 1990s. However, the quantification, of ecosystem services that Churia can provide for Tarai’s development, as well as how the Tarai region can support Churia’s conservation, remains to be articulated, which we accomplish later in this chapter.

The main objective of this chapter, therefore, is to capitalize on how the exchange of carbon between plants and the atmosphere results in gross primary productivity (GPP) where the vegetation captures and stores carbon from the atmosphere through the process of photosynthesis. When other factors, such as water (soil moisture) and precipitation, nitrogen, and temperature, become non-limiting, the GPP of a forested area increases, resulting in the net primary productivity (NPP). As more NPP accumulates in an ecosystem, the net ecosystem productivity (NEP) level also increases, which in turn then increases the net biome productivity (NBP).
Net ecosystem exchange (NEE) results from an abundance of GPP\(^1\) (Grace and Zhang 2006). These relationships justify the practice of using trees of the forested ecosystem to capitalize on the atmospheric and soil carbon stocks, in addition to other regulatory and protective services that a forested ecosystem can provide. This will be an opportunity for Nepal to build more carbon stock and gain more access to international climate funds. Nepal could even utilize a less skilled or an untrained workforce to increase the country’s greenery and carbon stock. The carbon stock from this greenery can be sold to developed countries, resulting in increased monetary revenue for Nepal. The funds received from such activities can then be used to reduce poverty, enhance development infrastructure, and implement adaptation plans, which will make the green economy a catalytic agent for the country’s development.

This chapter’s source of synthesized information therefore comes from peer-reviewed journals, gray literature including government documents, views of civil society organizations, ideas expressed by planners and experts in various newspapers, and the websites of various projects and government agencies. The synthesized information is also based on the interactions with government officials, planners, policy makers, social workers, and forestry user groups from 2012 to 2020. The interviews were particularly helpful in understanding the development of the REDD+ program in relation to community forestry management (CFM), in terms of its geographic distribution, legal framework, institutional capacity, and stage of design and implementation of various forestry activities.

Following this brief introduction, the rest of the chapter is structured as follows. First, it presents a theoretical foundation illustrating on how a forested ecosystem functions and mitigates the environment. Second, the land use and cover situations of Nepal by six elevation classes (62–999 m, 1000–1999 m, 2000–2999 m, 3000–3999 m, 4000–4499 m, and 4500 m and above) from 1980 to 2010 are discussed. Third, the evolution of the forest policy of Nepal since it became the nation-state till date. Fourth, it presents the classifications of forest types by management regimes. Fifth, efforts made in the conservation and linking of Churia and Tarai regions to improve ecosystem services are discussed. Sixth, it delineates the watershed areas that link different parts of Churia with the Tarai plain. Seventh,

\[^{1}\text{GPP} = p\]

\[\text{NPP} = P - Ra\]

\[\text{NEP} = P - Ra - Rh\]

\[\text{NBP} = P - Ra - Rh - D\]

Where,

\begin{itemize}
  \item GPP = Gross primary productivity; NPP = Net Primary productivity
  \item NEP = Net ecosystem productivity; Ra = Autotrophic (green vegetation) respiration
  \item NEP or NEE = Net ecosystem exchange
  \item NBP = Flux at a border spatial and timescale (1 km\(^2\) upwards and 1 year upwards)
  \item D = Disturbances
\end{itemize}
theoretical and practicable models of ecosystem services linking Churia and Tarai communities. Finally, a conclusive summary followed by the references.

8.2 Theoretical Foundation

Planners, ecologists, politicians, diplomats, and administrators have expressed growing concerns on the rapid deterioration of Nepal’s forest resources and the increasing environmental problems the country is facing due to global climate change. Many have expressed concerns related to the destructive deforestation, landslides, large-scale downstream flooding, as well as the rural and forest-dwelling inhabitants’ increasing poverty, malnutrition, and food insecurity. Concern has also been raised regarding how the degrading Himalayan ecology has significantly impacted the southern plain areas of Nepal in particular, as well as the entire Gangetic belt and the Ganges and Brahmaputra Deltas of Bangladesh in general. Such debates have pervaded the evolution of policy making in areas of conservation, resource development, and foreign aid and, eventually, in the development of the Theory of Himalayan Environmental Degradation (henceforth referred to as theory).

The intellectual heart of this theory requires a comprehensive analysis to understand, in general, the contemporary environmental problems of South Asia and particularly of Nepal. Taken as a commendable “family” of insightful authorities, Eckholm (1976), Blaikie et al. (1980), Blaikie and Brookfield (1987), Ives and Ives (1987), Ives and Messerli (1989), and Ives (2011), taken together as a “set of exemplars” have published the most compelling and trend-setting set of literature characterizing the Himalayan region and its anticipated eco-disaster. This literature concludes that land degradation is due to multiple factors, including extreme weather conditions, particularly droughts, and human activities that pollute and/or degrade the quality of soils. Land utility negatively affects food production, livelihoods, and the production and provision of other ecosystem goods and services. The film, Fragile Mountain, produced by Sandra Nichols (1982) and the publications mentioned earlier have become trail blazers in explaining the ongoing vicious cycles of eco-disasters that are now destructively affecting the mountain and plain ecosystems of Nepal.

The Indo-Gangetic Plain ecosystems will experience substantial repercussions as the Himalayan ecosystem, including the mountain and hill regions of Nepal, degrades. An unprecedented wave of population growth occurred in the southern plain (with a slogan of paharization of the Tarai plain) of Nepal, along the Indo-Nepal border, with the advent of and introduction of modern health care, medicine, and malaria eradication in the Tarai region in the late 1950s and 1960s era. This rapid population explosion, with an overall doubling period of about 27 years, led to massive deforestation in the Tarai region. In addition, the indigenous population in the Tarai region is augmented by uncounted and uncontrolled immigration into the region from India and across a virtually open southern border. The erstwhile royal families and rulers of Nepal enticed many Indians, some from elite families,
and many belonging to blue color working classes, to convert impenetrable Nepali forests into uncontrolled, spontaneous settlements and paddy rice farmlands. Over 90% of the erstwhile population settled were rural and depended on subsistence farming, which led to the rapidly increasing demands for fuelwood, construction timber, and fodder for domestic animals. More than 90% of Nepal’s energy depends upon the combustion of biomass. Furthermore, the domestic animal population in Nepal underwent a parallel, or even greater, growth compared to that of the human population. Timber exportation to India for railway construction also led to the massive destruction of the commercial Tarai Sal forest (*Shorea robusta*; Bhattarai et al. 2002).

A vicious cycle developed as the burgeoning subsistence population started exerting increasing pressures on the forest cover in the mountain and hill regions. Additionally, the disbanding of private forests with the nationalization of all Nepali forests led to confusion about the ownership of woodlots in these regions. This has led to massive deforestation, amounting to a loss of half the forest of Nepal within a 30-year period (1950–1980) and a prediction that by 2000 AD, no accessible forest cover will remain (World Bank n.d., http://unu.edu). In the mountain and hill regions, increased deforestation and modification of the landscape to develop agricultural terracing on steeper and marginal slopes has led to a catastrophic increase in soil erosion. It has also resulted in the loss of productive land through accelerated landslide incidences in the seismically sensitive landscapes, (Chap. 3) and the disruption of the normal hydrological cycle (Chap. 6). This situation, in turn, has led to the increase in runoffs during the summer monsoons with disastrous flooding and massive siltation in the foothills of the Mahabharat Lekhs, Churia, Bhabar, and Tarai plains. In the Bhabar and Tarai zones, the water table has become low, and the majority of rivulets, springs, and wells desiccated during the dry season. Other consequences of unprecedented land degradation include rapid siltation of reservoirs, abrupt changes in the courses of rivers resulting in them becoming braided, spread of barren sand and gravel across rich agricultural land on the plains, and an increase in the incidences of waterborne diseases in downstream areas. The increased sediment load of the rivers emanating from the Himalayan system, extending to the Bhabar and Tarai regions of Nepal and up to the double deltas of Ganges and Brahmaputra, caused the formation of islands in the Bay of Bengal. The unilateral export of fertile soils from Nepal often clogs many braided rivers and rivulets in India leading to massive floods and significant losses of infrastructures, lives, and individual properties.

In the mountain and hill regions, the continued loss of agricultural land has led to several rounds of deforestation. Farmers made herculean efforts to construct more terraces to continue and also expand their subsistence farming of terraced slopes and paddy fields. The small size of land holdings left no options for farmers other than exerting pressures on nearby available forests. As more areas became deforested, people started having to walk greater distances from their villages to gather forest products. In many areas, a critical threshold has been reached whereby the available human energy (principally female) becomes progressively overtaxed and an increasing quantity of animal dung is use for fuel (Nightingale 2003, 2005; www.unu.edu).
Consequently, several vicious cycles ensued: (1) terraced soils were deprived of compost and animal manure fertilizer because animal dung started becoming used for fuel; (2) farmers started using commercial fertilizers if they were able to afford the cost; (3) organic farming began decreasing for reasons of cost and because of labor losses; (4) soil structures were weakened, further augmenting the incidences of landslides and soil erosion; (5) even more trees were cut on more marginal and steeper slopes for extensive farming to feed the ever-growing subsistence population; and (6) unplanned developmental activities started occurring.

The emerging situation as discussed above led to the expansion of the theory which states that a series of linked vicious circles, operating inexorably in both the upstream and downward sectors of watersheds, are leading to widespread environmental and socioeconomic ruin that becomes more serious every year (Ives 2011). Population growth in the Tarai, for example, including both natural increase and in-migration, has added intensive pressures on lowland forests. The net results of the various destabilizing processes in the upstream Mahabharat, Churia, and Bhabar ranges are considered threats to the future of Tarai with decreasing crop productivity (both in terms of total national production and as yield per unit area), increase in absolute numbers and percentage of the subsistence farming population with nutrient intake below a minimum acceptable level, and progressive mountain desertification. Since the mountain deforestation is assumed to be occurring on steep slopes, the associated processes of gullying, soil erosion, and landsliding are cited as having calamitous downstream effects (Ives 2011), such as (1) rapid siltation of reservoirs, (2) excessive shortening of the useful life of major hydroelectric and irrigation projects (Chap. 6), (3) increased flooding on the plains, (4) raised in the levels of riverbeds, and (4) destruction of rich low-level farmland by the spread of sand and gravel as rivers break their banks and change their courses.

Almost four decades ago, Eckholm (1976) wrote about how Nepal was exporting topsoil to India, thereby becoming the main “commodity” that often clogged reservoirs, turbines, and irrigation works in the Indo-Gangetic Plain. Such a broad theory seems to have been widely accepted locally and has raised two contentious issues: (a) the downstream communities—as victims of the unwarranted and irresponsible environmental disruption in the upstream regions—could justify reprisals in economic and political terms, and (b) Nepal could benefit from proportionate amounts of international and bilateral development aid for the conservation and management of forest resources in these upstream watersheds. Such international aid will be in the interest of lower catchment areas as well, such as those in India and Bangladesh.

Environmentalists emphasize the importance of forest conservation and management because individual trees, woodlots, and forests absorb and store much of the atmospheric carbon dioxide that otherwise would be contributing to climate change. Also, forests are home to about 80% of the remaining terrestrial biodiversity. Forests regulate water cycles, maintain soil quality, and reduce the risks of natural disasters such as floods, soil erosions, and intense solar radiation. However, conserving forests has been a challenging issue.

On the global scale, about 14.5 million hectares of forests, almost the size of Nepal, is lost each year (World Bank 2013), and recent image analysis shows that
Nepal loses its tropical forest at the annual rate of 0.5% due to agriculture, development activities, and natural disasters. The World Bank has stated that on a global scale, an estimated two billion hectares of lost or degraded forest landscapes could be restored and rehabilitated, returning landscapes and communities to their healthy productive potential. In Nepal, about 1.45 million households (35% of the country’s population) are involved in community-based forest management programs. Specifically, they have formed over 17,685 Community Forest User Groups (CFUGs) and are engaged in the management of 1,652,654 ha of national forest handed over to them as community forests (FECOFUN 2020; BJ 2016; DoF 2015). Among these CFUGs, only a few have been rewarded for the carbon enhancement in their forests (Adhikari 2016; BJ 2016) as pilot programs. It is hoped that many more CFUGs will receive financial assistance to undertake climate mitigation and adaptation activities (UNFCCC 2015). Likewise, each year, the Government of Nepal also afforests and reforests hundreds of hectares of degraded and barren areas to increase forest cover which will act as a carbon sink and could also be a source for carbon fund.

The Intergovernmental Panel on Climate Change’s (IPCC) Fifth Assessment Report (AR5; 2014) clearly identified forestry as one of the key sectors responsible for GHG emissions and mitigation (Victor et al. 2014). Through greenery, it mitigates the problems of GHG emissions while supporting the livelihoods of forest-dependent communities, particularly the local poor. It also reduces the amount of global deforestation (Chap. 3), which was estimated at 17.4% (IPCC 2007). In sum, trees can be both sources and sinks of carbon, depending on the ecological niche and specific management regime and nature of human interventions (IPCC 2000).

Individual tree species or forest types respond to climate change and human intervention either by changing their ecological ranges or by increasing or decreasing their abundance. Various models have been developed to predict how species distributions may change in accordance to climate changes. These changes could include increases or decreases in productivity of forests, forest area, changes from one forest type to another, or movements of specific species from place to place. It is expected that species will migrate to the North due to global warming. However, this migration will not be uniform across all geographic regions, and Nepal’s case is phenomenal because of its complex hydroclimatic situation.

Resource managers are concerned with the productivity of the land as the climate changes. Understanding how land productivity will change with the climate is very complicated. The existing literature reveals that (a) carbon fertilization is likely to increase individual tree growth; (b) the CO₂ uptake by trees makes water use more efficient, thereby making trees less vulnerable to drought; (c) the effects of carbon fertilization decline as trees age; and (d) CO₂ uptake varies by species. Unfortunately, most of these outcomes are from the observations of individual trees in experimental conditions rather than on entire forest ecosystems. In natural forests and even managed forests, enhanced growth in trees can be offset by increased natural mortality, factor of etiolation, and density of vegetation. This is certainly the case for plantation forests where foresters usually predict increased thinning with higher growth in well-stocked stands. An increase in the atmospheric carbon in
forested ecosystems could increase forest productivity if carbon fertilization enhances forest growth, but depending on the age and types of species of the trees, it will decline if carbon fertilization does not occur. Plant-level experiments suggest that carbon fertilization will enhance tree growth, at least for some period of time provided that other factors are not limiting. Though scaling these results up to the ecosystem level becomes complex, available studies suggest that carbon fertilization will be limited by competition, anthropogenic disturbance, and nutrient limitations. These conditions suggest that better managed forests sequester more carbon than forests in natural conditions with high species competition. However, biodiversity that helps to conserve more carbon may be at a higher rate in a natural forest than in plantation (man-made) forests.

Plants quickly acclimatize to new environments, and their stomatal response also changes with the availability of water. In dry conditions, stomatal conductance (opening) will be low. If plants are growing on a site with poor quality and dry conditions, the elevated CO₂ will not help them grow; hence the gross primary production (GPP) and net primary production (NPP) will remain low. However, if water and soil moisture are not limiting factors, plant productivity will increase with elevated CO₂ levels (McGuire and Joyce 2005). An understanding of climate change on ecosystem productivity is limited by the lack of scientific understanding of several key factors that control the response of natural and managed forests. Although the majority of the existing literature primarily focuses on the different scenarios based on temperature levels and CO₂ and changing rainfall patterns, this chapter briefly discusses the effects of climate change on economic aspects of a forested ecosystem. These components are important because of their direct relations to the net primary production of plants as described in the paragraphs below.

8.2.1 The Effect of Increased Temperature

Although plants respond to temperature differently, at least 5 °C (centigrade) (41 °F [Fahrenheit]) temperature is needed for any plant to remain photosynthetically stable (Bisgrove and Hadley 2002). The rate of photosynthesis, although varying across plant species, is generally optimal between 20°C and 35 °C (Mellilo et al. 1990). Among varying types of trees (e.g., strong and moderate light demanders, shade tolerant, etc.), an increase in temperature has substantial effects on photosynthesis, respiration, soil nutrients, and plant physiological activities (Kehlenbeck and Schrader 2007; Lewis et al. 2005). As a rule of thumb, when water is available, the increase in temperature will have a positive impact on plant growth and development² (Nemani et al. 2003), especially, in low-temperature regions. Depending on

²The earlier claim was that an increase in global temperature will have a positive impact on plant growth, yet recent findings have proven that when the temperature exceeds the optimum level, it increases the rate of respiration. This then causes the NPP to continuously decline, as an increase in
the type of plant species, as the temperature rises, photosynthesis will initially be positive, but the photosynthesis activities will slow down as the temperature reaches an optimum level. If the temperature increases too high, the rate of respiration may exceed the rate of photosynthesis, making the process of carbon assimilation negative (Dhiaulhaq 2011). An increase in temperature beyond the tolerance limit will decrease the gross GPP and NPP (Grace and Zhang 2006). In such instances, plants may eventually die, and those dead plants become a source for CO₂ instead of remaining as a sink for CO₂ (Bisgrove and Hadley 2002; Hawkins et al. 2008; Melillo et al. 1990), which then contributes to more GHG emissions in the atmosphere. Similarly, if the level of CO₂ concentration increases on plants, a decrease in temperature between the ranges of 10°–14° C will make NPP negative (Grace and Zhang 2006).

### 8.2.2 The Effect of Elevated CO₂

As a rule of thumb, when the level of atmospheric CO₂ increases, plant productivity increases, but responses vary based on plant species and age. When the amount of CO₂ increases, plants efficiently consume the available nutrients and water, and the rate of photosynthesis becomes higher (Lloyd and Farquhar 1996) than at the normal level of CO₂. That means trees growing in a site with poor quality consume less CO₂ because of the lack of nutrients, thus resulting in a lower GPP. Elevated CO₂ may increase the rates of photosynthesis leading to the increase in biomass, but this increase will be higher only in the C₃ plants (Dhiaulhaq 2011; Stitt and Krapp 1999), if other factors are non-limiting. About 85% of plant species come under the C₃ category.³ Melillo et al. (1993) predicted that doubling the amount of CO₂ at the optimum temperature level in a terrestrial ecosystem will increase the NPP by 16.3%. The existing literature reveals that a terrestrial tropical ecosystem will respond well when increasing 22.2% of biomass with the increase of CO₂ levels above normal. However, in low-temperature regions (e.g., temperate and alpine), the biochemical cycle becomes slow, and the effects of CO₂ uptake become minimal, or nonexistent, even if the CO₂ is elevated beyond the normal level due to the lack of respiration will be higher than the increase in GPP. As a result, the net ecosystem productivity (NEP) will continuously decline. Furthermore, when annual temperature reaches 10–14 °C, NEP will be negative under both normal and elevated CO₂ concentration.

³The photosynthetic efficiency of C₃ plants suffer in hot dry conditions due to a process called photorespiration. When the CO₂ concentration in the chloroplasts drops below about 50 ppm, the catalyst Rubisco that helps to fix carbon begins to fix oxygen instead. This wastes considerable amounts of energy that has been collected from the light, and it causes Rubisco to operate at perhaps a quarter of its maximal rate. Elevated CO₂ may increase carboxylation (i.e., increases the amount of carbon dioxide) rates and decrease oxygenation (i.e., increases the amount of oxygen) rates of ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) in C₃ plants, which leads to a higher net rate of photosynthesis and increased synthesis of carbohydrates.
nitrogen in the soil. Thus, an increase in CO$_2$ does not necessarily mean more plant production in low-temperature regions, as growth will be constrained from the lack of soil mineral nutrients (Melillo et al. 1993; Stitt and Krapp 1999). These findings justify that plants become a sink for CO$_2$ under normal conditions only.

### 8.2.3 The Effect of Changes in Rainfall Patterns

Soil moisture is essential for plant productivity, whereas dry soil and erratic rainfall patterns are not conductive to their productivity. Since the late 1990s, the monsoon in Nepal has become more intense for a short time period with the occurrences of prolonged dry periods. Also, since the late 1990s, the monsoon started arriving in Nepal 2 weeks later than usual, and often intense rainfall began occurring towards the middle of October (Chap. 3) when the temperature started subsiding—which is typically not enough for the growth of some tropical C$_3$ plants. This variation in rainfall patterns has affected the phenology of different vegetation. For example, intense rainfall for shorter periods of time and a lack of soil moisture contents for longer periods of time result in a reduction of water uptake by plants and restrict nutrient absorption (e.g., Nitrogen) by their roots (Hanson and Wetzin 2000). From their analyses of global climate data from 2000 to 2009, Zhao and Running (2010) concluded that the NPP has declined due to widespread droughts occurring in various areas over the last decade. Ciais et al. (2003) observed almost a 57% decrease in GPP between 1998 and 2002, and a 30% decrease in 2003 in European forests. Philips et al. (2009) observed a decrease of 5.3 mega grams of above-ground carbon biomass per hectare with a decrease of 100 millimeters of water.

The above accounts reveal that the effect of CO$_2$ on plant productivity may be limited by other factors, such as nitrogen availability, plant acclimatization, and water availability. Under low nitrogen conditions, plants have difficulty in transforming elevated CO$_2$ into production. In the long run, if carbon is accumulated in plants, more carbohydrates will accumulate in plant tissues, which may reduce photosynthetic rates or decrease photosynthetic response to elevated CO$_2$ levels. For example, if the amount of atmospheric carbon increases beyond the normal level in the tropical areas of Nepal, the greenery alone will not be a panacea to mitigate the environment, as plants cannot utilize elevated CO$_2$ due to the constraints of other essential components. Nonetheless, it has been clear that vegetation could act as one of the curative agents against natural and man-made disasters, given that temperature, soil moisture, and nutrients are not limiting factors.

The conservation and management of a forested ecosystem within the framework of Agenda 21, one of the principal results of the 1992 United Nations (UN) Conference on Environment and Development$^4$ (popularly known as the

---

$^4$Agenda 21 reflects a global consensus and political commitment at the highest level on development and environment cooperation. It states that for successful implementation of its environmental
Rio Earth Summit (1992) would benefit Nepal through the carbon fund. An analysis of the rainfall and temperature data available from the Department of Hydrology and Meteorology (DHM) from 1963 to 2009 and climate data obtained from the World Bank Climate Portal from 1900 to 2009 reveal that in higher elevations, the temperature is rising at a relatively faster rate than at lower elevations, which is causing Himalayan glaciers to recede at an unprecedented rate. As the glaciers melt, there are risks of glacial lake outburst floods (GLOFs) and also potential withering of the rivers originating from the Tibetan Plateau into seasonal streams, which heralds further massive loss of life due to desertification and food insecurity. Evidence presented from the Great Himalayan Trail (GHT) by multiple times Everest climber Appa Sherpa (Fig. 3.5) suggests that global climate change has brought many phonological changes across many ecological regions of Nepal.

Proper management of the forested ecosystem should be employed to save mountain and hill ecologies, based on the 1970 assumption that degradation of the Himalayan ecology was due to the faster rates of population growth and the over dependence on nearby forests for fuel, fodder, and building materials, as well as excessive conversion of steep forest lands into agricultural fields (Ives 2011). The World Bank (WB) even predicted that there would be no accessible forests remaining in Nepal by the year 2000 AD; however, today’s situation is contrary to what the WB’s predicted based on limited socioeconomic data. Further assumptions were that rapid and catastrophic deforestation of steep hillslopes under a monsoon climate will lead inexorably to a series of dependent assumptions: (a) increased soil erosion and worsened landslide incidence; (b) accelerated flooding and siltation on the plains of Gangetic India and Bangladesh; and (c) social and political unrest and potential serious armed conflict, as a ramification of ecopolitical conflicts. These predictions assume that the Himalayas will be a zone of a world super crisis, and such phenomena will expand across the Hindu Kush Himalayas containing about 10% of the world’s population, which is also about 30% of the poorest world population (Ives 2011).

Although the problems of soil erosion and flooding in the plain areas of the Indo-Gangetic belt of Bangladesh have been unprecedented, forests coverage in the mountain and hill regions of Nepal are not lost to the extent the World Bank predicted in the 1970s. The arithmetic population densities in the mountain and hill regions are decreasing due to out-migration (Chap. 2); yet, the physiological population densities have not decreased because of smaller landholdings (Chap. 3). Community participatory activities have been phenomenal in combating deforestation in the mountain and hill regions. Nonetheless, deforestation has been massive in the Tarai region and in nearby motorable areas, even considering that the forests in these areas are under the communities’ management. The reasons for such massive...
deforestation in the Tarai regions and accessible areas are due to the higher values of forest products compared to the remote mountain and hill regions. Additionally, a small land holding per family has increased pressures on nearby forests in all physiographic regions of Nepal. Yet, based on the visits by one of the authors to various parts of Nepal in 2012 and 2015 to 2016, deforestation impacts are less visible in the mountain and hill regions for farming and forest products due to out-migration. Developmental activities have marred the environmental conditions including the substantial loss of forest cover. The Tarai regions and other areas with good road networks, nevertheless, are densely populated, and the rate of deforestation in these areas has been rapid both for development and subsistence needs.

Within the past four decades, there has been an increase in socioeconomic polarization between the eastern and western regions of Nepal. Since the 1980s, many parts of eastern Nepal have experienced phases of polycentric development, which has attracted people from all over the country making the Central and Eastern Development Regions more populated than the western regions (Chap. 2). Notably, the population in the mountain and hill regions have decreased in all the development regions and even more so in the western regions. Despite the decreasing population in the mountain and hill regions, the per capita landholding has been very low throughout Nepal.

Situations related to minimal landholding and an overdependence of households on nearby forests have led to severe land degradation. Rapid land degradation in the Himalayas has been a prominent environmental research agenda for quite some time in Nepal (Ives 2011). Land degradation has adverse impacts on agricultural productivity and has led to land fragmentations and increased environmental problems. The scientific understanding of land degradation and land use and cover management are highly fragmented in the existing literature, and the gaps between science and policy are substantial (Brogaard and Olsson 2011; Grainer 2009; Warren 2002). Further research is warranted for a clear understanding about the relationship between land use, land degradation, environmental change, and changes in forest ecosystem services. Though many theoretical debates are taking place about the practical aspects of forest ecosystem services using location-specific data, modeling techniques that have quantitative outputs of ecosystem services are either nonexistent or still in the developing stages for Nepal.

5InVEST is a suite of free, open-source software models used to map and value the goods and services from nature that sustain and fulfill human life. If properly managed, ecosystems yield a flow of services that are vital to humanity, including the production of goods (e.g., food), life-support processes (e.g., water purification), and life-fulfilling conditions (e.g., beauty, opportunities for recreation) and the conservation of options (e.g., genetic diversity for future use). Despite its importance, this natural capital is poorly understood, scarcely monitored, and, in many cases, undergoing rapid degradation and depletion (http://www.naturalcapitalproject.org/invest/).
Forests in Nepal are distributed across tropical to alpine/sub-alpine climatic regions. Stainton (1972) has divided Nepal’s forests, full of very diverse flora, into 35 forest types. These types are categorized into ten major groups, namely, (1) tropical, (2) subtropical broad-leaved, (3) subtropical conifer, (4) lower temperate broad-leaved, (5) upper temperate broad-leaved, (6) upper temperate mixed broad-leaved, (7) temperate coniferous, (8) sub-alpine, (9) alpine, and (10) alpine scrub forest. Plantation forests or man-made forests are not included in these forest types.

At the national level, the forest cover assessment started in the 1960s. Since then six national level, forest cover assessments have been completed (DFRS 1999, 2015). The Land Resource Mapping Project (LRMP 1984) completed the first detailed mapping of the available land resources for the entire country and estimated 6.22 million hectares (mha), or about 42%, of the total geographic area of Nepal is under forest cover (Table 8.1). From the national forest inventory conducted under the financial assistance of Finland in 1994 (Forest Research Survey [FRS]), it was estimated that Nepal’s forest cover was 4.27 million hectares (mha), or 29%, of the total geographic area of Nepal. Shrubland was determined to be 10.6%, which made the total forested area of Nepal 39% of its total geographic area. Nepal’s forests are classified into four different sub-types according to their ownership: national, community, leasehold, and religious. Of these, most of the deforestation has occurred in the national forests, with the coverage declining from a total growing stock of 522 million m$^3$ in the middle 1980s to 387.5 million m$^3$ in 1999 (i.e., a decline of 134.5 million m$^3$ over a 19-year period or seven million m$^3$ year$^{-1}$ (Singh and Smith 2009).

Another inventory was conducted in 1994/1995 by the Department of Forest Research and Survey (DFRS), and the annual rate of deforestation was estimated at 1.7% (Table 8.2).

According to the Forest Resource Assessment (FRA) of 2014, the current total forest cover of Nepal is 5.96 m ha or 40.36%, of the total geographic area of Nepal. Although this figure has been disputed by some, the Department of Forest Research and Survey (DFRS 2015) provided the following justifications for this data: (1) the

Table 8.1  Forest area of Nepal: 1985/86

| Ecological zone       | Forest land (Area’ 000 ha) | Shrub area (Area’ 000 ha) | Total forest (Area’ 000 ha) | Percent of total |
|-----------------------|----------------------------|---------------------------|-----------------------------|------------------|
|                       | Area 3 (000 ha)            | Area 4 (000 ha)           | Area 5 (000 ha)             | Percent          |
| Tarai (Churia hills)   | 3996                       | 1913                      | 59                          | 47.87            |
| Mid-hills             | 4443                       | 404                       | 90.94                      | 28.44            |
| High mountains        | 6309                       | 1794                      | 243                         | 3.85             |
| Total                 | 14,748                     | 5518                      | 706                         | 4.79             |

Source: Master Plan for the Forestry Sector (MPFS 1988)
recent survey used a refined tool including high-resolution imagery and a refined classification algorithm to map even very small areas of forested lands; and (2) the active involvement of communities has helped increase forest areas due to their conservation and reclamation of degraded forested areas (DFRS, 2015). Indeed, it is very difficult to conclude that forest area is actually greater now than in the 1990s because many of these areas have already been converted into farmlands, settlements, and other developmental spaces.

To acquire comparative estimates of the variety in Nepal’s forested areas, we divide Nepal into six elevational ranges: (a) less than 999.99 m, (b) 1000–1999.99 m, (c) 2000–2999.99 m, (d) 3000–3999.99 m, (f) 4000–4499.99 m, and (e) above 4500 m (Fig. 8.1). Figure 8.2 presents a land use profile of Nepal showing the distribution of forest types by elevation, temperature, and potential increase in temperatures by elevation, as predicted by the IPCC (2000).

Utilizing images taken in the 1980s, 1990s, 2000s, and 2010s (with the possible closest dates identified per decade), Figs. 8.3a, 8.3b, 8.3c and 8.3d presents the classification of land use and cover classes for Nepal.
These classified images were divided into six elevational classes based on Fig. 8.1. Land use and cover data was derived by six elevation classes (Tables 8.3a, 8.3b, 8.3c, 8.3d, 8.3e and 8.3f).
Analyses of data presented in Tables 8.3a, 8.3b, 8.3c, 8.3d, 8.3e and 8.3f show that overall Nepal’s forests cover almost 40% of the country’s total geographic area (Khanal et al. 2016). Almost 18,000 Community Forest User Groups (CFUGs) manage approximately 1.2 million ha of forest and are represented by the Federation

![Fig. 8.3b](Land use and cover 1990. (Source: University of Maryland; see, ftp://ftp.glcf.umd.edu/glcf/Landsat/WRS2/ for raw data and ICIMOD for classified data))

![Fig. 8.3c](Land use and cover 2000. (Source: University of Maryland, ftp://ftp.glcf.umd.edu/glcf/Landsat/WRS2/ for raw data and ICIMOD for classified data))

Analyzes of data presented in Tables 8.3a, 8.3b, 8.3c, 8.3d, 8.3e and 8.3f show that overall Nepal’s forests cover almost 40% of the country’s total geographic area (Khanal et al. 2016). Almost 18,000 Community Forest User Groups (CFUGs) manage approximately 1.2 million ha of forest and are represented by the Federation
of Community Forestry Users (FECOFUN). This federation advocates for the rights of CFUGs and seeks to represent them in the policy-making process (DoF 2016; Acharya 2002). The government retains forest ownership in community forests, but individual CFUGs have access, use, and management rights to these forests as well (Newton et al. 2015). Most community forests and associated CFUGs are in the middle hills of Nepal rather than in the low-lying, more carbon-rich Tarai forests, as

![Fig. 8.3d Land use and cover 2010. (Source: University of Maryland: ftp://ftp.glcf.umd.edu/glcf/Landsat/WRS2/ for raw data and ICIMOD for classified data)](image)

| Land use/cover class | Area ('000 ha) | Forest types<sup>a</sup> |
|----------------------|----------------|--------------------------|
| Forest              | 1980 | 1990 | 2000 | 2010 | Major species include: |
|                     | Tropical forest | Shorea robusta; Acacia catechu; |
|                     |                  | Dalbergia sissoo; |
| Shrubland           | 51.13 | 52.84 | 48.71 | 58.00 |
| Grassland           | 51.73 | 52.89 | 51.12 | 37.89 |
| Agriculture         | 2291.35 | 2566.29 | 2609.89 | 2620.32 |
| Bareland            | 157.50 | 179.88 | 160.17 | 198.29 |
| Settlement          | 29.54 | 32.07 | 33.51 | 33.13 |
| Water bodies        | 65.74 | 67.19 | 66.33 | 74.64 |
| Total               | 5208.16 | 5279.49 | 5276.99 | 5272 |

<sup>a</sup>Forest types were compiled from various reports such as Jackson (1994), FRA (2013), DFRS (2015), opinions published in MyRepublica, information from the Great Himalayan Trail by multiple times Mt. Everest climber Appa Sherpa, authors’ personal observations, interviews with forestry officers working in Nepal, and their opinions published in Setopati, Ratopati, Online Khabar, Karobar Dainik, BBC Sajha Sawal, and Banko Janakari.
### Table 8.3b  Land use and cover changes for 1000–1999.99 m: 1980–2010

| Land use/cover class | Area ('000 ha) | Forest types |
|----------------------|----------------|--------------|
|                      | 1980           | 1990         | 2000         | 2010         |
| Forest               | 1665.23        | 1658.68      | 1642.43      | 1636.71      |
| Shrubland            | 86.55          | 84.43        | 79.81        | 83.13        |
| Grassland            | 86.75          | 86.05        | 64.85        | 56.23        |
| Agriculture          | 1427.35        | 1440.19      | 1486.62      | 1487.91      |
| Bareland             | 15.32          | 13.53        | 10.56        | 11.81        |
| Settlement           | 12.83          | 13.52        | 12.95        | 13.48        |
| Water bodies         | 4.06           | 4.17         | 3.23         | 3.81         |
| Total                | 3298.09        | 3300.57      | 3300.45      | 3293.08      |

#### Subtropical forests
- Low elevation—Shorea robusta
- Pinus roxburghii
- Schima-castanopsis forest
- Alnus nepalensis forest
- Riverine forest with Toona and Albizia

### Table 8.3c  Land use and cover changes for 2000–2999.99 m: 1980–2010

| Land use/cover class | Area ('000 ha) | Forest types |
|----------------------|----------------|--------------|
|                      | 1980           | 1990         | 2000         | 2010         |
| Forest               | 1317.23        | 1349.61      | 1301.19      | 1308.07      |
| Shrubland            | 86.12          | 85.79        | 88.01        | 80.75        |
| Grassland            | 142.36         | 143.79       | 150.92       | 149.74       |
| Agriculture          | 237.56         | 229.71       | 264.67       | 269.44       |
| Bareland             | 17.31          | 16.95        | 15.88        | 13.63        |
| Settlement           | 0.11           | 0.12         | 0.12         | 0.13         |
| Water bodies         | 3.75           | 3.55         | 2.50         | 3.48         |
| Snow/glacier         | 0.17           | 0.16         | 0.16         | 0.013        |
| Total                | 1804.61        | 1829.68      | 1823.45      | 1825.25      |

#### Lower temperate forest
- Quercus semecarpifolia forest
- Quercus leucotrichophora
- Quercus lamata forest (oak)
- Quercus floribunda forest
- Quercus lamellosa forest
- Lower temperate mixed broad-leaved forest with abundant Laureaceae species
- Pinus wallichiana forest (lower upper temperate coniferous forest)

### Table 8.3d  Land use and cover changes for 3000–3999.99 m: 1980–2010

| Land use/cover class | Area ('000 ha) | Forest types |
|----------------------|----------------|--------------|
|                      | 1980           | 1990         | 2000         | 2010         |
| Forest               | 549.77         | 550.58       | 538.90       | 549.76       |
| Shrubland            | 241.36         | 243.22       | 245.91       | 253.99       |
| Grassland            | 401.25         | 399.44       | 436.06       | 423.65       |
| Agriculture          | 11.77          | 11.14        | 9.05         | 8.45         |
| Bareland             | 157.21         | 162.48       | 164.37       | 156.11       |
| Settlement           | 0.0011         | 0.0011       | 0.0011       | 0.0011       |
| Water bodies         | 1.99           | 1.98         | 2.02         | 2.32         |
| Snow/glacier         | 41.08          | 40.48        | 12.88        | 11.26        |
| Total                | 1404.43        | 1409.32      | 1409.19      | 1405.54      |

#### Sub-alpine forests
- Abies spectabilis forest
- Betula utilis forest
- Rhododendron Forest
- Juniperus indica steppe
- Caragana steppe
there are some concerns about implementing community forestry in the high-valued Tarai forest (Bampton et al. 2007; Newton et al. 2015; Ribot et al. 2006). This is particularly because of the opportunities for timber smuggling by the unscrupulous members of local communities and local government officials or large landowners (Yonzon 2010).

Table 8.3e  Land use and cover changes for 4000–4499 : 1980–2010

| Land use/cover class | Area (’000 ha) | Forest types |
|----------------------|----------------|--------------|
|                      | 1980 | 1990 | 2000 | 2010 |            |
| Forest               | 3.021| 3.022| 3.85 | 4.76 | Betula utilis forest |
| Shrubland            | 5.93 | 6.99 | 17.64| 18.71| Juniperus species forest |
| Grassland            | 257.55| 261.17| 312.15| 319.51|            |
| Agriculture          | 0.11 | 0.11 | 0.423| 0.398|            |
| Bareland             | 297.44| 299.26| 342.43| 302.85|            |
| Settlement           | 0.0001| 0.0001| 0.048 | 0.049|            |
| Water bodies         | 0.24 | 0.14 | 0.328| 0.552|            |
| Snow/glacier         | 171.16| 168.38| 62.17 | 90.38|            |
| Total                | 735.45| 739.07| 739.039| 737.21|            |

Table 8.3f  Land use and cover changes at 4500 m and above: 1980–2010

| Land use/cover class | Area (’000 ha) | Forest types |
|----------------------|----------------|--------------|
|                      | 1980 | 1990 | 2000 | 2010 |            |
| Forest               | 0.0026| 0.0027| 0.048 | 0.049|            |
| Shrubland            | 0.072 | 0.072| 4.19 | 4.50|            |
| Grassland            | 211.12| 208.51| 163.01| 173.29|            |
| Agriculture          | 0.0171| 0.0172| 0.064 | 0.074|            |
| Bareland             | 801.33| 805.36| 1118.75| 875.62|            |
| Settlement           | 0.00 | 0.00 | 0.033 | 0.051|            |
| Water bodies         | 0.32 | 0.318| 0.935 | 1.91|            |
| Snow/glacier         | 1179.56| 1188.76| 917.42| 11.42.17|            |
| Total                | 2192.42| 2203.049| 1204.45| 1067.084|            |

glaciers, and ice on the high Himalayan ranges in the north; mostly without vegetation except for some lichens on exposed rocky places and few flowering plants such as *Stellaria decumbens*; Species like *Androsace, Saussurea, Primula*, and *Arenaria* complete their life cycle within 3 to 4 months during the rainy season.

8.3 Distribution of Forest Resources in Nepal 683
elevations except for above 4500 m, which is a permanent snow area. Barelands are increasing at lower elevations because of deforestation. However, such lands are decreasing between 1000 and 3000 m of elevation due to the conversion either to agriculture or to settlements. Settlement areas are increasing with the increase in population (Chap. 2) across all elevational ranges.

Overall, there is no clear trend of the increase or decrease of different land uses and cover by the six elevational classes, although there are some pocket areas where significant changes can be found (e.g., urbanized areas; Chap. 4). Though the overall classification accuracy was over 88% of the aforementioned data, they must nonetheless be interpreted with caution as there may be some classification errors due to limited visibility of exact trends in land use and cover over the last four decades. Nonetheless, Table 8.3g reveals that many farm areas may have been converted into bare or barren lands which were potentially classified as shrublands, grasslands, and just plains, barelands due to the out-migration of working-age people from various elevational regions (Chap. 2).

Since it is not clear from Table 8.3g which drivers are actually causing deforestation, we calculated forest areas by slope classes (Table 8.4a). We classified Nepal into six slope classes: 0°, 0–1°, 1.1–3.99°, 4–10°, 10–20°, and above 20° and presented the results in Table 8.4a and 8.4b. We presented the data in this method because 0° is flat with no slope, making it good for agricultural use; thus, areas with slopes anywhere between 0° and 10° can be utilized for agricultural activities. We examined land use and land cover changes from 1990 to 2010, dividing the 0 and 10° slope class into four different slope classes (Table 8.4a). We did not use 1980s images to examine the land use and cover changes because not much land use dynamics were noticeable until the 1980s. However, after the 1980s, there have been many changes in land use and cover associated with the political changes in Nepal, for example, the referendum on the party-less Panchayat system in 1980, the pro-democracy movement and establishment of a multiparty democracy in 1990, the Maoist insurgency from 1996 to 2005, and their election into the Constituent assembly in 2008. These political changes have impacted land use and cover due to the ineffectiveness of government offices. Thus, we examined forest cover changes based on the six slope classes for the 1990 to 2010 period. The results are presented in Tables 8.4a and 8.4b.

Table 8.3g  Trends of land use and land cover changes in Nepal: 1980–2010

| Land use/cover | Elevation in meters | 32–999 | 1000–1999 | 2000–2999 | 3000–3999 | 4000–4450 | 4500 and over | Remarks |
|---------------|---------------------|--------|-----------|-----------|-----------|-----------|-------------|---------|
| Forest        | Decreasing          | Decreasing | Decreasing | Decreasing | Increasing | Increasing | Increasing |         |
| Shrubland     | Decreasing          | Decreasing | Fluctuating | Fluctuating | Increasing | Increasing | Increasing |         |
| Grassland     | Decreasing          | Increasing | Increasing | Increasing | Increasing | Increasing | Increasing |         |
| Agriculture   | Increasing          | Increasing | Increasing | Increasing | Decreasing | No change |         |         |
| Bareland      | Increasing          | Decreasing | Decreasing | Decreasing | Increasing | Increasing | Increasing |         |
| Settlement    | Increasing          | Increasing | Increasing | Fluctuating | Fluctuating | Increasing | Increasing |         |
| Water bodies  | Fluctuating         | Decreasing | Increasing | Increasing | Increasing | Increasing | Increasing |         |
| Snow/glaciers | N/A                 | N/A     | Decreasing | Decreasing | Decreasing | Fluctuating | Decreasing |         |

684 8 Forestry and Environment
Table 8.4a  Land use and cover situations for 1990–2010 period by slope classes

| Land use classes | Land use and land cover area in square kilometers under six different slope classes |
|------------------|-----------------------------------------------------------------------------------|
|                  | Nearly level (0') | Gently sloping (undulating) (0–1') | Strongly sloping (rolling) (1–4') | Moderately steep (hilly) (4–10') | Steep (10–20') | Very steep (>45') |
|                  | 1990  | 2000  | 2010  | 1990  | 2000  | 2010  | 1990  | 2000  | 2010  | 1990  | 2000  | 2010  | 1990  | 2000  | 2010  | 1990  | 2000  | 2010  |
| Forest           | 8.24  | 8.049 | 7.822 | 193.78| 188.39| 184.39| 2624.79| 2559.47| 2506.56| 6346.59| 6238.54| 6105.27| 11692.21| 11615.2| 11451.9| 38026.3| 37382.11| 37376.33|
| Shrubland        | 0.288 | 0.288 | 0.584 | 7.049 | 7.202 | 12.982| 891.131| 891.77 | 149.369| 206.143| 207.601| 240.088| 536.579 | 566.204| 570.549| 3901.93| 3977.798| 4040.145|
| Grassland        | 0.66  | 0.669 | 0.551 | 16.48 | 16.194| 13.955| 219.575| 214.112| 188.506| 656.218| 629.015| 599.163| 1798.569| 1726.74 | 1737.92| 8818.35| 9208.44| 9104.715|
| Agriculture      | 37.69 | 38.14 | 37.09 | 868.22| 881.29| 858.78| 9003.44| 9239.35| 9033.21| 9173.65| 9379.36| 9361.78| 7477.513| 7623.66 | 7801.65| 15875.6| 16593.83| 16878.91|
| Bareland         | 3.22  | 2.986 | 3.803 | 74.35 | 68.68 | 86.149| 847.143| 807.406| 958.846| 1587.46| 1739.72| 1626.27| 2593.121| 3246.98 | 2684.23| 9674.82| 12247.72| 10333.812|
| Settlement       | 0.867 | 0.885 | 0.875 | 19.92 | 20.27 | 20.198| 203.547| 207.699| 207.383| 187.492| 192.642| 193.433| 37.058 | 36.412 | 37.768 | 9.941 | 9.943 | 10.632 |
| Waterbody        | 14.21 | 14.13 | 14.54 | 21.54 | 21.37 | 25.172| 223.532| 221.711| 260.871| 286.281| 280.424| 331.062| 135.545 | 121.486| 146.487| 100.806| 98.798| 99.854 |
| Snow/Snow        | 0     | 0     | 0     | 13.33 | 8.749 | 11.627| 194.063| 150.968| 196.353| 973.871| 745.043| 967.688| 2587.251| 1914.54 | 2467.94| 10299.4| 7171.723| 8770.538|
| Total            | 65.18 | 65.18 | 65.27 | 121.27| 121.27| 121.27| 14297.2 | 14292.6| 13501.1| 19417.7| 19412.4| 19424.8| 26857.9 | 26851.2 | 26862.4| 86707.2| 86690.36| 86714.92 |
Since forest diversity, composition, regeneration, and cover are also affected by slope type (Maren et al. 2015), we explored the effects of slope on land use changes for the 1990–2010 period. Except for forest areas that show clear decreasing trends across all slope classes, other land use and cover classes have mixed results. A decrease in the forest cover up to 0–10° slope suggests a possible transfer of forested land either into agriculture or shrublands (degraded forest due to human intervention) or settlements or barelands (deforestation). Settlement areas are increasing in all slope classes, whereas areas under agricultural lands began to decrease since the late 1990s. Bhattarai et al. (2000) from their analyses of land use and cover of Nepal’s seven provinces for the 1980 to 2010 periods found that the areas under agriculture have increased between 1980 and 1990 in all regions of Nepal and then decreased from the late 1990s in areas above 2000 m, especially, in higher than 15° slope areas. The decrease of agricultural lands can be attributed to many Nepali people leaving their natal homes for foreign countries when the Maoist insurgency was escalating throughout the country. After the peace agreement between the Maoist party and government in 2006, agricultural areas in plain areas started coming back into productive uses because a few young people started returning home to take-up subsistence farming again. Since December of 2019, due to COVID-19, Nepali working in 59 different countries started returning to their natal homes due to increasing economic recessions in the countries of their destinations (Bhattarai et al. 2020). Many shrub lands in all slope classes that were handed over to local communities in the form of community forests are coming up as forest because of the collective conservation practices of the local communities. It is probable that many forest vegetation in high slopes and elevations will come back, but it is difficult to predict that similar situations will emerge in low slopes and elevations. In the image analyses, water bodies and glaciers are not showing any distinct trends, which may be due to potential image classification errors. (Tables 8.5a and 8.5b).

Table 8.4b  Summary of land use and cover situations for 1990–2010 period by slope classes

| Land use types | Nearly level (0°) | Gently sloping (undulating) (0–1°) | Strongly sloping (rolling) (1–4°) | Moderately steep (hilly) (4–10°) | Steep (10–20°) | Very steep (>45°) |
|----------------|------------------|-----------------------------------|----------------------------------|----------------------------------|----------------|------------------|
| Forest         | Decreasing       | Decreasing                         | Decreasing                       | Decreasing                       | Decreasing     | Decreasing       |
| Shrubland      | Increasing       | Increasing                         | Increasing                       | Increasing                       | Increasing     | Increasing       |
| Grassland      | Decreasing       | Decreasing                         | Decreasing                       | Decreasing                       | Decreasing     | Increasing       |
| Agriculture    | Increasing-decreasing | Increasing-decreasing          | Increasing-decreasing           | Increasing-decreasing           | Increasing     | Increasing       |
| Bareland       | Decreasing-Increasing | Increasing-decreasing           | Increasing                        | Increasing                        | Increasing     | Increasing       |
| Settlement     | Increasing-decreasing | Increasing-decreasing         | Increasing                        | Decreasing                        | Decreasing     | Increasing       |
| Water bodies   | Decreasing-increasing | Increasing                      | Decreasing                        | Decreasing                        | Decreasing     | Decreasing       |
| Snow/glaciers  | Increasing       | Decreasing                         | Decreasing                       | Decreasing                       | Decreasing     | Decreasing       |

Since forest diversity, composition, regeneration, and cover are also affected by slope type (Maren et al. 2015), we explored the effects of slope on land use changes for the 1990–2010 period. Except for forest areas that show clear decreasing trends across all slope classes, other land use and cover classes have mixed results. A decrease in the forest cover up to 0–10° slope suggests a possible transfer of forested land either into agriculture or shrublands (degraded forest due to human intervention) or settlements or barelands (deforestation). Settlement areas are increasing in all slope classes, whereas areas under agricultural lands began to decrease since the late 1990s. Bhattarai et al. (2000) from their analyses of land use and cover of Nepal’s seven provinces for the 1980 to 2010 periods found that the areas under agriculture have increased between 1980 and 1990 in all regions of Nepal and then decreased from the late 1990s in areas above 2000 m, especially, in higher than 15° slope areas. The decrease of agricultural lands can be attributed to many Nepali people leaving their natal homes for foreign countries when the Maoist insurgency was escalating throughout the country. After the peace agreement between the Maoist party and government in 2006, agricultural areas in plain areas started coming back into productive uses because a few young people started returning home to take-up subsistence farming again. Since December of 2019, due to COVID-19, Nepali working in 59 different countries started returning to their natal homes due to increasing economic recessions in the countries of their destinations (Bhattarai et al. 2020). Many shrub lands in all slope classes that were handed over to local communities in the form of community forests are coming up as forest because of the collective conservation practices of the local communities. It is probable that many forest vegetation in high slopes and elevations will come back, but it is difficult to predict that similar situations will emerge in low slopes and elevations. In the image analyses, water bodies and glaciers are not showing any distinct trends, which may be due to potential image classification errors. (Tables 8.5a and 8.5b).
### Table 8.5a  Land use and cover classes for 1980–0210 period by aspect classes

| Land use class | Flat (1) | North and northwest (2) | Northeast (3) | South and southeast (4) | West and southwest (5) |
|----------------|---------|------------------------|--------------|------------------------|----------------------|
|                | 1990    | 2000       | 2010       | 1990       | 2000       | 2010       | 1990       | 2000       | 2010       | 1990       | 2000       | 2010       | 1990       | 2000       | 2010       |
| Forest         | 8.24    | 8.04       | 7.82       | 15739.29   | 15570.07   | 15636.11   | 14501.30   | 14261.89   | 14146.43   | 13587.64   | 13278.05   | 12960.15   | 15055.49   | 14873.61   | 14881.72   |
| Shrubland      | 0.288   | 0.288      | 0.584      | 1494.96    | 1593.67    | 1666.19    | 933.57     | 985.59     | 1031.45    | 1001.21    | 941.27     | 917.26     | 1311.09    | 1327.45    | 1398.23    |
| Grassland      | 0.662   | 0.669      | 0.551      | 1849.87    | 1764.32    | 1701.39    | 2881.77    | 2675.58    | 2652.84    | 3953.67    | 4216.31    | 4223.21    | 2823.89    | 3138.28    | 3066.81    |
| Agriculture    | 37.69   | 38.14      | 37.10      | 9171.15    | 9315.75    | 9172.16    | 9781.08    | 10104.59   | 10172.12   | 12632.31   | 13113.74   | 13440.56   | 10903.84   | 11183.41   | 11149.28   |
| Bareland       | 3.22    | 2.99       | 3.51       | 2939.19    | 4151.98    | 3179.66    | 3004.94    | 3913.41    | 3213.49    | 4252.98    | 4716.08    | 4410.11    | 4579.78    | 5329.05    | 4850.06    |
| Settlement     | 0.866   | 0.885      | 0.875      | 104.12     | 104.79     | 105.87     | 107.97     | 109.57     | 110.15     | 128.81     | 132.31     | 132.59     | 117.05     | 120.37     | 120.79     |
| Waterbody      | 13.10   | 13.13      | 13.33      | 205.42     | 201.57     | 216.96     | 169.16     | 165.39     | 196.33     | 190.17     | 178.31     | 223.84     | 202.92     | 198.52     | 226.32     |
| Snow/s         | 1.21    | 1.094      | 1.22       | 4046.62    | 2846.81    | 3879.45    | 3572.64    | 2370.12    | 3436.46    | 3077.61    | 2232.97    | 2522.62    | 3369.16    | 2181.23    | 2675.71    |
| **Total**      | 65.276  | 65.226     | 64.99      | 35550.62   | 35548.96   | 35557.79   | 34952.43   | 34586.14   | 34959.27   | 38824.4    | 38809.04   | 38830.34   | 38363.22   | 38351.92   | 38368.92   |
Maren et al. (2015) argued that aspect is one of the factors that influence forest diversity, composition, regeneration, and land use dynamics. Differences in insolation periods and intensity change with aspect, thereby forming a range of microclimates in multifaceted landscapes (Holland and Steyn 1975). Different radiations result in different land covers (Paudel and Vetaas 2014; Ghimire et al. 2010) because the requirements for light, soil and air temperature, humidity, and soil moisture vary from species to species (Maren et al. 2015). In general, for the Northern Hemisphere, south-facing slopes receive more sunlight and become more xeric and warmer, supporting drought-resistant vegetation. However, they are less conducive for tree growth. North-facing slopes retain moisture and are cold and humid, supporting moisture-loving plants. Since Nepal’s region exhibits a complex topographical structure, high intensities of solar radiation may have an impact on land use and cover. The understanding of aspect is important for forest management and planning because of its influence on growth and forest productivity. Table 8.5b reveals that forest areas are decreasing in the plain/flat, northeast, south, and southeast aspects, whereas forest patches are increasing in the north-northwest, west, and southwest aspects. Agricultural areas are increasing across almost all the aspects. Though there is a slight decrease in agricultural land from 1990 to 2000 in flat and north-northwest aspects, the decrease is minimal. Grasslands are increasing in the south, southeast, and southwest aspects. Settlements are increasing in all aspects. Overall, from the analysis of aspect classes, it is very hard to conclude that aspect has significant impacts on forest vegetation. After the inconclusive information from slope and aspect analyses, we examined land use scenarios by drainage and road densities for each of the six slope classes (Tables 8.6; Figs. 8.4, 8.5 and 8.6) and saw whether or not roads and rivers have influences on forest vegetation. It is hypothesized that when rivers flow in high slope areas, mass wasting and side cuttings from high currents cause the losses of forests and other types of land. Likewise, if roads are constructed on slope areas, more soil erosion and loss of vegetation (biodiversity) occur.

| Land use class | Flat (1) | North and northwest (2) | Northeast (3) | South and southeast (4) | West and southwest (5) |
|---------------|---------|-------------------------|---------------|------------------------|------------------------|
| Forest        | Decreased | Decreased-increased      | Decreased     | Decreased              | Decreased-increased     |
| Shrubland     | Decreased | Increased               | Increased     | Decreased              | Increased              |
| Grassland     | Increased-decreased | Decreased               | Decreased     | Increased              | Increased              |
| Agriculture   | Increased | Increased               | Increased     | Increased              | Increased              |
| Bareland      | Decreased-increased | Decreased-decreased     | Increased-decreased | Increased-decreased | Increased-decreased     |
| Settlement    | Increased | Increased               | Increased     | Increased              | Increased              |
| Water bodies  | Increased | Decreased-decreased      | Increased     | Decreased              | Decreased              |
| Snow/glaciers | Decreased-increased | Decreased-decreased     | Decreased-decreased | Decreased-increased | Decreased-increased     |
Table 8.6  River and road lengths by slope classes in 2010

| Features types | Length in kilometers (percentages) |
|----------------|------------------------------------|
|                | Nearly level (0°) | Gently sloping (undulating) (0.1–1°) | Strongly sloping (rolling) (1.1–4°) | Moderately steep (hilly) (4.1–10°) | Steep (10.1–20°) | Very steep (Over 20.1°) | Total |
| River length (percent) | 25.719 (0.047) | 412.64 (0.76) | 4984.28 (9.14) | 37839.73 (69.41) | 9350.23 (17.15) | 1907.82 (3.49) | 54520.42 (100) |
| Road length (percent) | 14.07 (0.041) | 279.50 (0.79) | 3200.16 (9.14) | 23864.65 (68.16) | 6758.64 (19.30) | 1077.26 (3.08) | 35014.28 (100) |
Roads and river topography can help determine patterns of land use and distribution of forest cover. We mapped roads and rivers by slope classes to examine whether road construction in steep gradients and rivers flowing through steep land has influences on land use and cover changes. By overlaying road and river layers (Figs. 8.4 and 8.5) transiting through steep gradients on land use and cover maps (Fig. 8.3c and 8.3d), have identified that there are changes in forest, grassland, shrublands, and agricultural lands. Further, the road and river layers transiting...
through strong (1–4°), moderately steep (4.1–10°), steep (10.1–19.99°), and very steep (over 20°) slopes were converted into Kml format and overlaid on Google Earth. These overlays show that in many places where new roads have been constructed on steep land surfaces, there are many landslides along the roads. Likewise, river layers also show landslides in many places when the rivers are transiting through steep gradients. Rivers also carry sediments as they flow down steep gradients; however, verification of river sedimentation dynamics is beyond the scope of this research. Nonetheless, from our overlay operations on the land use and cover maps (Figs. 8.3b, 8.3c and 8.3d) and Google Earth, it was confirmed that road construction has fragmented forest areas. The literature clearly states that there are strong causal relationships among forest dynamics and land use and slope. Roads had the strongest relationship with deforestation and forest fragmentation when the expansions of agriculture and buildings were limited to already deforested areas (Freitas et al. 2010). Roads leave permanent scars on the landscape and facilitate deforestation and forest fragmentation due to increased accessibility and land valorization, (which also influence land use and land cover dynamics. Forests are thus vulnerable when more roads are constructed. On the other hand, conservation strategies and land use policies can mitigate environmental conditions and forest fragmentation.

Following on from these analyses, the next section presents an overview of the “implementation story” of forest policy in Nepal to examine if (and in what ways) such policies have had an impact on land use.
8.4 Evolution of Forest Policy

In Nepal, forestry sector policies and institutional processes have been modified based on associated political changes rather than with the aim of mitigating contemporary environmental changes. Such political adaptations can be grouped into four temporal phases: (1) before the 1950s, during the Rana regime; (2) during the 1960s, when there was a ban on the democratic multiparty system and the party-less Panchayat system was emerging; (3) the 1970s, when the debate on the decentralization policy occurred after the environmental crises emerged in the mountain and hills and the beginning of community forestry; and (4) after the late 1980s, which marked the beginning of the multiparty democratic system and the overthrow of the Panchayat system, as well as the implementation of the Master Plan for the Forestry Sector MPFS 1988.

Prior to the 1950s, during the Rana’s feudal rule, or the “Rana Regime,” there was no fixed forestry policy, but rather a cocktail of rules solely benefiting rulers so they could garner wealth by exploiting Nepal’s natural resources (Bhattarai et al. 2002; Hobley and Malla 1996; Wagley et al. 2016). Most of the individuals who were trusted to control forest resources were relatives of the Ranas. Many productive forest areas ranging from a few hectares to hundreds of hectares were granted in the forms of birta\(^6\)/jagir\(^7\) to chosen members of the local elites and such elites used to collect taxes from the communities for using the forests (Bhattarai et al. 2002; Gautam et al. 2004; Malla, 2001). Thus, the local people needing to use the forest resources were required to make tax payments in the form of grains (mana, pathi).\(^8\) If these individuals did not have cash or gains for payment, they had to engage in mandatory labor. However, this system varied from place to place; for example, in the eastern hills of Nepal, forest areas were managed extensively under the kipat\(^9\) system, where a talukdar,\(^10\) or village head, was in charge of the forests and collected taxes from others who used the forests (Joshi and Maharjan 2007). Prior to 1957, most of the accessible forests of Nepal were under the control of various local elites such as talukdars (tax collectors), jimmwal-mukhiyas (village heads), and chitaidars (forest watchers), who collected fees from local forest users in the form of cash and kind under birta, kipat, and jagir systems (Wagley et al. 2016: p3). The Rana rulers were at the center of this system, and their employers—the elites—were in the local levels (Regmi 1976). During those periods, 1/3 of the forests were under the birta system (Gautam et al. 2004). The Ranas benefitted from all the valuable

---

\(^6\)Land granted to an individual in exchange for special services, such as tax collection and forest protection. These lands were tax exempted and were inheritable.

\(^7\)Land assigned to local functionaries as a salary for serving the government in areas such as civil and military work. These lands were tax exempted and were inheritable.

\(^8\)Grains were measured in mana (one pathi = eight manas; one mana = 4 chauthai = ten handful of grains).

\(^9\)A kind of communal ownership system

\(^10\)Village head man deployed for the collection of land revenues
commercial forests of the Tarai region by deploying contractors to extract commercial timbers. Exporting valuable timber to India also helped the Ranas in establishing good relationships with the British East India Company (Bhattarai et al. 2002). Indian forestry consultants, who were hired by Nepali rulers, influenced the forest trading with India, which often bypassed Forest Inspection Offices (Banjanch Adda) and check posts (Hobley and Malla 1996) to evade taxes.

In 1942, the Department of Forests (DoF) was established as a state agency in Nepal. It was supported by 3 regional offices (named as circles) and 12 Forest Inspection Offices, under the supervision of British foresters. Its function was to protect and manage the forest resources of Nepal (HMG 1976) without the involvement of the local people. Then, in 1951 the Rana regime was abolished. After its abolition, the new government tried to weaken the power base of the feudal lords. The private forests were nationalized with the promulgation of the Private Forest Nationalization Act in 1957 (Kanel n.d.). This act legally centralized the authority of forest management in the Tarai and hills under state control, although local communities were already informally managing patches of forests that were adjoining their settlements. In 1959, the Ministry of Forests was established to oversee the Department of Forest (DoF) imitating the Indian forest administration systems, which was itself a “copycat model” of the British system (Hobley and Malla 1996). Forest officials felt comfortable working under this system, since most of the officers were trained in India because of the lack of forestry educational institutions in Nepal.

Then, the newly formed His Majesty’s Government of Nepal (HMG/N) formulated the Forest Act of 1961 with the intention of implementing stronger state control over forestry resources. According to the Forest Act of 1961, special rights to issue permits to harvest trees for any purposes were assigned to forest officials. This Act gave further authority to forest officers to arrest forest offenders without any warrant and to register the case in the Forest Conservation Special Court following the framework of Forest Protection (special arrangements) Act of 1967. The Divisional Forest Officer (DFO) used to preside over the one-person special court. These Acts of 1961 and 1967 were extremely impracticable for villagers who were very dependent on forest resources to fulfill their daily subsistence needs, namely, firewood, leaf litter, and fodder. The Forest Act 1961 denied the local people access and rights to use forest resources, which created antagonism between the authorities and local communities (Bhatta et al. 2007; Malla 2001). As the government had complete control over the forests to export valuable timber to India, the forestry needs of the local people were entirely ignored without any decentralization of power. As a result, government forestry institutions lost their credibility with the local people, which led to the decline of public support for forest conservation. Two corporations, the Timber Corporation of Nepal (TCN)—established in 1964 to make constructional timber—and The Fuelwood Corporation of Nepal (FCN), established in 1966 to make fuelwood available to urban dwellers (Hobley and Malla 1996), worsened the situation. Despite the corporations’ aim to provide forest products to the general public, especially urban dwellers, at a subsidized rate (Dugan 1993), the corruption within these corporations became institutionalized. Additionally, the
TCN and FCN disregarded the forestry needs of the rural people, since they only served the interests of elites and Indian markets’ commercial traders. As trees were felled in the Tarai region, many dense forests became cleared and deforested.

This was a tenuous and unstable period following the massacre of the democratically elected government in 1960, with the replacement government’s actions being condemned both inside and outside the country. King Mahendra moved cautiously not to have Indian influence in the Tarai region. He implanted the nationalist slogan\textsuperscript{11} to relocate Nepali-speaking people from the mountain and hill regions to the Tarai region, which was previously dominated by the indigenous Tharu people who spoke non-Nepali languages (e.g., languages similar to India’s Hindi/Maithili/Abadhi). The slogan, “green forests are Nepal’s gold mines,” became widespread and the Tarai forests were exploited regardless of the danger for environmental problems to be ever-present. In 1964, the process of Nepalization through \textit{Poharization} of the Tarai (Shrestha 1990) began with the Nepalese Government establishing the Nepal Resettlement Company to start a resettlement program aimed at relocating people from the hill areas to the Tarai region in the areas clear of forestry (Bhattarai et al. 2002). With the eradication of malaria in the Tarai plain, an appreciable amount of forests were destroyed either by granting them to royal elites and their supporters or to government officials for their unconditional loyalties to the party-less Panchayat system. And this practice would continue until the late 1970s, resulting in the destruction of substantial amounts of forest areas and the conversion of forest lands into de facto open access resources (Wagley et al. 2016).

In the 1970s, the issue of Himalayan Degradation was much deliberated to identify what was causing the vicious environmental crises in Nepal. Eckholm’s (1976) seminal publication \textit{The Losing Ground: Environmental Stress and World Food Prospects} called for scholars and policy makers to raise their sights beyond the pressing problems of the developed world to consider the equally serious but overlooked environmental problems of the Third World. Eckholm’s ideas were applied to the severe problems created in Nepal’s mountain and hill areas from soil erosion and loss of productivity due to the practice of agriculture in uncultivable areas (e.g., steep slopes; Eckholm 1976). The popular 1982 film, \textit{Fragile Mountain}, by Sandra Nichols, also entered into this public discourse and international news throughout the late 1970s during its development and then in the 1980s when it was aired widely throughout Nepal. Meanwhile, the ecological crises in Nepal were significantly worsened with many regional ecosystems becoming dysfunctional. Planners, policy makers, diplomats, eco-environmentalists, and foresters realized there was a deepening ecological crisis occurring in the Nepalese hills (e.g., scarcity of forest resources, landslides, flooding, and siltation, coupled with severe impacts on the associated downstream systems; Eckholm 1976). These issues were raised in several international forums, and the chain of ecological disasters later gave rise to

\textsuperscript{11}King Mahendra implanted a slogan “our king, national dress, language, and culture is much more precious than our own life” to have mountain and hill dominance in the Tarai. It was similar to the Russification Lenin and Stalin did during the expansion of communism in the former Union of Soviet Socialist Republic (USSR).
the highly controversial “Theory of Himalayan Environmental Degradation” (Blaikie and Muldavin 2004, p. 520).

In the midst of the debate on Himalayan Degradation and the issues of decentralization, the Ninth Forestry Conference of Nepalese Foresters was held in Kathmandu in 1974. This conference became the major “torchbearer” for the management of Nepal’s forests that opposed the command and control actions of the government. The causes and consequences of deforestation in Nepal and its subsequent effects in downstream and neighboring countries were raised in several platforms at the 1974 Kathmandu Conference, and the Nepali government was urged to take strong and effective actions to halt the deforestation and address the crisis of land degradation (Blaikie and Brookfield 1987; Springate-Baginski and Blaikie 2007). It was now firmly believed by experts and involved governments alike that without the involvement of local people, management of forest resources would not be effective.

At long last, the Government of Nepal embraced the notion advocating the importance of peoples’ participation in forest management and as a consequence, the National Forest Plan of 1976 was approved (Kanel et al. 2005). Accordingly, the Forest Act of 1961 was amended in 1977 to make provisions to hand over part of the government forests to the appropriate local political unit called “Panchayat,” a territorially based politico-administrative unit established under the party-less Panchayat system (in operation from 1960 to 1990) (Kanel nd.). According to the 1977 amendment to the Forest Act, the Panchayat Forest (PF) and Panchayat Protected Forest (PPF) Rules of 1978 were enacted. These rules marked the official initiation of the community forestry program implementation in Nepal. The PF and PPF rules also allowed for the transfer of responsibility for forest management from the government to the local Panchayat system, as Panchayat Forest (PF)\(^{12}\) and Panchayat Protected Forest (PPF)\(^{13}\) (Joshi 1993; Bartlett 1992). Decentralizing forest management from a national to a local government body was a positive move based on the ability for the communities to participate, yet it did not consider how upstream and downstream ecosystems would be managed in a sustainable fashion. With the benefit of hindsight, we can agree that it might have been beneficial to incorporate the slogan of peoples’ participation under the Decentralization Act of 1982 to manage the many fragile watersheds and also to ameliorate many environmental problems resulting from land degradation. The PF and PPF became ineffective because people who were popular in the communities but critical of the party-less Panchayat system were mostly discouraged to lead the community forestry user groups.

It was only after 1989 that a 25-Year Master Plan for the Forestry Sector (MPFS 1989) further emphasized the decentralization of forest management authority to

---

\(^{12}\)A Panchayat Forest, described as a degraded or barren land within the jurisdiction of a Panchayat, where the local community living within the jurisdiction of a Panchayat will afforest tree crops and manage it for the benefits of local people.

\(^{13}\)A Panchayat Protected Forest (PPF) described as an existing forested area within the jurisdiction of a Panchayat, where people may do some enrichment planting and manage the forest.
local communities and away from the local government’s control (Wagle et al. 2016). This was also a period when pro-democracy agitation against the Panchayat system was at the tipping point and which dislodged the Panchayat system and eventually led to the multiparty system in 1990. Along with the multiparty system, it also opened doors to encourage the formation of community forestry user groups (CFUGs) with the intention of involving the local people in forestry governance. Instead of the PF and PPF, the process of transferring potential forest areas to local communities began with the formation of CFUGs as the governing unit for community forestry (Gilmour and Fisher 1991). Public participation in community forest management increased after this provision at the grass-roots level (Malla 2001; Wagle et al. 2016). In line with the spirit of the new Nepali Constitution of 1990 and the Forestry Sector Master Plan of 1988, an entirely new forestry act (Forestry Nepal 1993) and forestry regulatory document (Forestry Nepal 1995) were issued.

The Forest Act 1993 and Forest Rule 1995 broadly classified Nepalese forests into private and national forests based on their ownership. These legislative measures opened for forest management practices that were more democratic and independent by means of involving the local communities (Blaikie and Springate-Baginski 2007; Wagle et al. 2016). According to the Forest Department, today, almost 1.8 million hectares of forests are managed under community forestry, while the remaining forests are managed by the government (BJ 2016; DOF 2015). At present, the management of community forestry is largely emphasized in order to address the people’s needs and support their livelihoods (Blaikie and Springate-Baginski 2007; Wagle et al. 2016). Furthermore, a shift in the political system from a constitutional monarchy to republicanism in 2008 expedited the emergence and influence of nongovernment and community-based institutions in forestry development processes outside the government (Wagle et al. 2016).

Currently, Nepal’s forests are managed by governmental and nongovernmental institutions. The Ministry of Forests and Soil Conservation (MFSC) and its subsidiary branches are operating under the Nepali government’s regulations. Community-based organizations, civil society organizations, and donor agencies/development partners are nongovernmental organizations, and they include the following entities: community-based forestry institutions, community forestry user groups (CFUGs), leasehold forest user groups (LFUGs), religious forest user groups (RFUGs), and collaborative forest management user groups (CFMUGs). In addition, some civil society organizations (CSOs), namely, the federation of community forestry user groups (FECOFUN) and the Himalayan Grassroots Women Natural Resource Management Association (HIMAWANTI), are engaged in the forestry sector. They have made significant contributions to forestry policy advocacy efforts and forest resource management at the grass-roots level. These nongovernmental organizations are doing better than those affiliated with the Nepali government. Yet, the Nepali

14The private forests of Nepal are all considered a part of privately owned land, whereas the national forests are defined as all of Nepal’s forests that are not on private land. The national forests are divided into four major categories: (1) community, (2) leasehold, (3) religious, and (4) protected.
people’s dependency on state-controlled forests continues to be substantial. Most of the government forests are under pressures from local communities, especially, after the promulgation of the Nepal Constitution in 2015. Forest areas have been used for developmental activities such as construction of government complexes in all seven provinces for the establishment of new urban areas, settlements of displaced people including the distribution of forestland to landless and homeless people. Unfortunately, many settlements decisions are made without any long-term land use planning. Some land distributions are done on an ad-hoc basis to favor political cadres. Since non-governmental organization only prefer protecting non-government forests (which are under their management regimes), many government forest areas are likely to be converted into other developmental activities without any scientific land use planning. Thus, pressures on the government forests are increasing each day to meet forestry needs. Importantly, despite the Nepali government claiming to have introduced sustainable forest management systems, the 75% of Nepal’s forests that are under the government’s control are largely degraded. These forests areas are under pressure from villagers, encroachers, timber smugglers, and politicians. Even forestry officials are engaged in the trade of forest products for personal benefits, for which they often lobby politicians and forestry user groups. In many instances, the government bodies have become dysfunctional as their activities have been overshadowed by political activists.

The above account reveals that Nepal’s forestry policy has evolved from feudal to semifeudal systems. Currently, it is moving towards local control by the nongovernmental sector, yet a large area of Tarai commercial forests remains under government control. Due to the implementation of proper management practices, the forests in nongovernmental sectors, compared to government forests, have been contributing more effectively to the carbon sequestration processes. However, the nongovernmental sectors also are not without their limitations, with many political parties becoming involved in illegal timber dealing activities by misusing the rights of the CFUGs. Our field visitations in 2012, 2014, 2016, 2017, 2018, 2019, and January 2020 revealed that more productive forests [government or nongovernment] that are located in areas with greater accessibility are degraded rapidly for various developmental purposes. Though in some areas forests are coming back (as the Kuznets Curve hypothesizes), these improvements are merely associated with the uses of electricity and propane gases for cooking and the coming back of forests through natural regeneration on agricultural fallow lands due to mass exodus of young people for remittance purposes. However, the protected areas, which currently occupy 17% of the total geographical area of Nepal, contribute

---

15The protected areas are under the control of the Department of National Parks and Wildlife and are strictly protected by the Nepal Army. The Government of Nepal is planning to increase the total area under strict protection from 17% to 25% of the total geographical area of Nepal. Since the number of landless and nearlandless is almost 33% in Nepal’s population, it would be impracticable to increase the total area under strict protection. Should the government meet its goal by placing 25% of the total geographic area under strict protection, it would be worthwhile to increase the protection status of areas in remote inaccessible places that are currently more difficult to convert into farmlands.
more to carbon sequestration both in tree biomass and soil organic carbon because of the dense stock of forests with abundant biodiversity. Even the isolated /fragmented hardwood forests located in the tropical and subtropical regions are contributing more to carbon sequestration than the dense forests located in temperate and alpine regions.

8.5 Protected Areas and Biodiversity

Nepal’s complex geography supports rich biodiversity. The National Park and Wild Life Conservation Act (NPWCA) of 1973 and the network of protected areas provide institutional support for biodiversity conservation in Nepal (FRA 2000). Currently, Nepal has placed 17% of the country’s total geographic area under strict environmental protection. Establishing these protected areas has been very helpful in recent efforts to preserve (and sustain) a “green environment” and to prioritize carbon sequestration. Although these areas are not accessible for public uses, the establishments of buffer zones in and around many national parks have been helpful to meet some of the basic forestry needs of the people dwelling in the nearby protected areas. Two of the eight national parks (Chitwan Park and Sagarmatha National Park) are World Heritage sites. The Koshi Tappu Wildlife Reserve (Fig. 8.7) has wetlands of international importance, especially for migratory waterfowl. This reserve is also listed under the Ramsar Convention, which is an international treaty aimed at the conservation and sustainable use of wetlands.

The Government of Nepal is committed to the protection and management of high biodiversity resources through the implementation of sustainable practices.

![Fig. 8.7 National Parks, wildlife, and hunting reserve and conservation areas](image-url)
(KC and Gautam 2016; MoFSC 2014). As a signatory country of the Convention on Biological Diversity (CBD), the Government of Nepal (GoN) revised the country’s National Biodiversity Strategy and Action Plan (NBSAP) in 2014. In addition, the GoN has put a significant amount of effort in the past into the implementation of international agreements, as well as the formulation of strategies to include local communities in biodiversity conservation practices by reducing poaching, trade, and illegal activities within the protected areas (KC and Gautam 2016). While public participation has been a positive step, development activities, such as road construction, have fragmented the forested ecosystems (Geneletti 2003) and created several edge effects (Seiler 2001). Though roads provide a basis for long-term development in rural areas, the environmental consequences from many unplanned developmental activities, especially roads constructed in sloped landscapes, could cause more damages in the long run compared to the short-term benefits associated with physical development. After a thorough review, the findings of the World Wildlife Fund (WWF, 2013) and the Ministry of Forest and Soil Conservation (MoFSC, 2014), KC and Gautam (2016) concluded that unplanned rural roads constructed by local governments have been one of the major threats to environmental and biodiversity conservation. By 2010, the Government of Nepal has opened 25,000 kilometers of rural road tracks, most of which were constructed without any consideration of environmental regulations (DoR 2010). Hall et al. (1992) termed forest roads as “forest ecosystems,” as they occupy ecological spaces. Lugo and Gucinski (2000) agreed to this logic because such roads provide a habitat for associated plants and animals. The reduction in biodiversity of woody plants are associated with the disturbances to wildlife habitats and reductions in carbon sequestration both in soil and tree biomass (KC and Gautam 2016), which is due to the loss of soil moisture and overall carbon stock (Newton et al. 2015).

Having a complete understanding of these ecosystems and the possible services they can provide is imperative for policy making, particularly with respect to environmental mitigation through resource conservation. Unfortunately, such services are not well understood and are quite often taken for granted. Carbon sequestration becomes an important climate-mitigating service provided by protected (Kulshrestha et al. 2000) and forested areas (IPCC 2014). Through photosynthesis, plants absorb atmospheric carbon dioxide and store it in the form of organic carbon in various plant and root biomasses over their lifetime. Once these organic materials decay, an even higher body of carbon pool is created in the soils. Some soils, such as the peatlands, have an even higher level of carbon storage. In the context of global warming, the carbon sequestration function has great economic importance. This importance has been realized with the signing of the Framework Convention on Climate Change following the Kyoto Agreement of 1997, aiming to reduce the level of greenhouse gas emissions to the atmosphere from various anthropogenic activities (Chap. 3). Nepal’s protected areas (Fig. 8.7; Table 8.7) are providing good habitats for wild animals (Plates 8.1 and 8.2) and are also contributing to climate mitigation activities as carbon is stored in higher amounts in densely forested areas (more in plant biomass pool and the soil pool, compared to open areas). The plant biomass includes above-ground and root biomass, and the latter includes peatlands and other soils. All three carbon pools are considered in the modeling approach for the areas located in the Churia–Tarai watershed section later in this chapter.
Table 8.7  List of National Parks, Wildlife Reserve, and Conservation Areas and their current land use and cover situations

| National parks/ Reserved/ Conserv. (Elev range, m) | Year established | Area (Km²) | Land use areas in square kilometers | Pop. places, flora, and fauna |
|--------------------------------------------------|------------------|------------|------------------------------------|-----------------------------|
| Chitwanª (107–564) | 1973 | 932 | 824.17 17.93 32.89 30.09 26.55 1.93 0.0 | Elephant, rhinoceros, deer, tiger, leopard, and boar. Many local and migratory birds such as kingfisher and golden-backed woodpecker |
| Sagarmathaª (2676–8848) | 1976 | 1148 | 6.73 30.71 84.11 6.42 0.23 796.15 212.75 0 | Lhotse, Cho Oyu, Thamserku, Nuptse, Ama Dablam, Pumori, and Khumbu Valley Bear, langur, jackal, and over 118 species of birds |
| Langtangª (2465–6500) | 1976 | 1710 | 551.85 88.74 367.85 9.96 0.24 342.31 398.43 0 | Peaks over 6500 m—Langtang, Lirung, Dorijee Lagpa and Phubichya. Animals—wild dog, red panda, pika, musk deer, black bear, thar, goral, serow, rhesus monkey, and langur |
| Raraª (2909–4000) | 1976 | 106 | 73.04 7.03 18.27 1.37 5.61 0.015 0.58 0 | Peak 4000 m Chuchemara, leopard, black bear, musk deer, goral, serow, bharel, and wolf. Birds: pheasants, munal, and chukor. Snow trout recorded in the Rara Lake |
| Protected Area | Years | Area | Altitude | Elevation Difference | % Forest | % Small < 5ha | % Small > 5ha | % Very Small | % Under 1ha | % Urban |
|----------------|-------|------|----------|----------------------|----------|---------------|---------------|-------------|-------------|---------|
| Koshi Tappu\(^b\) (80–90) | 1976/87 | 175 | 6.58 | 0.51 | 64.05 | 73.32 | 29.88 | 0.73 | 0 | 0 |
| | | | | | | | | | | | Wild bufalo, tigers, and ungulates and about 295 bird sps. Swamp partridge and Bengal florican. |
| Parsa\(^b\) (159–739) | 1976 | 175 | 132 | 0.55 | 2.71 | 40.32 | 0 | 0 | 0 |
| | | | | | | | | | | Wild elephants, tiger, leopard, sloth bear, gaur, blue bull, wild dog, and rhinoceros. Over 300 bird sps. |
| Shey Phoksundo\(^a\) (2130–3660) | 1984 | 3555 | 21.62 | 28.29 | 358.67 | 2.37 | 5.08 | 1670.77 | 1468.27 | 0 |
| | | | | | | | | | | Snow leopard, blue sheep, goral, thar, serow, wolf, jackal, black bear, and yellow throated marten |
| Shivapuri\(^b\) (1432–2645) | 1985 | 97 | 90.75 | 0 | 0 | 6.13 | 0.00 | 0.233 | 0.00 | 0 |
| | | | | | | | | | | Himalayan bear, leopard, deer, wild boar, and langur |
| Khaptada\(^a\) (2005–2937) | 1986 | 225 | 203.77 | 0.00 | 3.84 | 18.07 | 0.00 | 0.0126 | 0 | 0 |
| | | | | | | | | | | Leopard, yellow throated marten, black bear, wild dog, wild boar, musk deer, wolf, and langur. Bird sps: Impeyan pheasant, kalij pheasant, and munal |
| Dhorpatan\(^b\) (2191–7014) | 1987 | 1325 | 358.73 | 123.35 | 463.02 | 11.57 | 3.03 | 198.13 | 156.71 | 10 |
| | | | | | | | | | | Leopard, goral, thar, black bear, barking deer, blue sheep, wild boar, mouse hare, and langur |
| Bardiya\(^a\) (229–657) | 1988 | 968 | 842.97 | 0.87 | 0.49 | 33.64 | 9.56 | 22.15 | 0 | 0 |
| | | | | | | | | | | Tiger, leopard, elephant, wild bufalo, swamp deer, spotted deer, sambhar, and wild boar. (continued)|
Table 8.7 (continued)

| National parks/Reserved/Conserv. (Elev range, m) | Year established | Area (Km²) | Land use areas in square kilometers | Popular places, flora, and fauna |
|-----------------------------------------------|------------------|------------|-----------------------------------|-------------------------------|
|                                               |                  |            | Forest   | Shrubland | Grassland | Agri. land | Water bodies | Bareland | Snow/glacier | Other |
| Shuklaphanta  (169–212)                       | –                | 0.305      | 215.16   | 22.65     | 0.127     | 78.57       | 13.71       | 37.67    | 0          |
|                                              |                  |            |          |           |           |            |             |          |            |
| Annapurna  (846–6512)                        | 1986/92          | 7629       | 1167.7   | 310.33    | 1631.5    | 235.54      | 7.001       | 3791.73  | 376.89     | 109.3 |
|                                              |                  |            |          |           |           |            |             |          |            |
| Makalu Barun  (1464–8463)                    | 1993             | 830        | 377.57   | 217.57    | 267.06    | 18.99       | 2.39        | 296.09   | 518.27     |
|                                              |                  |            |          |           |           |            |             |          |            |
| Kanchanjanga  (2025–6215)                    | 1997             | 2035       | 181.81   | 131.52    | 404.02    | 20.78       | 0.87        | 175.61   | 859.09     | 262   |

Aquatic species: Gangetic dolphin, gharial, crocodile, otter, and mahseer fish. Over 35 sps of mammals, 260 sps of birds, 60 sps of fish, and 25 sps of reptiles.

Tiger, leopard, elephant, wild boar, gharial, and crocodile. Local and migratory birds.

Contains many villages from Kaski, Myagdi, Lamjung, Manang, and Mustang districts.

Clouded leopard, grey wolf, black bear, red panda, musk deer, barking deer, and wild goat. Over 440 bird sps, 30 reptile sps, and 15 amphibian sps.

The second highest mtn. (Kanchenjunga) in the world. Transboundary wildlife reserve. In India, it is protected though Khangchendzonga National Park and in Tibet by Qomolongma nature preserve.
| Location       | Year | Population | Area (km²) | Altitude (m) | Elevation Gain | Land Area (km²) | Land Use (km²) | Vegetation | Wildlife |
|----------------|------|------------|------------|--------------|----------------|----------------|----------------|-------------|----------|
| Manaslu<sup>c</sup> (430–8163) | 1998 | 1663       | 215.03     | 319.46       | 30.09          | 1.196          | 821.63        | 113.36      | 115.5    |
|                |      |            |            |              |                |                |                | Includes seven village development committees (Samagaun, Lho, Prok, Bihi, Chumchet, Chhekampar, and Sirdibas), Manaslu (8163 m) |
| Kailash<sup>c</sup> (2521–4972) | 2010 | 1912       | 575.41     | 458.64       | 93.99          | 4.14           | 550.47        | 62.78       | 50       |

<sup>a</sup>National Park; <sup>b</sup>wildlife reserve; <sup>c</sup>conservation area. Koshi Tappu received Ramsar status in 1987. Annapurna conservation area: Received status of protected area in 1992.
Plate 8.1  Rhinos in Chitwan National Park. (Photo courtesy Dr. Prakash Neupane)

Plate 8.2  Endangered wildlife in Chitwan National Park. Tiger in the Chitwan National Park. (Photo courtesy by Galaxy Adventure)
8.6 Forest Cover and Carbon Sequestration

The following paragraphs present the importance of forest in the climate amelioration at the global and Nepal’s contexts.

8.6.1 The Global Context

Around 15 billion trees are cut down each year; since the onset of agriculture about 12,000 years ago, the number of trees worldwide has dropped by 46% (Crowther 2015). When trees’ population was enumerated based on satellite imagery, it was believed that the earth has around 400 billion trees, but as the information obtained from the analysis of remotely sensed images was verified with the ground-based samplings from sample plots covering a total 430,000 ha areas from all over the world between 2003 and 2012, it had revealed that there are over 3 trillion trees on the earth (Ehrenberg 2015). The differences occurred because the remotely sensed images do not provide the same level of resolution that a person counting trunks would achieve (Crowther 2015). These 3 trillion trees either sucks up carbon dioxide from the air or releases CO$_2$ into the atmosphere and help regulate the earth climate. If these tree stands are brought under scientific management, they absorb carbon. However, if these trees are unmanaged, old and moribund trees are left start in a natural stage without intervention, such trees emit more carbon than they absorb each year (Malhi 2015). Forest resources collectively hold around 650 billion tons of carbon. The undisturbed ecosystems rapidly reach an equilibrium, and the tree species balance the atmospheric carbon. Human intervention leads to accelerate or decelerate the process of carbon sequestration based on the types of interventions (Houghton 2016). Properly managed forests help in mitigating the atmospheric carbon source and increasing carbon sinks (Brown et al. 1996), as forest vegetation and soils together share almost 60% of the world’s terrestrial carbon (Winjum et al. 1992). However, the rate of carbon sequestration differs based on geographic location and forest types (Shrestha and Devkota 2016). Also, the management type and depth of soil also affect the amount of carbon sequestration (Pandey and Bhusal 2016).

World’s tropical forests release approximately 425 million tons of carbon annually, equivalent to roughly 5% of the globe’s annual fossil fuel emissions (Popkin 2019), if they are not properly managed. If this happens, by the end of the century, CO$_2$ would increase from 400 parts per million to roughly 550 parts per million (Baccini et al. 2017). If managed well, earth’s forests could take up around half of the carbon emitted by human activity, which would substantially slow down global warming.

During the period of 2003 and 2014, many tropical forests experienced various distortions, and they released 861 m tons of carbon with a net carbon loss of 425 m tons. Of this carbon, the land degradation and disturbance accounted for 69% of total carbon losses from tropical forests (Baccini et al. 2017). Replacing these forests with new plants might reduce the level of atmospheric carbon, but such increase in tree
covers helps only if such increase in the coverage of vegetation is in the tropical regions and trees are at the active photosynthetic stage. Tropical forests are drying out or being cleared, burned, and logged so fast that they now spew out more carbon a lot more than conserve carbon. The proliferation of coniferous trees has reduced the carbon storage capacity, for example, the Europe’s forests (Tollefson 2016). Trees store most of their sequestered carbon in their trunks, branches, and leaves—not in the soil or root system, but when felled, almost all of its carbon is likely to go back into the atmosphere. Currently, deforestation accounts for roughly 1/5 of the man-made carbon emissions.

The juvenile vegetation in the tropics and subtropics absorb carbon at a rapid rate, particularly in areas where abandoned farmland had given way to young, fast-growing trees. High-latitude boreal forests consume very little of the atmospheric carbon. Because trees require CO$_2$ for photosynthesis, the atmospheric buildup of this gas can fertilize plants, allowing them to grow faster. Also, CO$_2$ warms the planet, which can lengthen the growing seasons of trees and speed up temperature-dependent processes involved in the growth of plants. It is time to do extensive research whether this increasing CO$_2$ at different geographic locations has created opportunities or challenges to human kinds.

Simply planting trees or increasing the areas under forest everywhere will not necessarily slow down climate change (Naudts 2016). At the global scale, although the forests have expanded by 10% since 1750, timber harvesting from topical forest and shifts to more commercially valuable tree species have resulted in a net release of carbon to the atmosphere. A tree in the tundra is not the same as a tree in the rainforest (Trumbore 2015). The changes have also had local effects with the rise of surface temperature by 0.12 °C by increasing the absorption and retention of heat. In fact, in the tropical areas where trees would be expected to thrive, human activities such as farming have largely pushed forests aside. For example, redwood trees can store carbon for more than 2000 years (Popkin 2019), and so does the Sal (Shorea robusta) tree. This is why a Sal tree has a thick xylem (black circle in the cambium core).

From 1750 to 1850, roughly 190,000 square kilometers of Europe’s forest were cut down for fuel and to clear land for agriculture. Forests have since rebounded on an area more than twice that size, but fast-growing conifers have replaced deciduous trees on roughly 633,000 square kilometers of forest owing to interest in timber harvesting. Although European forests continue to take up carbon, the shift in composition means that they now hold 3.1 billion tons less than they did in 1750.

Through evapotranspiration, trees release water vapor into the atmosphere, and evapotranspiration increases as the temperature increases, if water is available for plants from groundwater table. When CO$_2$ concentration increases in the atmosphere, it enhances tree growth, but tree may quickly use up other vital nutrients, such as nitrogen. The increase in the land coverage by coniferous trees would absorb more sunlight than that would have been done from the deciduous trees. That means increasing the areas of coniferous trees by replacing the deciduous trees means increasing global temperature (Cescatti 2016). Today, although the highest tree densities, calculated in stems per hectare, are found in the boreal forests of North America, Scandinavia, and Russia, global temperature is rising because these tightly packed skinny conifers 750 billion trees, 24% of the global total, consume less
carbon than the tropical and subtropical forests. The subtropical and tropical forests with 1.3 trillion trees, or 43% of the total (Brack 2019) global forest, consume more carbon than the high altitude forests.

### 8.6.2 Nepali Context

In Nepal, it is estimated that the **total carbon stock** in the hill’s community-managed forest (CMF) is at 234.54 t ha\(^{-1}\), and the biomass carbon stock density is at 123.15 t ha\(^{-1}\) (Pandey and Bhusal 2016). For the Terai, the total carbon stock was estimated at 479.29 t ha\(^{-1}\) and the biomass carbon stock density at 384.20 t ha\(^{-1}\). Also, Pandey and Bhusal (2016) observed varying carbon densities in various parts of trees across geographic regions. For example, significantly, more carbon pools were observed in trees, saplings, leaf litter, grasses, and herbs in the forests of the Terai region than in the hill region. Likewise, their observations revealed that the highest amount of soil organic carbon (SOC) can be found in the uppermost soil horizon in both Terai and hill region forests. Tree species like Sal (*Shorea robusta*), found in tropical and subtropical forests (Jackson 1994) in the Terai and Bhabar regions, share the highest tree volume (i.e., 109.4 million m\(^3\); 28.2% of the total tree volume: Amatya and Shrestha 2010), have the highest economic value among timber species, and serve as an important sink for atmospheric carbon (Shrestha et al. 2009). Acharya and Kafle (2009) and Oli (2009) observed that Nepal’s Terai forest has a higher carbon stock at 479.29 t ha\(^{-1}\) than the global average of 285.0 t ha\(^{-1}\) for tropical forests.

Similarly, Pandey and Bhusal (2016) estimated that the **total carbon stock density** of the forest vegetation including carbon in trees, saplings, leaf litters, herbs, and grasses, together with deadwood and stumps, is at 123.15 t ha\(^{-1}\) in the hills’ forests. They estimated the total carbon stock density at 384.20 t ha\(^{-1}\) for the *Shorea robusta* forests in the Terai region. This data was based on 91% of the total biomass carbon stock density above ground and 9% below ground (root) for both the Terai and hill ecological regions.

In terms of the **soil organic carbon (SOC)**, Pandey and Bhusal (2016) found that the community-managed *Shorea robusta* forest stored 111.4 t ha\(^{-1}\) in the hill region but only 95.1 t ha\(^{-1}\) in the Terai region’s government managed forest. The SOC contained in the topmost layer of soil at 0–20 cm depth and at a depth of 60–80 cm depth in the hill forest was 28.45 t ha\(^{-1}\) and 16.9 t ha\(^{-1}\), respectively. In the Terai forest, the SOC contained in the soil at 0–20 cm depth and 60–80 cm in depth was 36.6 t ha\(^{-1}\) and 9.4 t ha\(^{-1}\), respectively. There was a gradual decrease in carbon density with an increase in soil depth. Although the trend line decreased drastically with the soil depths (80–100 cm), it fluctuated quite a bit in the middle horizons (40–60 cm and 60–80 cm depths) in the Terai forest, depending upon the nature of human interferences. When the soil depth increased, so did soil bulk density, while the carbon content decreased. These findings suggest that proper management of forestry crops can enhance carbon sequestration. In addition, it can be concluded that
the amount of soil organic carbon depends on various biotic and abiotic factors, such as microclimate, faunal diversity, and land use and management. Leaf litter and root litter inputs also play major roles in forest soil carbon dynamics (Shrestha and Singh 2008).

Another aspect of forest carbon sequestration is the **combined carbon stock density**, which is the sum of biomass carbon and SOC stock density. In 2006, the total organic carbon stock density in the *Shorea robusta* dominated forest was 234.54 t ha$^{-1}$ in the hills, whereas the stock density in the Tarai was 479.29 t ha$^{-1}$ (Nepal 2006). Importantly, carbon sequestrations differed across varying geographic locations in the hill region, ranging from 186.95 t ha$^{-1}$ carbon stock density (Nepal 2006) to 235.95 t ha$^{-1}$ (FRA 2013, 2014). Likewise, carbon stock density also differed at a similar soil depth in two different locations in the hill’s Sal forests, for example, 211.184 t ha$^{-1}$ (ANSAB 2013) to 285 t ha$^{-1}$ at 30 cm depth (Jina et al. 2008). In the hill’s *Shorea robusta* forest, 48% of carbon was found above the ground biomass, whereas for Tarai’s Sal forests, 48% was found above the ground biomass. Likewise, the SOC for the hill region’s Sal forests had a below-ground carbon biomass of 4%, whereas for the Tarai’s *Shorea robusta* forests, it was 21%.

This data reveals that well-managed Tarai forests have overall more carbon content than the hill forests. Community-managed forest in both regions had higher amounts of carbon sinks than the government managed forests. Well-managed and well-stocked forested stands sequester more carbon than opened and degraded forests with no ground litter. This occurs because opened forests with minimum ground litter loses soil moisture quickly, and the amount of SOC decreases even in the top soils.

Many communities have been involved in the management of various forests in Nepal for the past three decades. Nonetheless, due to the lack of proper instruments to evaluate the amount of carbon sequestered by various forest types across specific geographic locations, the economic values of carbon sequestration have not yet been evaluated. This is one of the lost incomes$^{16}$ for Nepal (UN-REDD 2014).

Forests sequesters 20–100 times more carbon per unit area than croplands (Brown and Pearce 1994), and trees, until they reach maturity, can store about 43–50% more of the dry biomass compared to carbon (Malhi et al. 2002; Negi et al. 2003) (Anonymous 2004; Shrestha and Devkota 2016). Carbon stocks in the forest are dynamic and depend on various factors. For examples, land use, land use/cover changes, age of trees, soil erosion, and deforestation (IPCC 2000; Van Noordwijk et al. 1997). In order to assess the impact of deforestation and regrowth rates on the global carbon cycle, it is necessary to know the stocks of carbon as biomass per unit area for different forest types. This can be determined with the above-ground biomass and below-ground root biomass (Hamburg 2000). Various studies have been done on carbon sequestration, for example, carbon sequestration under different land uses (Gautam, 2002; Shrestha and Singh, 2008) and organic carbon stocks

---

$^{16}$With proper evaluation, it is estimated that Nepal can earn approximately $20–86$ million year$^{-1}$ from the REDD+ program.
in different forest soils of Nepal (Awasthi et al. 2002; Shrestha et al. 2009; Shrestha et al. 2004; Sitaula et al. 2004). The model presented for the management of the Churia-Tarai watershed will highlight this aspect, but first the advance of community forests over government forests in carbon sequestration will be discussed.

### 8.6.3 Community Forestry and Carbon Sequestration

In its 40-year journey since the late 1970s, community forestry has become one of the biggest development interventions in Nepal, with more than 18,000 registered forest user groups, covering the country’s forest lands (Paudel 2012, 2016a, b) in all the physiogeographic regions. Community forestry organizes the production of commercial goods (e.g., timber and medicinal herbs) and subsistence means of livelihood (e.g., fodder and firewood) simultaneously to regenerate the conditions for the possibility of the accumulation of resources among user groups vis-à-vis cumulative actions. This form of accumulation allows commercial and subsistence modes of production to coexist and reproduces itself as a strategy of capitalist development in peasant societies without entirely degenerating community structures. Community forestry practices have increased social capital and livelihood opportunities in local communities through collective actions and have also enhanced coping mechanisms to support community members during adverse vulnerable situations (Paudel 2016).

About 1.45 million households, or 35% of the population, in Nepal are involved in community-based forest management programs—Community Forest User Groups (CFUGs)—that are managing 1,652,654 ha of the national forests handed over to them (DoF 2015). Among these CFUGs, only a few of them have been rewarded for the carbon enhancement in their forests (Adhikari 2016) as pilot programs, and they have performed well in conserving forests (Klein et al. 2005) and supporting climate amelioration. However, the caveat is that communities might be motivated to increase carbon stock only for possible REDD+ payments (Caplow et al. 2011; Stern 2007), largely by planting trees that conserve carbon, which may undermine the importance of biodiversity. If the biodiversity of a forested ecosystem decreases, an ecosystem may not function well and will potentially fail to fulfill the needs of the forest-dependent communities (e.g., meeting the needs for food, fiber, and other livelihood support to maintain the well-being of the community during situations of low agricultural production). This may create a less resilient society, particularly during adverse climatic conditions. Nevertheless, since the local people bring indigenous knowledge, a group-based management is always

---

17The REDD+ program may provide up to 30% of the cost-effective global mitigation potential. There are many initiatives under implementation in developing countries like Nepal. In order to get high benefits, communities may be lured into planting mono-crops that conserve atmospheric carbon while ignoring the importance of biodiversity.
considered the most effective sustainable approach in climate change adaptation (Keenan 2015). Communities that are engaged in enhancing the biomass of a forested ecosystem will also contribute to climate change mitigation, which is fundamental for payment from the REDD+ program (Angelsen et al. 2012). Many communities in both the hill and Tarai regions are performing well. With their indigenous knowledge, they possess the capability to change the existing community practices in order to promote trees capable of producing higher carbon stock to maximize REDD+ payments, while continuing to maintain biodiversity for their social security\(^\text{18}\) (Aryal et al. 2013; Pandey et al. 2016; Shrestha and Dhillion 2006).

However, it will take a considerable amount of time to observe changes because of the time-consuming process of soil organic carbon accumulation (Houghton et al. 2000). Additionally, CFUGs allow local communities to collect fallen dry litter for cattle bedding materials, which decreases the amount of litter debris that accumulates and decomposes to form soil organic matter in community forests. Government policies rewarding local communities for increasing biodiversity may aid in climate mitigation approaches. Many local communities have already invested additional efforts into the existing forest management practices to increase carbon stock once REDD+ is implemented as a pilot program in community forests (CFs). They are actively engaged in controlling damages from forest fires, reducing the amount of firewood for fuel using improved cooking stoves [ICSs] that consume a smaller quantity of firewood than traditional one and also using biogas and propane gas (Aryal et al. 2013).

Community forestry management (CFM) has been one of the strongest pillars contributing to the sustainable global initiative on Reducing Emissions from Deforestation and Forest Degradation (REDD+) in Nepal. The REDD+ project was built to benefit from the environmental, social, human, and institutional capital associated with existing community forest governance (Newton et al. 2015). Most of the REDD+ pilot projects have been located in community forest sites, particularly in high-carbon forests. Notably, these projects need greater institutional coordination, equitable benefit sharing mechanisms, and higher community capacity for monitoring, reporting, and verifying.

Based on his 15 years of experience in the area, the senior author identified the CFM approach as more effective in improving forest management and delivering better environmental and socioeconomic outcomes compared to the existing

\(^{18}\) Community forests sequester significant amounts of carbon stock (48.2–129.9 MgC/ha) depending on vegetation type. With the REDD+ program, the average carbon stock increased by 5.1 MgC/ha/year (1.9–8.0 MgC/ha/yr). Community-managed mixed *Shorea robusta* broad-leaved forests, followed by *Rhododendron-Quercus*-dominated forests, pine forests, and *Schima-Castanopsis* forests, had the highest biomass carbon stock. Their average rate of carbon sequestration in dense forested conditions ranged from 48.2 to 126.8 MgC/ha. The *Shorea* broad-leaved forests conserved 126.8 MgC/ha in average stock density (1600 trees per hectare), whereas the sparse *Rhododendron-Quercus* forests conserved 48.2 MgC/ha. With the REDD+ intervention, the rate of carbon sequestration in each forest increased on average by 5.1 MgC/ha/year, with the highest increment in dense Pine forests (8.0 MgC/ha/yr) and the lowest increment in sparse *Schima–Castanopsis* forests (1.9 MgC/ha/yr).
alternative management regimes, particularly in rural and inaccessible areas. Many of the tropical forests of Nepal are accessible via all weathered roads. It is often difficult to evaluate the potential benefits and risks of using CFM to contribute to REDD+ goals, as the agendas of governmental and nongovernmental organizations do not always match. Communities are interested in gaining benefits immediately, whereas the government wants to control community activities, even if it is not directly beneficial for them [the communities]. For example, communities dearly wish to trade forest products for local developments, but the government controls such activities. Our experiences revealed that there is a conflict of interest between government employees and CFUGs in the management of valued forests (e.g., Tarai hardwood forests) because of the high monetary values of forest products. Further, the local proximities of the forests to the Indian markets where forest products fetch higher prices than those within Nepali markets also contribute to the conflict of interest. The Tarai hardwood forests represent 62.4% of Nepal’s total above-ground carbon stock (Baral et al. 2009; ICIMOD 2011; Newton et al. 2015), yet only 16% of the Tarai population is engaged in community forest management (Bampton et al., 2007; Newton et al. 2015) because the rest of the forests are controlled by the government. Since many of the community user groups live far away from forested areas in the Tarai region, it is not certain how the users may get direct benefits from the REDD+ projects except from the theoretical justification of ameliorating the global climate.

Payments to REDD+’s community beneficiaries at the watershed are initially made from the National Trust Fund (West 2012). Based on the performances, the REDD+ networks distribute payments to individual CFUGs, which then disseminate the monetary rewards to individual households. This mechanism connects the local community to national levels, satisfying both the need to administer payments

---

19REDD+ was developed, primarily, to mitigate climate change by reducing terrestrial greenhouse gas emissions and for delivering livelihood benefits through carbon sequestration. Accordingly, in 2010, the Government of Nepal approved the REDD+ strategy within the Ministry of Forests and Soil Conservation, which developed a national Readiness Preparation Proposal (R-PP) with donors’ support. Six REDD+ pilot projects were initiated between 2009 and 2011 in the managed forests in the Tarai community. When the REDD+ program was initiated, it was largely focused on community social safeguards, livelihood benefits, and economic development, but now with the main REDD+ funding coming from the Forest Carbon Partnership Facility (FCPF) and the United Nations REDD program, carbon sequestration, promotion of biodiversity, and livelihood goals have become inseparable components. REDD+ also aims to maintain existing ecological, socio-economic, and institutional equilibria in the forest landscapes in which they are developed and implemented. It also aspires to maintain this equilibrium among those who have access to forest resources. Many community forestry management (CFM) programs have developed substantial natural institutional human and social capital.

20Seed grants from the Norwegian Agency for Development Cooperation (Norad) have been distributed annually to CFUGs since 2011. For example, in 2011, CFUGs in the Chanawati [households 10,270; Y = 27.58781 N; X = 85.93845 E] Dolakha District received $45,535; Kayarkola [households 3935; Y = 27.66883 N; X = 84.55719 E] Chitwan District received $21,905; and Ludikhola [households 4000; Y = 27.99552 N; X = 84.6783 E] Gorkha District received $27,560.
centrally and the need to make payments to households that reflect local heterogeneity in participation and costs (ICIMOD 2011; Newton et al. 2012; Newton et al. 2015). Only 40% of payment values go to forest carbon enhancement, while 20% go to households in poverty, 25% to indigenous and Dalit members, and 15% to female members (ICIMOD 2011). In sum, the Forest Carbon Trust Fund’s nested differentiated payments are intended to foster equity and provide social benefits, while also introducing performance-based incentives (Newton et al. 2015). The watershed-level REDD+ networks may be the basis of a payment distribution mechanism that effectively transfers funds from a national to a local level, should REDD+ be implemented widely to connect forest management with livelihood and climate change.

8.7 Forest Management, Livelihood, and Climate Change

Forest resources are vital for mitigating climate change and providing livelihood options for local communities in Nepal. Various actors have been involved in managing forests in the past four decades (MOFSC 2016; Newton et al. 2015). Since 2009, REDD+ has been implementing several programs with the help of local communities in exchange for financial incentives (Pandey et al. 2016). The objectives of these programs include mitigating climate change (Pandey et al. 2016); conserving biodiversity (Newton et al. 2015); producing alternative food products (Aryal et al. 2009), medicines, and raw materials for cottage industries (Subedi 2006); and sequestering carbon on plant biomass and soil. The REDD+ pilot projects in community-managed forests have (a) efficiently used natural, human, social, and institutional capital associated with existing community forest sites; (b) overcome the historical financial, administrative, and technical barriers through

---

21Actors include policy actors, science actors, corporate actors, resource managers, and stakeholders. Forest management involves assessing vulnerability, identifying and implementing adaptation options, and monitoring and revising management actions.

22Besides tree plantation in available areas, the REDD+ project supported the promotion of alternative energy means, raising awareness of sustainable harvesting practices, guarding to control illegal harvesting, and implementing fire protection and income-generating activities in poor households.

23Local people collect different products from the forests while some indigenous Chepang communities in the Makawanpur District of Nepal support their livelihood for a fourth of the year from wild food gathered from the local forest. If the biodiversity in a forest decreases, then the ecosystem is impacted negatively from the excessive demands for forest products, which then will further degrade the quality of forested ecosystems during adverse climatic conditions.

24With financial support from the Norwegian Agency for Development Cooperation (Norad), a pilot REDD+ project was implemented jointly by the International Centre for Integrated Mountain Development (ICIMOD), the Asia Network for Sustainable Agriculture and Bio-resources (ANSAB), and the Federation of Community Forestry Users Nepal (FECOFUN).
REDD+ funding (Phelps et al. 2010; Skutsch et al. 2009) and helped to expand the area of forests managed by communities (RECOFTC et al. 2011; TFCG 2009); (c) augmented the existing community forest capacity by investing in the development of new institutions, benefit-distributing, monitoring, reporting, and verifying mechanisms; (d) quantified the nature of interactions between community forestry users and REDD+ by measuring environmental and socioeconomic outcomes; (e) examined the trade-offs between additionality, leakage, and livelihood impacts of REDD+ in community forestry management; (f) enhanced carbon sink maximization, reducing community access to government subsistence by increasing income-generating forest resources such as firewood, charcoal, and construction timber (Karky and Skutsch 2010); (g) strengthened decentralization by reverting towards a centralized forest governance system (Dangi 2012; Phelps et al. 2010) and minimizing monopolies of elites in resource sharing (Burgess et al. 2010; Sandbrook et al. 2010; Toni 2011); (h) embedded REDD+ in the existing legal framework so that communities will be able to work beyond donor commitment25 (Hagen 2014; Puliti 2012) through the Forest Carbon Trust Fund tree planting program; and (i) enhanced the net carbon stock or rate of sequestration in existing community forestry sites or bringing additional forest areas under community management at a faster rate.

In Nepal, community forests tend to be small, often less than 300 ha (DoF 2015). Small forest sites may result in high administrative transaction costs, unless these costs can be spread across bundles of forest sites. Community-managed forests have been attractive for REDD+ projects because communities receive financial incentives to strengthen their institutional capacity. The pilot projects are built directly upon preexisting natural, social, and institutional capital. Pandey et al. (2016), while surveying 105 CFs located in three watersheds that represent four major vegetation types in the Central Development Region, concluded that REDD+’s intervention has strengthened communities’ roles in carbon mitigation. Using the concept of REDD+ intervention and benefit sharing, the discussion that follows now deals with the linkages between Churia and Tarai regions through ecosystem services and climate change mitigation approaches.

8.8 Linking of Churia and Tarai Regions

This section of the chapter will discuss the linkages between socioeconomic and demographic information with the remotely sensed images of 1980, 1990, 2000, and 2010. We discuss a time series of ecological conditions of Churia and recommend a sustainable management approach. The socioeconomic and demographic

25There are relevant lessons to be learned from the experiences of community forest management in Bolivia, Brazil, Colombia, Guatemala, India, Kenya, Mexico, Thailand, and Uganda in the context of REDD+.
information integrated with remote sensing data will be corroborated with the biomass data gathered from the Forest Resource Assessment (FRA) Office of the Government of Nepal. We also discuss the ways to sustainably manage the rapidly deteriorating ecological conditions of Churia using the ecosystem services concepts. The Churia (Shiwalik in India) range extends from Assam (eastern India) to the Sutlej River (western India/Pakistan). In southern Nepal, Churia forms a geologically active landscape between the Indo-Gangetic Plain—Tarai26 and Mahabharat Mountains (Mugnier et al. 1999). This region’s ecology has been degrading rapidly, resulting in several environmental and economic problems along the Indo-Gangetic belt. Attempts made to manage the Churia-Tarai-Madhesh watershed during the past four decades have failed to find any viable solutions. Today, the Churia Range of Nepal has been treated like a contested area—similar to a disputed international bordering area—by the people of the Hill and Tarai-Madhesh regions (Fig. 8.7).

Churia’s elevation varies from 61 m to 2000m, and it has been providing various ecosystem services to downstream communities. The watersheds of Churia and Tarai-Madhesh include 37 of the 77 administrative districts of Nepal (Constitution of Nepal 2015; Survey Department 2001). These watersheds also include Bhabar and the Inner Tarai subregions of Nepal between the Churia and Tarai-Madhesh regions (Fig. 8.7). The deteriorating ecological conditions of Churia and Tarai Madhesh are not only impacting the livelihood of 17 million Nepali living in the watersheds but also that of 350 million people living along the Indo-Gangetic belts of the Uttar Pradesh (UP), Bihar, and West Bengal (WB) states of northern India. Likewise, low coastal areas of Bangladesh are also equally affected due to the rise in sea surfaces from the sedimentation of denuded hills of Churia (Ives 2011; Ives and Messerli 1989). Thus, exploring a proper management alternative for Churia ecosystems has become a vital initiative from regional, national, and international perspectives. Past failures of Churia management have raised several questions: (a) what efforts were made in the past, and why are problems continuing despite so many efforts?; (b) what information is needed to sustainably manage and regulate ecosystem services to downstream communities?; and (c) what can be done to make every household and community responsible for resource management both in the upper and lower catchments? (Fig. 8.8)

8.8.1 Past Efforts

The Churia region became a high conservation priority in Nepal’s fourth 5-year periodic plan (1970–1975). The Land Resources Mapping Project (LRMP) of 1986 and the National Conservation Strategy of 1988 alerted that Churia’s ecosystem would become beyond repair if rampant collections of timber, sand, gravel, and boulders continued. Such activities would lead to frequent flashfloods and

26There have been many political debates about the term Tarai; some prefer to call it Madhesh, while others prefer Tarai. To avoid controversy, this section refers to this region as Tarai–Madhesh.
inundations in the downstream along the Indo-Gangetic Plain (MoFSC 2014). Many donor agencies such as the World Wildlife Fund (WWF), the Netherlands Development Organization (SNV-Nepal), Gesellschaft für Technische Zusammenarbeit (GTZ), the International Union for Conservation of Nature (IUCN), CARE Nepal, and the Department for International Development (DFID) have been involved in the conservation of the Churia ecosystem in various ways. After the enactment of the community forestry rules in 1993, many buffer zones of various perimeters outside the protected areas, located within the Churia and Tarai-Madhesh ranges (Fig. 8.9), have been trusted to local communities. Despite these efforts, Churia’s ecosystem continues to deteriorate. This issue was heavily debated in the installed Interim Constitutional Assembly from 2005 to 2008, and in the elected Constitutional Assembly from 2008 to 2013 (details in Chap. 2). In 2008, the Ministry of Forest and Soil Conservation (MoFSC) prepared the Churia Area Program Strategy. Additionally, the President, Churia Conservation Program (PCCP) started in 2010. It was aimed at perpetually offering ecosystem services to downstream, Tarai-Madhesh, communities including transboundary management of environmental systems (MoFSC 2011). The PCCP was also assisted by other programs such as the Tarai Arc Landscape (TAL) and the Western Tarai Landscape Complex Project (WTLCP). The Churia Conservation Program was prioritized in Nepal’s twelfth (2011–2013) and thirteenth (2014–2015) national plans. In addition, a sustainable land management project has been implemented to conserve the Churia ecosystems within various hotspot areas of Makwanpur, Bara-Parsa, and Rautahat districts (Figs. 1.1 and 8.7), with financial support from the Global Environment Facility (GEF) and the World Wildlife Fund (WWF) Nepal in coordination with the Ministries of Forest and Soil Conservation (MoFSC), Land Reform and Management (LRM), Agricultural Development, and Science and Technology and Environment (MSTE).

The land management project sought to empower local communities to sustainably manage their forests and promote community-based conservation (WWF 2013). However, minimal progress has been made with this approach. Recently,
the Government of Nepal has declared Churia as a special protection region and formed the President Chure-Tarai-Madhesh Conservation Development Committee to look after the Churia Range within 36 districts (MoFSC 2014). This newly formed committee enforced sale prohibitions on timber, sand, and gravel extraction effective July 15, 2014. Almost all Churia programs either have community or government components. The community programs implemented by the Community Forest User Groups (CFUGS) operate under the umbrella of the Federation of Community Forestry Users Nepal (FECOFUN), whereas the government-based programs are looked after by the respective District Forest Offices (DFOs). The National Parks and Wildlife Department looks after the protected areas (Fig. 8.7). The DFO is responsible for providing technical services to CFUGS. In addition, there are also leasehold and religious forests in the Churia Range to address the economic and cultural needs of local people, but all such measures have miserably failed. The annual rate of Churia’s deforestation has been estimated at 0.42% over the last two
decades (1990–2010), almost the same rate (0.40%) between 1991 and 2001 and a slightly higher rate (0.44%) between 2001 and 2010 (DoFRS 2014). However, inside the protected area, the annual deforestation rate is 0.18% (DoFRS 2014). These rates should be interpreted with caution, as they are not reported consistently across publications. Thus, we present our own estimates in Tables 8.8a, 8.8b, 8.8c and Table 8.9.

### 8.8.2 Reasons for CFUG’S Failure

The CFUG approach failed miserably because of (a) the inability of local communities to control tree felling and the exposition of gravels and sandstone, as some tree felling and quarry sites are located away from community households, and (b) penetration of various political parties’ representatives into CFUGs with ill motives of extracting timber, sand, gravel, and boulder from Churia and selling them to the high-priced Indian markets for personal benefit. Likewise, the government- and NGO-run programs also failed to (a) convince people, politicians, and CFUGs about the possible regional, national, and international ramifications, of deterioration if the Churia ecosystem continues as it is today; (b) engage local people in resource development and management by dovetailing their daily needs with the Churia management programs in a transparent manner; (c) utilize revenues obtained from the auctions of commercial timber, sand, gravel, and boulder for local development (Plate 8.3); and (d) to tailor conservation efforts with the employment of the local people. Today, many forest lands of Churia are either encroached or badly

## Table 8.8a Land use and cover changes inside the protected areas in Churia and Tarai-Madhesh: 1980–2010

| Land use/cover class | Area (‘000 ha) | 1980 and 1990 | 1990 and 2000 | 2000 and 2010 |
|---------------------|----------------|----------------|----------------|----------------|
| Forest              | 425905.25      | 425979.45      | 424491.69      | 418351.95      |
| Shrubland           | 5365.43        | 5276.43        | 5823.72        | 4691.07        |
| Grassland           | 17215.62       | 17214.75       | 16594.83       | 10687.41       |
| Agriculture         | 121702.22      | 121711.23      | 128765.61      | 129476.34      |
| Bareland            | 30901.25       | 30897.99       | 28560.42       | 34701.21       |
| Settlement          | 685.56         | 663.03         | 650.07         | 648.18         |
| Water bodies        | 18625.23       | 18451.62       | 14068.71       | 15927.48       |
| Total               | 620400.56      | 620194.5       | 618955.05      | 614483.64      |
### Table 8.8b  Land use and cover changes in Churia (outside the protected area): 1980–2010

| Land use/cover class | Area (ha) | 1980  | 1990  | 2000  | 2010  | Annual changes in land (percent) between |
|----------------------|-----------|-------|-------|-------|-------|------------------------------------------|
|                      |           | 1980  | 1990  | 2000  | 2010  | 1980 and 1990 | 1990 and 2000 | 2000 and 2010 |
| Forest               | 1052115.62| 1051914.69| 1041804.54| 1004319.54| 0.001909| 0.096111| 0.359808|
| Shrubland            | 10903.25  | 10964.07| 10659.15| 7788.33| +0.055781| 0.278108| 2.693291|
| Grassland            | 10023.33  | 9608.31| 8541.00| 9029.97| 0.414054| 1.110810| +0.572497|
| Agriculture          | 352905.66 | 353711.43| 367588.17| 405724.14| +0.022832| +0.392318| +1.037464|
| Bareland             | 40957.94  | 41765.94| 37855.35| 34310.97| +0.197275| 0.936310| 0.936295|
| Settlement           | 6409.28   | 7010.37| 7397.10| 7421.85| +0.937843| +0.551654| +0.033459|
| Water bodies         | 10895.69  | 11924.64| 11412.18| 15348.78| +0.944364| 0.529748| +3.449472|
| Total                | 1,484,211 | 1,486,899| 1,485,257| 1,483,944|                  |                 |              |
deteriorated with scanty vegetation (DoF 2015). The increasing demands for construction materials in bordering India after the Economic Liberalization Policy of 1991 have put much pressure on the Churia Range, as it was found as a substitute for the Deccan Plateau located in the distant South, in Madhya Pradesh of India, for boulder and sandstone. Both the local people and politicians are lured by high prices of forests in the Indian market, and the extraction of forest resources, including gravel, and using crushers on the site continue (Dixit 2014). This occurs despite the negative consequences of such activities, including worsening of the Churia ecosystems and services to the Tarai-Madhesh region. In order to restore Churia’s ecosystems, a new approach is essential.

### Table 8.8c Land use and cover changes in Tarai-Madhesh (outside the protected area): 1980–2010

| Land use/cover class | 1980          | 1990          | 2000          | 2010          | 1980 and 1990 | 1990 and 2000 | 2000 and 2010 |
|----------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Forest               | 332100.87     | 313093.98     | 301986.00     | 286613.10     | 0.001498      | 0.354781      | 0.509060      |
| Shrubland            | 10002.36      | 10478.70      | 9005.04       | 20413.53      | +0.047622     | 1.406338      | +12.669005    |
| Grassland            | 7503.52       | 8072.73       | 9167.22       | 7881.84       | +0.075859     | +1.355786     | +1.402148     |
| Agriculture          | 1349103.55    | 1350710.46    | 1364757.03    | 1339938.00    | +0.001191     | +0.103993     | 0.181856      |
| Bareland             | 89305.33      | 89851.32      | 78009.12      | 111631.77     | +0.006113     | 1.317977      | +3.100092     |
| Settlement           | 2122.22       | 18305.91      | 18692.91      | 18297.99      | +7.625830     | 0.211407      | 0.211267      |
| Water bodies         | 17967.38      | 17684.91      | 21363.84      | 22268.16      | 0.015721      | +2.080265     | +0.423294     |
| Total                | 1808105.20    | 1808198.00    | 1802981.20    | 1807044.40    |               |               |               |

### Table 8.9 Indicators of land use changes inside and outside the protected area in Churia and Tarai-Madhesh regions

| Land use/cover       | Summary of land use changes |
|----------------------|----------------------------|
|                      | Inside protected areas     | Churia outside protected areas | Tarai outside protected areas |
|                      | 1980–1990 | 1990–2000 | 2000–2010 | 1980–1990 | 1990–2000 | 2000–2010 |
| Forest               | NC        | SD        | SD        | SD        | D         | D         | D         |
| Shrubland            | SD        | I         | D         | D         | I         | I         | I         |
| Grassland            | NC        | SD        | D         | D         | I         | I         | I         |
| Agriculture          | SD        | I         | SI        | I         | I         | I         | D         |
| Bareland             | NC        | D         | I         | D         | I         | D         | I         |
| Settlement           | SI        | SD        | SD        | I         | I         | I         | D         |
| Water bodies         | SD        | D         | I         | D         | I         | D         | I         |

Indicators: NC no change, SD slight decrease, D decrease, SI slight increase, I increase


8.9 Ecosystem Services (ES) Concepts for Downstream Communities

A large body of literature discusses various aspects of ecosystem services (ES) for downstream communities. Some consider biodiversity conservation as very important for downstream ES, whereas others consider global climate change mitigation, timber production, soil, and water contents, and water recharge for ES (Gassmand et al. 2007; Kumar 2010; Stankey et al. 2005). In Australia, Canada, Europe, Southeast Asia, South Africa, and the United States, many sustainable ES models have been in operation (Stankey et al. 2005). A historical antecedent revealed that Marsh (1874) discussed the importance of ecosystem management in the nineteenth century when the earth was sparsely populated. Later, Leopold (1949/1989), Carson (1962/2011), Krutilla and Fisher (1975), and Westman (1977) also highlighted the importance of the ecosystem sustainability for humans’ well-being. Ehrlich and Ehrlich (1981) specifically conceptualized various aspects of ES. Later work by Hueting (1980), Ehrlich and Mooney (1983), De Groot (1987), Odum (1989), Folke et al. (1991), Costanza et al. (1997), Daily (1997), and Folke et al. (2004) also related ES with various economic and environmental activities. Lawton (1997), Danovaro et al. (2008), Losey and Vaughan (2006), and Schneiders et al. (2012) discussed the biodiversity aspect of ES, while Egoh et al. (2011) discussed the effect of grassland management on ES to downstream communities. Cong et al. (2014) and Egoh et al. (2008) discussed the importance of sustainable agricultural management in the upstream to provide ES on the downstream communities. These accounts revealed that ES cannot be regulated merely by managing one component and treating ES as a standalone issue (e.g., providing a blanket prescription; “one size fits all”). Instead,
ES can be sustained with an integrated approach by evaluating economic trade-offs for various service providing units (SPUs). A SPU is the upslope area that contributes water flow to a common outlet as concentrated drainage. It can be part of a larger watershed and can also contain smaller watersheds, called sub-SPUs. SPUs and sub-SPUs have boundaries between them (Fig. 8.8). Within these SPUs and sub-SPUs, one or several ecosystem services can be developed to provide services to downstream communities to form three pillars—sustainable economic development, social development, and environmental protection.

Some areas, such as the Bhabar zone (between the Tarai and Churia), which is one of the largest ground reservoirs in the world, would serve as the main water recharge to the Indo-Gangetic Plains. Biodiversity hotspots such as Koshi, Bara-Parsa, Chitwan, Bardiya, and Shuklaphanta (Fig. 8.7) would serve recreational and environmental services through biodiversity conservation. Other areas would provide ES through the management of commercial timber species such as *Shorea robusta*, *Terminalia species*, and others, while also storing a huge amount of carbon stock.

Since resources in the Churia Range of Nepal are depleted at a rapid rate and many resource development program initiatives have failed, we propose the prioritization of watershed management based on their current conditions. This prioritization will be done based on biodiversity hotspots, soil types (Fig. 8.10), drainage density, surface water, groundwater, irrigation prospects, forest cover and land use, land cover conditions, and population prospects.

![Fig. 8.10 Major soil types found in Nepal (different types of soils are grouped together for mapping)](image-url)
8.9.1 Methodological Approach

Churia geology is very fragile. According to the World Wildlife Fund (WWF 2013), the Churia watershed needs to be categorized under very sensitive, sensitive, and less sensitive zones, with clear demarcation for respective land uses. The past approaches of considering Churia a standalone region did not provide an effective solution. The upstream communities, comprise of about 3.6 million people (0.8 million households), and the downstream communities comprise of about 14 million people (1.6 million households of 13,080 villages) and include 36 of the 75 districts of Nepal. These two regions—the Churia and Tarai-Madhesh—need to be linked with respective ecosystem services generated by individual service providing units (SPUs) and subunits (sub_SPUs).

Analyzing ecosystem services (ES) has become very complex for Churia and Tarai–Madhesh because of the recent developments of road networks and unplanned settlements in Churia. Evaluating ES for Churia based on the five river basins (Chap. 5), which were created for ecological and economic integration among mountains, hills, and Tarai regions in the past, failed to address the location-specific needs for upstream and downstream communities. Thus, in order to identify ES needs for downstream communities, we propose, in this section, the delineation of the entire Churia Range into 91 main SPUs varying in size from 17 to 2313 square kilometers (4.24–893 square miles) and 25 sub-SPUs (ranging from 0.1 to 16.99 square kilometers). This will help to evaluate the types of ES from each SPU and sub-SPU from the perspectives of biodiversity, timber production, global climate change mitigation, and water recharge and also to develop a market-based instrument to make each community and household responsible in each SPU and sub-SPU to sustain ecosystem services. In order to do so, it is essential first to prioritize the management strategies by analyzing the land use and cover scenarios from 1980 to 2010 for Churia, Tarai-Madhesh, and protected areas (Fig. 8.9).

8.9.2 Land Use and Cover Scenarios in Churia and Tarai-Madhesh: 1980–2010

An analysis of the land use and cover (LUCC) scenarios from 1980–2010 suggests that there have been more rapid changes outside the protected areas compared to the inside. Thus, the LUCC analysis from 1980–2010 is done for Churia, Tarai-Madhesh, and protected areas separately and is presented in Tables 8.8a and 8.8b.

Accounts presented in Tables 8.8a, 8.8b and 8.8c reveal that there is not much change in land use and cover inside the protected areas; however, there are changes in the Churia and Tarai-Madhesh regions. Recent changes are drastic in some land use classes. Table 8.9 presents the overall land use and cover scenarios for protected, Churia, and Tarai-Madhesh areas from 1980 to 2010.
Table 8.9 does not show any clear trends in land use and land cover scenarios for the Churia and Tarai-Madhesh regions. Since we did not see clear trends in land use and land cover changes by land use and cover classes, we analyzed the effects of soils by slope classes on land use and cover inside the protected areas (Table 8.10).

The soil types found in the study regions are identified as Dystrochrepts, Eutrochrepts, Argiudolls, Haplaquents, Haplaquepts, Psammaquents, Ustorthents, Udipsamments, Rhodustalfs, Haplustalfs, Hapludalfs, and Haplustalfs-Calcarious materials. Since the soil types are taken from the LRMP (1986) 1:50,000 maps, we observed that a combination of different types of soils occur at each location. This combination of different soil classes has made the analysis very complicated.27

The Fig. 8.10 shows how different soil types are grouped together as mapping units, which makes it harder to see the effects of soils on land use and cover. Unfortunately, it is hard for Nepal to find clear soil descriptions. When they are grouped together, many soils appear like entisols, which have the suffix “-ent,” indicating they are young soils that have not developed much. They are generally found on sand dunes, in floodplains, or other geomorphically active areas such as Churia along the riverbeds.

There is no doubt that soil quality and types impact vegetation growth, land use, and land cover types, which eventually impact biodiversity, timber production, and carbon sequestration. Soils with high textures have high erodibility indices when they are found in open areas and on slope landscapes. Good vegetation cover often acts as a protective shield from heavy rainfall and protects the soil from erosion. Table 8.11 presents areas under different soils and slope classes in Churia/Tarai-Madhesh. Table 8.12 presents areas under various land use and cover classes by slope for protected areas, the Churia, and Tarai-Madhesh regions. Tables 8.11 and 8.12 together help to understand what types of land use classes are found in various soil types under the different slope classes.

Table 8.13 shows that only 11% of forest cover is present for very steep slope (over 45°) areas and 30.45% of cover for steep slope (10.1–20°) areas. These slope areas are very prone to soil erosions and land degradation. Table 8.13 presents data on the major forest types of Churia and Table 8.13 presents forests by slope classes.

27Haplaquent is a young type of soil with minimal development in a wet environment, and it is mostly found on riverbeds, perhaps the floodplains. Haplaquept soils have a bit more horizonation, indicating that they are a bit older floodplains. These types of soils are found along the agricultural terraces in the Churia and Bhabar range and in the Inner Tarai valleys (Fig. 8.11). Udipsamment soil types are young with a lot of sand, which are generally found in areas with more total precipitation than evapotranspiration from the soil. Ustipsamment is similar to Udipsamment types of soil but are found in a climates with less total precipitation or perhaps with a more profound dry season (often associated with semiarid conditions) in the western part of Nepal. Argiudoll soils are generally found in “A” horizon in a humid climate with a bit of clay translocation (often associated with tall grass), and they can act as good sinks for carbon. Haplustalfs soil types are found in forested areas, generally with an “E” horizon below the “A” and occur in dry (arid) climates with simple horizonation. Psammaquents soil types are young, wet, and sandy, generally found near cultivated irrigated lands.
| Soil types                                      | Nearly level (0°) | Gently sloping (undulating) (0–1°) | Strongly sloping (rolling) (1.1–4°) | Moderately steep (hilly) (4.1–10°) | Steep (10.1–20°) | Very steep (Over 45°) | Soil code |
|------------------------------------------------|-------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------|-----------------------|-----------|
| **Protected areas**                             |                   |                                     |                                     |                                     |                   |                       |           |
| Dystrochrepts, Eutrochrepts, Argiudolls         | 55.08             | 3455.28                             | 25471.26                            | 18872.10                            | 2560.59           | 119.52                | 06        |
| Haplaquents, Haplaepts, Eutrocrepts              | 126.18            | 7838.73                             | 41714.73                            | 13616.37                            | 430.92            | 5.04                  | 01        |
| Haplaquents, Psammaquents, Ustorthents           | 76.05             | 4669.74                             | 27687.6                             | 9169.11                             | 227.16            | 0.36                  | 03        |
| Udorthents, Ustorthents, Haplaquents             | 174.6             | 10924.11                            | 80361.45                            | 49677.57                            | 8654.85           | 926.1                 | 04        |
| Udipsamments, Dystrochrepts, Rhodustals          | 72.45             | 3693.33                             | 37914.84                            | 88738.92                            | 94726.98          | 30832.83              | 07        |
| Udorthents, Ustorthents, Haplaquents             | 59.22             | 3729.87                             | 26608.32                            | 17459.46                            | 3915.00           | 410.76                | 05        |
| **Total area (percent)**                         | 563.58 (0.092)    | 34311.06 (5.58)                     | 239758.2 (38.99)                    | 197533.53 (32.12)                   | 110515.5 (17.97)  | 32294.61 (5.25)       |           |
| **Churia Range**                                |                   |                                     |                                     |                                     |                   |                       |           |
| Dystrochrepts, Eutochrepts, Argiudolls          | 201.51            | 12652.20                            | 83726.73                            | 49367.43                            | 9052.47           | 999.36                | 06        |
| Dystrochrepts, Haplustals, Rhodustals            | 2.34              | 157.59                              | 1723.86                             | 5504.67                             | 9268.65           | 3448.53               | 08        |
| Dystrochrepts, Hapludalfs, Haplustals-Calcicous materials | 1.35 | 117.81                              | 1347.93                             | 4027.14                             | 8452.71           | 5974.20               | 09        |
| Haplaquents, Haplaepts, Eutrocrepts              | 0.18              | 29.34                               | 194.40                              | 91.26                               | 3.87              | 0                     | 01        |
|                | Total area (percent) | 625.86 (0.047) | 38607.03 (2.926) | 144,334 (10.939) | 460027.6 (34.868) | 491988.6 (37.291) | 183742.10 (13.927) |
|----------------|---------------------|----------------|------------------|------------------|------------------|------------------|-------------------|
| Haplaquents, Haplaquents, Psammaquents, Ustorthents | 0 | 0.36 | 0.36 | 0 | 0 | 0 | 03 |
| Rhodustalfs, Dystrochrepts, Haplustalfs | 0.18 | 14.40 | 183.78 | 802.26 | 2788.56 | 2673.63 | 10 |
| Udipsamments, Dystrochrepts, Rhodustalfs | 334.53 | 20465.46 | 17959.72 | 368611.74 | 449919.90 | 168606.99 | 07 |
| Udorthents, Ustorthents, Haplaquents | 85.77 | 5169.87 | 39197.25 | 31623.12 | 12502.44 | 2039.40 | 04 |

**Tarai-Madhesh region**

|                | Total area (percent) | 625.86 (0.047) | 38607.03 (2.926) | 144,334 (10.939) | 460027.6 (34.868) | 491988.6 (37.291) | 183742.10 (13.927) |
|----------------|---------------------|----------------|------------------|------------------|------------------|------------------|-------------------|
| Haplaquents, Haplaquents, Eutrocrepts | 2245.68 | 138605.31 | 721841.31 | 1735887.36 | 3665.79 | 105.84 | 01 |
| Haplaquents, Eutrocrepts, Haplaquents–calcareous materials | 210.6 | 12935.88 | 56675.34 | 8153.55 | 110.70 | 0.36 | 02 |
| Haplaquents, Psammaquents, Ustorthents | 301.05 | 18087.66 | 81419.85 | 14817.69 | 218.16 | 1.17 | 03 |
| Udipsamments, Dystrochrepts, Rhodustalfs | 32.22 | 2050.47 | 14741.28 | 9028.35 | 1557.36 | 175.41 | 07 |
| Udorthents, Ustorthents, Haplaquents | 889.83 | 56217.78 | 344023.65 | 136861.02 | 6984.73 | 337.77 | 04 |
| **Total area (percent)** | 3679.38 (0.109) | 227897.10 (6.766) | 1218701.40 (36.182) | 1904748.00 (56.551) | 12536.74 (0.372) | 620.55 (0.018) | 17 (0.001) |
It is very difficult to relate soil types, forest cover, and slope classes because various soil groups are lumped into one class (Fig. 8.10). Different types of soils have different erodibility indices, but in this manuscript a generalization is done for different soil types, which will make the soil erodibility model less accurate. Nonetheless, the above information is taken to prioritize the management of criteria for various service providing units in the Churia and Tarai-Madhesh regions.

### 8.9.3 Prioritizing the Management of Service Providing Units

Data presented in Tables 8.11, 8.12 and 8.13 indicate that in the steep slope areas, the percentages of forest coverage is low. These steep slope areas are prone to soil erosion in the absence of vegetation cover. Within the study areas, there are three hydropower plants,\(^\text{28}\) and these hydropower plants need well-managed catchment areas to sustain their estimated life and produce electricity as targeted. Utilizing the available information, we prioritized the watershed areas of Churia and Tarai-Madhesh for their management (Fig. 8.11) based on the following criteria.

**Business as Usual (BAU)**

We suggest the BAU approach for the protected and steep and very steep slope areas. Under a BAU scenario, the assumptions are that deforestation, forest degradation, and reforestation/afforestation would occur at a slower pace because (a) core protected areas are strictly guarded by Nepal military and people have fewer or no accesses to these areas, but people will have access to buffer zones in and around the protected areas and they are required to using such areas with proper care; and (b) steep slope areas are far away from human settlements and people rarely disturb these areas. Thus, the management of protected areas and forest areas located in steep slope will be under BAU.

Though people have less access to protected areas and steep slopes, they expect incentives from the Reducing Emissions from Deforestation and Forest Degradation (REDD+) (FAO et al. 2008). It is hoped that through the REDD+ program, Churia communities will get financial assistance from developed countries (core areas) to improve ecosystem services for the downstream communities. This will be a win-win situation for both Churia and Tarai-Madhesh communities. As suggested by Busch et al. (2009) and Gutman and Aguilar-Amuchastegui (2012), while

\(^{28}\)Tinau hydropower station (27.716667° N and 83.458333° E) and Gandak hyrdodam (27.4225° N and 83.785556° E); both have been operating since 1997; Kulekhani Third Hydro Project (27.458333° N and 85.025° E) has been operating since 2005; Mai (26.789167° N and 87.866667° E) has been operating since 2011; Mai Cascade (26.761944° N and 87.867222° E) has been operating since 2013; and they are still in service. Except for the Gandak Hydropower station, all other hydropower stations are located in the Churia region.
| Land use classes | Land use in hectares by slope classes |
|------------------|-------------------------------------|
|                  | Nearly level (0°) | Gently sloping (undulating) (0–1°) | Strongly sloping (rolling) (1.1–4°) | Moderately steep (hilly) (4.1–10°) | Steep (10.1–20°) | Very steep (>45°) |
| Forest           | 732.51 (0.43)    | 47412.09 (2.77)               | 409928.49 (23.96)                     | 542924.55 (31.74)                   | 520797.06 (30.45) | 188590.95 (11.03) |
| Shrubland        | 53.19 (0.16)     | 3182.94 (9.65)                | 18399.15 (55.79)                      | 7048.53 (21.37)                     | 2679.3 (8.12)     | 1617.57 (4.91)    |
| Grassland        | 32.67 (0.12)     | 2183.13 (7.88)                | 14515.38 (52.38)                      | 7698.33 (27.78)                     | 1798.92 (6.49)    | 1482.48 (5.35)    |
| Agriculture      | 3547.98 (0.19)   | 219639.24 (11.71)             | 1168838.37 (62.29)                    | 381023.19 (20.31)                   | 80020.08 (4.26)   | 23202.9 (1.24)    |
| Bareland         | 326.16 (0.18)    | 19575.63 (10.86)              | 107006.49 (59.34)                     | 45050.49 (24.98)                    | 7128.72 (3.95)    | 1233.54 (0.68)    |
| Settlement       | 60.03 (0.23)     | 3776.31 (14.27)               | 18105.12 (68.41)                      | 4362.30 (16.48)                     | 149.76 (0.56)     | 10.53 (0.04)      |
| Water bodies     | 123.03 (0.23)    | 5329.71 (9.99)                | 29938.32 (56.16)                      | 14975.55 (28.09)                    | 2416.59 (4.53)    | 529.74 (0.99)     |
| Total area       | 4876.57 (0.125)  | 301101.05 (7.705)             | 1766734.32 (45.214)                   | 1003086.94 (25.671)                 | 614995.43 (15.739) | 216673.71 (5.545) |
Table 8.12  Major forest types in Churia

| Forest types     | Elevation range (m) | Slope in ° (percent) | Description                  |
|------------------|---------------------|----------------------|------------------------------|
| SK/KS            | 256–627             | 4.7 (6.99)           | Relatively flat surface      |
| Sal forest       | 172–1016            | 13 (23.1)            | Lower and flatter land       |
| THM              | 144–1221            | 16 (28.7)            | Moderate slope area          |
| Chir pine        | 1380–1574           | 21 (38.4)            | Slope to steep slopes        |
| LMH              | 221–1640            | 22 (40.4)            | Average slope                |

*THM* Tarai Hardwood Mixed forest, *LHM* Low Mixed Hardwood forests, *SK/KS* Sissoo-Khair/Khair-Sissoo forests. Source: FRA (2014)

Table 8.13  Churia forests by slope classes

| Slope (percent) | Slope (degree) | Area (hectares) | Percentage |
|-----------------|----------------|-----------------|------------|
| Below 15        | 8.5            | 387,170         | 28.18      |
| 15–35           | 8.5–19.0       | 357,502         | 26.02      |
| 35–60           | 19.0–31.0      | 431,257         | 31.39      |
| 60–100          | 31.0–45.0      | 184,896         | 13.46      |
| Above 100       | >45.0          | 12,917          | 0.94       |
| Total           |                | 1,373,743       | 100.00     |

Source: FRA (2014)

Fig. 8.11  Climate mitigation scenario by conserving forests
benefitting from REDD+ within Nepal and getting help externally, some reference levels have to be setup. A reference level is perceived differently by different communities. In terms of climate mitigation through REDD+ (green business), a reference level indicates a baseline to conserve forest resources with plentiful biodiversity, in order to qualify for financial incentives from developed countries. Available records revealed that Churia forests have stored 160.5 teragram (tg) (1 tg = 1012 grams) of atmospheric carbon. Accordingly, 116.9 tons (t) ha\(^{-1}\) (hectare) of carbon is stored, of which 84.73 t ha\(^{-1}\) is stored in timber, 0.31 t ha\(^{-1}\) in litter, and 31.9 t ha\(^{-1}\) in soils within various service providing units (SPUs) that can be traded at the rate of $0.55 to $3.70 per ton. The Government of Nepal has signed an Emission Reduction Purchase Agreement (ERPA) with the World Bank (WB) in 2006 (Gyawali 2012) and the Churia communities qualify for that.

**Setting a Reference Level for Global Climate Mitigation**

A reference level will be set based on two criteria: (a) the rate of forest cover change in terms of percentage for the period of 1980–2010 (Tables 8.8a, 8.8b and 8.8c) and (b) associated forest biomass information. Both are necessary to determine an emission profile. The rate of deforestation should not exceed the set level, for example, 0.25%.

**Timber Production Model**

Forested areas located below 20\(^{\circ}\) slopes are categorized under the timber production zone and a computer model is prepared for this area to examine timber production. Timber volume is estimated using the biomass models used by the Ministry of Forest and Soil Conservation of the Government of Nepal. Since Churia, Tarai–Madhesh, and the Bhabar regions are the main areas where commercial tropical timbers are found (Sharma et al. 2005), the model prepared by MoFSC is aimed for these areas.

---

29 In 1992, at the Rio Earth Summit, UN Framework Convention on Climate Change (UNFCCC), it was discussed that as per Articles 3.3 and 3.4 of the Kyoto Protocol (KP), more developed countries (MDCs) would help developing countries (DC) to implement clean development mechanisms (CDM) because vegetation pools worldwide contain approximately 61% of the atmospheric carbon. Nepal could capitalize forest carbon stocks under the REDD+ program.

30 Forest biomass information will be based on the findings from the Forest Resource Assessment of 2014.

31 The “Bhabar” zone is an area contiguous with the Tarai region. It has good hardwood forest coverage. This zone also serves as the main water recharge area for the Tarai region. Forests in the Bhabar zone need proper conservation to protect the levels of groundwater. Since the Bhabar is located in the tropical region of Nepal, forest cover helps in retaining ground moisture from intense solar radiation. Though the high rate of evapotranspiration from the broad-leaved trees might lose an excessive amount of water, trees’ shading helps to balance such losses.
Biodiversity Model

Biodiversity refers to the number of relative abundance of diverse genes within an ecosystem that performs various activities as part of the ecosystem services (Wall and Nielsen 2012). Until the early 1980s, the Churia Range used to be very rich in biodiversity, especially, in hardwood species. It has provided ecosystem services to the downstream communities in the form of soil conservation, water recharge, and various forest products. It was an area where dense Tarai Hardwood Mixed (THM), Sal forest, Low Mixed Hardwood forest (LHM), Sissoo-Khair/Khair-Sissoo forest (SK/KS), and chir pine (Pinus species) used to occur. THM forest mainly comprises of Shorea, Terminalia, Acacia, Dalbergia, and Bombax species. LHM forests used to be rich in both tree and herb species and have high percentages of organic carbon. Major species in LHM forest are Terminalia species, Desmodium oojensis, and Schima wallichii. The quality of Churia forests has been degraded recently; however, according to the Forest Resource Assessment (FRA 2014), on average, each hectare of forested land is stocked with 732 trees in a well-stocked forest, 182 stand on other woodlots, and 66 stand on degraded (other) lands. The rich biodiversity of trees and shrubs (Figs. 8.12, 8.13a and 8.13b) conserve the maximum amount of atmospheric carbon and timber stands (Tables 8.14, 8.15, 8.16 and 8.17) as the complementary services (Luck et al. 2009).

The high biodiversity hotspots of the Churia and Tarai-Madhesh regions are Shuklaphanta, Bardia-Banke, Chitwan National Parks, Parsa and Koshi-Tappu wildlife reserve. The Koshi-Tappu Wildlife Reserve is located in the Tarai-Madhesh region, while Parsa and other protected areas extend to both the Churia and Tarai-Madhesh regions. Public accesses to these protected areas are limited. Since the 1990s, the Government of Nepal has introduced the provision for buffer zones in and around the protected areas. These buffer zones have been helpful in regulating biodiversity services while complimenting forestry service needs to the general public living nearby the protected areas. These protected areas in addition to

Fig. 8.12 Priority areas for the management of Churia/Tarai-Madhesh. Protected and sensitive areas will be managed as “Business as usual” (BAU). Steep areas are sensitive to soil erosion as river flows bring sedimentation. These areas need high priority for management.
Fig. 8.13a High-carbon-sequestering tree species are dominant in Churia. (Adapted from FRA 2014)

Fig. 8.13b High-carbon-sequestering shrub species are dominant in Churia. (Adapted from FRA 2014)
### Table 8.14  Number of stems/ha in Churia forests by species and DBH class

| SN | Scientific name          | DBH class (cm) | Total  |
|----|--------------------------|----------------|--------|
|    |                          | 5–10  | 10.1–20 | 20.1–50 | ≥ 50 |        |
| 1  | *Shorea robusta*          | 108.02 | 62.00   | 43.50   | 9.03  | 222.55  |
| 2  | *Terminalia alata*        | 26.69  | 11.47   | 10.90   | 3.61  | 52.68   |
| 3  | *Lagerstroemia parviflora*| 19.60  | 11.32   | 4.45    | 0.10  | 35.48   |
| 4  | *Anogeissus latifolia*    | 17.93  | 9.59    | 6.40    | 0.21  | 34.13   |
| 5  | *Buchanania latifolia*    | 11.68  | 9.49    | 3.40    | 0.00  | 24.57   |
| 6  | *Desmodium ooejense*      | 6.67   | 5.73    | 2.74    | 0.03  | 15.18   |
| 7  | *Syzygium cumini*         | 5.00   | 3.44    | 3.37    | 0.22  | 12.03   |
| 8  | *Pinus roxburghii*        | 3.75   | 4.38    | 2.20    | 0.54  | 10.87   |
| 9  | *Schima wallichii*        | 2.92   | 3.13    | 1.70    | 0.20  | 7.95    |
| 10 | *Adina cordifolia*        | 1.25   | 1.77    | 1.31    | 0.38  | 4.72    |
| 11 | Other species             | 185.46 | 93.45   | 30.59   | 1.80  | 311.30  |
| **Total** |                | **388.99** | **215.78** | **110.55** | **16.12** | **731.45** |

Source: FRA (2014)

### Table 8.15  Characteristics of common tree species (in average per hectare)

| SN | Species (Scientific name) | Number of stems/ha | Weighted DBH (cm) | Weighted height (m) |
|----|---------------------------|-------------------|-------------------|---------------------|
| 1  | *Shorea robusta*          | 222.55            | 43.19             | 20.27               |
| 2  | *Terminalia alata*        | 52.57             | 52.50             | 21.76               |
| 3  | *Pinus roxburghii*        | 10.87             | 43.36             | 23.72               |
| 4  | *Anogeissus latifolia*    | 33.89             | 22.55             | 15.48               |
| 5  | *Lagerstroemia parviflora*| 35.48             | 25.12             | 14.69               |
| 6  | *Adina cordifolia*        | 4.72              | 61.14             | 22.56               |
| 7  | *Buchanania latifolia*    | 24.57             | 21.03             | 11.42               |
| 8  | *Syzygium cumini*         | 12.03             | 33.39             | 14.36               |
| 9  | *Schima wallichii*        | 7.95              | 39.32             | 18.42               |
| 10 | *Desmodium ooejense*      | 15.19             | 25.09             | 12.23               |
| 11 | Other species             | 311.63            | –                 | –                   |
| **Total** |                          | **731.45**      |                   |                     |

Source: FRA (2014)
providing shelter to wildlife sink huge amounts of atmospheric carbon along with the conservation of soil and water.

All the protected areas are good habitats for various wildlife species. Wildlife has the greatest functional importance in the Churia and Tarai-Madhesh ecosystems; however, it is difficult to measure economic values of various species except for income by tourism. In order to capture the ecosystem services of wild animals (e.g., tigers), the evaluation of ecological production functions that defines the relationship among various trophic levels is required. For example, the tiger helps in regulating deer and other wild animal populations, which otherwise would require hunting and culling regulations. Evaluating the ecological production

Table 8.16  Basal area of various species by diameter classes

| SN | Scientific name          | DBH class (cm) and Basal are (m³/ha) | Total |
|----|--------------------------|--------------------------------------|-------|
|    |                          | 5–10 | 10.1–20 | 20.1–50 | ≥ 50 |       |
| 1  | Shorea robusta           | 2.04 | 6.29    | 34.66   | 31.91 | 74.91 |
| 2  | Terminalia alata         | 0.38 | 1.09    | 8.59    | 12.96 | 23.02 |
| 3  | Pinus roxburghii         | 0.08 | 0.42    | 2.04    | 2.70  | 5.24  |
| 4  | Anogeissus latifolia     | 0.30 | 0.98    | 3.24    | 0.46  | 4.98  |
| 5  | Lagerstroemia parviflora | 0.32 | 1.22    | 2.43    | 0.21  | 4.19  |
| 6  | Adina cordifolia         | 0.01 | 0.13    | 0.83    | 1.65  | 2.61  |
| 7  | Buchanania latifolia     | 0.19 | 0.88    | 1.38    | 0.00  | 2.45  |
| 8  | Syzygium cumini          | 0.06 | 0.28    | 1.46    | 0.52  | 2.32  |
| 9  | Schima wallichii         | 0.05 | 0.26    | 1.04    | 0.78  | 2.13  |
| 10 | Desmodium oojeinense     | 0.11 | 0.48    | 1.21    | 0.06  | 1.86  |
| 11 | Other species            | 2.96 | 7.52    | 14.28   | 5.53  | 30.29 |
| Total|                          | 6.50 | 19.56   | 71.16   | 56.78 | 153.99 |

Source: FRA (2014, Table 1.12)

Table 8.17  Number of stems/hectare in Churia forests by species and site quality class

| SN | Scientific name          | Number of stems/hectare | Total |
|----|--------------------------|-------------------------|-------|
|    |                          | Quality-1 | Quality-2 | Quality-3 |       |
| 1  | Shorea robusta           | 89.79      | 68.54     | 64.21     | 222.54 |
| 2  | Terminalia alata         | 18.37      | 14.60     | 19.71     | 52.68  |
| 3  | Anogeissus latifolia     | 6.50       | 11.26     | 16.37     | 34.13  |
| 4  | Lagerstroemia parviflora | 6.23       | 8.89      | 20.36     | 35.48  |
| 5  | Pinus roxburghii         | 4.80       | 1.98      | 4.08      | 10.86  |
| 6  | Buchanania latifolia     | 4.76       | 10.69     | 9.11      | 24.56  |
| 7  | Schima wallichii         | 1.77       | 2.55      | 3.63      | 7.95   |
| 8  | Syzygium cumini          | 1.33       | 3.32      | 7.39      | 12.04  |
| 9  | Adina cordifolia         | 1.24       | 1.22      | 2.26      | 4.72   |
| 10 | Desmodium oojeinense     | 0.48       | 3.21      | 11.49     | 15.18  |
| 11 | Others                   | 25.07      | 59.5      | 226.73    | 311.30 |
| Total|                          | 160.36     | 185.76    | 385.33    | 731.45 |

Source: FRA (2014)

providing shelter to wildlife sink huge amounts of atmospheric carbon along with the conservation of soil and water.

All the protected areas are good habitats for various wildlife species. Wildlife has the greatest functional importance in the Churia and Tarai-Madhesh ecosystems; however, it is difficult to measure economic values of various species except for income by tourism. In order to capture the ecosystem services of wild animals (e.g., tigers), the evaluation of ecological production functions that defines the relationship among various trophic levels is required. For example, the tiger helps in regulating deer and other wild animal populations, which otherwise would require hunting and culling regulations. Evaluating the ecological production
functions not only captures the cost of operation but also the biophysical relationships between ecological systems and the services the nature provides. Making an ecosystem functional, for example, retaining the tiger population requires the conservation of dense forests, in turn can help with carbon sequestration, predation, and nutrient recycling. Some of the components are within human control and are possible to put a price tag on them, for example, value of timber, as well as the amount of carbon sequestered by vegetation at different ages that also serve as the niche for wildlife. Economists discuss the social investment in natural capital because the work of ecological restoration through the conservation of species can lead to significant economic savings through soil conservation, minimization of anthropogenic and environmental stresses, and shocks without loss of values (Mallapaty 2016; Kinzig et al. 2001). It also leads to greater numbers and a relative abundance of diverse genes within a service providing unit (SPU) and performs various activities to become part of the ecosystem services (ES) (Wall and Nielsen 2012).

Various researchers have identified wildlife and human conflicts by calculating the ecosystem fragmentation impact score (EFIS). These researchers have used EFIS to determine values of water recharge and carbon trading (FRA 2013; Kumar 2010; Schneider et al. 2012) from various watersheds. Such concepts can be applied to evaluate ecosystem services from each proposed SPU.

The literature reveals that each species makes a unique contribution to ecosystem services. An ecosystem experiences stresses if certain species are removed or extinct; however, none of the literature makes it clear how to measure the economic value of a single species. Ives and Carpenter (2007) and Wohl et al. (2004) discussed how increasing species richness leads to greater ecosystem functioning because of increased nutrient retention and greater stability in terrestrial ecosystems. Hol et al. (2010) analyzed how a loss in biodiversity changes plant-herbivore relationships. A distortion in the plant-herbivore relationship also impacts the functioning of soils (Bardgett and Wardle 2010). This has been evident from the poor regeneration of Shorea robusta in the Churia region because of the loss of soil moisture with the change of species composition. A loss of species means a decrease in positive interactions (Wall and Nielsen 2012) and a decrease in the net primary production of an ecosystem.

One of the methods of measuring the economic value of biodiversity is by calculating the area involved in the biodiversity conservation. A survey of the existing literature suggests that biodiversity loss occurs because of habitat fragmentations. This is represented by the Eq. (8.1):

$$f_i = \left(\frac{n_i}{N}\right) \times 100$$  \hspace{1cm} (8.1)

where,

- $f_i =$ Frequency of species $i$
- $n_i =$ Number of sample plot on which species $i$ occurs
- $N =$ Total number of sub-plots under study
In the Churia Range, several species are interacting and competing for similar resources or they are sharing a similar environment. Likewise, certain species are found in different locations having similar climatic and physiographic conditions. These species provide ecosystem services to the downstream communities, but the requirements of downstream communities vary. Detailed analysis is needed to assess the ecosystem services generated by individual species from each service providing unit (SPU) and sub-SPU. For example, an SPU or sub-SPU can have the Tarai Hardwood Mixed (THM) and Low Mixed Hardwood (LMH) ecosystems, and both THM and LMH have a total of 22 species, of which 10 species are found in THM, plus 12 more species are found in LMH, but not in THM, the SPU, or sub-SPU will provide combined services from all species to the downstream communities. However, it is very difficult to convert biodiversity into monetary terms, but the frequency index \((f_j)\) in Eq. (8.1) suggests how effective the ecosystem service could be to the downstream community. The higher the biodiversity index is, the higher the quality of ecosystem services will be. Many ongoing developmental activities are impacting the ecological services of Churia for Tarai–Madhesh, and calculating such indices will help to understand the nature of ecosystem services.

**Measuring the Impact of Development on Ecosystem Services**

Several developmental activities are ongoing in the Churia and Tarai-Madhesh regions that are mostly fragmenting ecosystems and escalating human wildlife conflicts. Equation (8.2) calculates the ecosystem loss impact score from developmental activities.

\[
\sum_{i=1}^{n} l_i = \sum (A_j R_j)
\]

where

- \(\sum l_i = \) Ecosystem loss impact score of alternative \(j\)
- \(A_j = \) predicted area loss for ecosystem type \(j\)
- \(R_j = \) assessed rarity value\(^{32}\) of ecosystem type \(j\) (Leroy et al. 2013)
- \(n = \) number of ecosystem types

Equation (8.3) calculates the ecosystem loss impact score for areas that are away from the core area and are close to roads or other development activities.

\[
\text{Core area} = S - (P \times 100)
\]

\(^{32}\)The rarity cutoff point is the weight assignation depending on the chosen rarity cutoff point. The rarity weighting function varies with species and it increases exponentially below the rarity cutoff point. Conversely, above the rarity cutoff point, the weight decreases and even reaches 0.
Any area located 100 m away from the core area will be affected by external factors as given by Eq. (8.4).

\[
\sum_{i=1}^{n} f_t = \sum (VI_j S_j R_j)
\]  

\(\sum f_t\)=ecosystem fragmentation impact score of alternative \(i\).
\(VI_j\)=assess loss in viability of ecosystem patch.
\(S_j\)= area of ecosystem patch \(j\).
\(R_j\)= rarity value of ecosystem patch \(j\).

The actual value estimated from the equation “8.4” could become subjective and is difficult to quantify with a definite value. Generally, biodiversity remains higher in an undisturbed area, which is considered the core area. In Churia and Tarai-Madhesh region (mainly the protected areas), core areas are becoming very rare due to various developmental activities that have resulted in human-wildlife conflicts. After experiencing several human-wildlife conflicts, the Government of Nepal has proposed buffer zones in and around national parks and wildlife reserves. These areas also have human settlements in and around them. There are continuous clashes between human and wildlife. In 2014 alone, over 17 people were killed, and over 50 people injured by wild animals (DNWLC 2014). Though the Ministry of Forest and Soil Conservation (MoFSC) has eased the process of receiving compensation for death or injury by wild animals in the buffer zone areas, the amount of monetary compensation that is received within 7 days of the application is very small. As a result, a rare synergy between wildlife and human beings has promoted the poaching of even endangered species. Minimizing these conflicts will not only help in promoting biodiversity but also in the mitigation of global climate through the process of carbon sequestration, which then will result into “act locally and serve globally.”

Soil Conservation Prospect

The Churia region is prone to soil erosion. Using the universal soil loss equation, a computer-based model is developed focusing on the variables applicable for the Churia and Tarai-Madhesh regions. It is hoped that this model will be applicable for all the watersheds including the protected areas, with needed modifications.

The Churia Range is facing serious soil erosion problems and a degradation of water catchment areas. It has also become one of the factors leading to the reduction

---

33Community forestry user groups (CFUGs) active in Churia have expressed apprehension that the government is likely trying to bring Churia under the national park or reserve category and create buffers around these areas.

34The government provides compensations (depending upon the situation) for each family if [a] family member/s is/are killed or injured by wild animals.
of agricultural productivity in the Tarai region. Rivers and rivulets crossing through the Churia become “sorrow” for the Tarai region during the monsoon season. Over 75% of the Churia falls under the category of severe erosion-prone area (Fig. 8.12). The universal soil loss equation (USLE) will be used to determine average annual soil loss. The USLE predicts soil loss for a given site as a product of six major erosion factors, whose values at a particular location can be expressed numerically. USLE is suitable for predicting long-term averages and the soil erosion is estimated as follows:

\[ A = R \times K \times L \times S \times C \times P \]

where

- \( A \) is the average annual soil loss rate in tons per hectare per year (t ha\(^{-1}\) year\(^{-1}\)).
- \( R \) is rainfall erosivity factor (MJ-mm ha\(^{-1}\) year\(^{-1}\)).
- \( K \) is soil erodibility factor (t ha\(^{-1}\)/MJ/mm).
- \( L S \) is topographic factor.
- \( C \) is crop management factor.
- \( P \) is conservation supporting practice factor.

### 8.10 Model Components

The authors have developed executable soil conservation, timber production, and carbon sequestration models. These models will be available in the near future. Users can use it to evaluate the significance of any ecosystem services.

#### 8.10.1 Timber Volume and Carbon Sequestration Model

Timber Volume and Income from the Timber

1. A tree’s circumference (C) is measured in inches or meters at the breast height (BH).

---

35 **Board foot (BF):** a piece of wood 1 foot by 1 foot by one inch; **Cubic foot (sq.ft.):** a piece of wood 1one foot by 1 foot; **DBH,** tree diameter at breast height considered to be 4.5 feet from the ground; **Circumference (C),** length around a circle; **Diameter (D),** measure of a straight line segment that passes through the center of a circle; **Radius (r),** one-half the diameter of a circle; **pi (π),** the mathematical constant that is the ratio of the circle’s circumference to its diameter or 3.1416; **area (A),** measurement of a surface; **volume (V),** the amount of three-dimensional space an object occupies.
2. Circumference (C) is divided by pi (\( \pi = 3.14 \)) to convert it into diameter, or a diameter tape (\( C/\pi = DBH \)) is used to calculate diameter at the breast height.

3. Radius of bole is calculated as \( r = (DBH/2) \) and converted into feet by multiplying by 0.08333, i.e., \[ r = (DBH/2) \times 0.08333 \] to convert into feet or by multiplying by 0.0254 to convert into meters.

4. A tree’s bole area is calculated as \( A = \pi r^2 \), either in square feet or square meter.

5. Tree height is measured either in feet or in meters.

6. Volume of a tree is calculated as \[ V = A \times \text{height in cubic feet or cubic meters} \] and multiplied by 0.25 taking into account the tapering factor of a tree bole.

7. Board foot volume of tree is calculated using a multiplication factor of 0.83333 [in cubic feet] or 0.254 [in cubic meters].

(a) **More conservative thought**: Generally, foresters use 0.166 or 0.1433 to remove the bark or dust during the cutting process.

8. **Income from Timber production:**
   
   Enter the cost of timber per cubic feet or cubic meters (Cost): $
   
   (i) **Number of trees**: Cost x Number of trees (\( N_T \))
   
   (ii) **Total income from timber**: $ (\( N_T \times \text{Cost} \))

**Carbon Sequestration and its Income**

9. Calculate the carbon content of a tree.

   (a) Calculate a tree weight (\( W \)) to calculate the carbon contents.

   (i) If the diameter of a tree is <11 inches or 0.2794 m, then
   \[ W_{\text{tree}} = 0.25 \times (DBH)^2 \times H \] [0.25 could differ by species].

   (a) If the diameter of a tree is >11 inches or 0.2794 m, then \[ W_{\text{tree}} = 0.15 \times (DBH)^2 \times H \] [0.15 could differ by species].

10. Since the root portion is 20% of the total tree above biomass, the total of stem biomass and root biomass becomes \( W \times 1.20 = W_{\text{stem}} + W_{\text{root}} \).

11. In average, a tree contains 27.5% of the moisture. The total weight of tree and root biomass is \[ W_{\text{tree}} \times 0.725 = W_{\text{tree}} + W_{\text{root}} \text{ dry} \].

12. Enter the age of a tree: TreeAge.

13. Determine the weight of carbon dioxide sequestered in a tree.

   CO\(_2\) is composed of one molecule of carbon and two molecules of oxygen.
   Atomic weight of Carbon is 12.00115.
   Atomic weight of Oxygen in 15.9994.

---

\(^{36}\)Mokany et al. (2006) suggested using 0.27 for tropical and sub-tropical forests and 0.3 for temperate forests. Further suggestions are that all biomass estimates need to be converted into carbon stock by multiplying by 0.47 as recommended by the IPCC Good Practice Guidelines (2006).
The weight of CO$_2$ is $C + 2 \times O = 12.001115 + 2 \times 15.9994 = 43.999915$.

The ratio of CO$_2$ to C is $\frac{43.999915}{12.001115} = 3.6663$.

Carbon sequestered by a tree = $W_{\text{tree and root dry}} \times 3.6663$.

The amount of carbon stored in tree in its full life: $\text{Carbon}_{\text{total}} = \frac{W_{\text{tree and root dry}} \times 3.6663}{\text{TreeAge}}$.

14. **Total income from the carbon sequestration from a tree is:**

Income from carbon sequestration = $\text{Carbon}_{\text{total}} \times [\text{unit cost of carbon}]$

Income from the whole plot = $\text{Carbon}_{\text{total}} \times [\text{unit cost of carbon}] \times N$, where N is the number years of tree age.

The above model could be expanded for specific cases such as above and below-ground biomass for specific species and cases based on locations as explained in the following paragraphs, if sufficient information is available by following the IPCC Good Practice Guidelines (2006).

### 8.10.2 Litter Biomass Estimation

The biomass of litter and herbs can be calculated from the relationship between total fresh weight in the plots, plot area, and biomass fraction (ratio of the dry to fresh weight).

### 8.10.3 Above-Ground Tree Biomass and Carbon

Nepal-specific biomass tables can be used as reference to estimate the above-ground sapling biomass (AGSB) (1–5 cm DBH). These tables are developed by Tamrakar (2000) to estimate green biomass. Using these tables, green biomass can be converted into dry biomass by multiplying species-wise fractions\(^{37}\) (Bhatt and Tomar 2002; Jain and Singh 1999; Kati and Konwer 2002; Shrestha et al. 2006; Wirersaari 2005). Where the fraction was not available, mean fractions of closely related species can be used (Baker et al. 2004; Ngugi et al. 2011; Pandey et al. 2014a, b). The total above-ground tree biomass can be calculated using the equations (models) developed by Chave et al. (2005).

\(^{37}\) *Quercus spp.* (0.627); *Lyonia ovalifolia* (0.613); *Pinus roxburghii* (0.58); *Alnus nepalensis* (0.57); *Schima wallichii* (0.545); *Albizia lebbeck* (0.537); *Shorea robusta* (0.517); *Terminalia tomentosa* (0.5); *Pinus wallichiana* (0.45)
For moist forest stand,

\[
\text{Above ground total biomass (AGTB)} = 0.0509 \times \rho \times D^2 \times H \tag{8.5}
\]

where

\( \text{AGTB} = \text{above-ground tree biomass (kg)} \)
\( \rho = \text{wood specific gravity (g cm}^{-3} \text{)} \)
\( D = \text{tree diameter at breast height (cm)} \)
\( H = \text{tree height (m)} \)

### 8.10.4 Above-Ground Sapling Biomass and Carbon

Biomass of trees varies in different locations with the variations in age and size of the trees, forest composition, and tree density. Different factors affect an ecosystem carbon pool, including the net primary productivity of plants and biomass decomposition. Net primary productivity differs according to vegetation types, age of the stand, and the surrounding environment. The bulk density (BD) depends on several factors such as compaction, consolidation, and amount of SOC present in the soil. It is also highly correlated to the organic carbon content.

The following regression model can be used to calculate biomass of saplings:

\[
\log (\text{AGSB}) = a + b \log (D) \tag{8.6}
\]

where

\( \log = \text{natural log (dimensionless)} \)
\( \text{AGSB} = \text{above-ground sapling biomass (kg)} \)
\( a = \text{intercept of allometric relationship for saplings (dimensionless)} \)
\( b = \text{slope allometric relationship for saplings (dimensionless)} \)
\( D = \text{over bark diameter (cm) at breast height (measured at 1.3 m above-ground)} \)

### 8.10.5 Leaf Litter, Herb, and Grass (LHG) Biomass

In the case of herbs, grass, and litter, the amount of biomass per unit area can be calculated by using the formula:

\[
\text{LGH} = \frac{W_{\text{field}}}{A} \times \frac{W_{\text{subsample,dry}}}{W_{\text{subsample,wet}}} \times \frac{1}{10000} \tag{8.7}
\]
where

\[ \text{LHG} = \text{biomass of leaf litter, herbs, and grass (t ha}^{-1}) \]

\[ \text{W} \text{field} = \text{weight of the fresh field sample of leaf litter, herbs, and grass, destructively} \]

\[ \text{s} \text{ampled within an area of size A (g)} \]

\[ A = \text{size of the area in which leaf litter, herbs, and grass were collected (ha)} \]

\[ \text{W} \text{subsample, dry} = \text{weight of the oven-dry sub-sample of leaf litter, herbs, and grass in} \]

\[ \text{grams (g); and} \]

\[ \text{W} \text{subsample, wet} = \text{moisture contents (g = grams) determined from the weight of the} \]

\[ \text{fresh sub-sample of leaf litter, herbs, and grass.} \]

The carbon content in biomass (above-ground tree, sapling, leaf litter, herb, and grass) can be calculated by multiplying the respective biomass with the IPCC (2006) default carbon fraction of 0.47.

### 8.10.6 Below-Ground Biomass

The Following Relationship Can Be Used to Estimate the Root Biomass Developed by MacDicken (1997)

\[ \text{Below – ground biomass} = 0.15 \times \text{above – ground biomass} \quad (8.8) \]

The carbon content in below-ground biomass (BB) can be calculated by multiplying BB with the IPCC (2006) default carbon fraction of 0.47.

### 8.10.7 Soil Sampling and Soil Organic Carbon (SOC) Estimation

Soil organic carbon (SOC)\(^{38}\) can be determined using the methods prepared by Pearson et al. (2005).

\[ SOC = \rho \times d \times \% \ C \quad (8.9) \]

where

\[ SOC = \text{soil organic carbon stock per unit area (Mg ha}^{-1}) \]

\(^{38}\)Soil samples are gathered from a 0.56 m radius plot at 30 cm depth. The soil bulk density is gathered using 100 cm\(^3\) soils from three depths (0–10 cm, 10–20 cm, and 20–30 cm) by using a Soil Sampling Corer. These three depths represent organic carbon weighed at a precision of 0.1 g. About 100 g of composite samples were collected from a plot. Bulk density (g cm\(^{-3}\)) denotes soil particles less than 2 mm in diameter, whereas coarse fragments include particles greater than 2 mm in diameter. The density of rock fragments assumed to be 2.65 g cm\(^{-3}\).
\[ \rho = \text{soil bulk density (g cm}^{-3}) \]
\[ d = \text{the total depth where the sample will be taken from (cm)} \]
\[ C = \text{Percentage of carbon (% or carbon concentration}} \]

### 8.11 Total Carbon Stock Density

The carbon stock density of a stratum can be calculated by summing the carbon stock densities of the individual carbon pools of that stratum except carbon in dead wood and stumps using the following formula:

\[
C(LU) = C(AGB) + C(AGSB) + C(BB) + C(LHG) + C(DWS) + SOC
\]

where

- \( C(LU) \) = carbon stock density of a stratum (Mg \( C \) ha\(^{-1}\))
- \( C(AGTB) \) = carbon in above-ground tree biomass (Mg \( C \) ha\(^{-1}\))
- \( C(AGSB) \) = carbon in above-ground sapling biomass (Mg \( C \) ha\(^{-1}\))
- \( C(BB) \) = carbon in below-ground biomass (Mg \( C \) ha\(^{-1}\))
- \( C(LHG) \) = carbon in litter, herb and grass (Mg \( C \) ha\(^{-1}\))
- \( C(DWS) \) = carbon in dead wood and stumps (Mg \( C \) ha\(^{-1}\))
- \( SOC \) = soil organic carbon (Mg \( C \) ha\(^{-1}\))

### 8.12 Conclusion

In this chapter, we discussed the importance of forests in climate mitigation, biodiversity, soil and water conservation, and timber production. Our discussion started with how deforestation, landsliding, and large-scale downstream flooding from the Himalayas created the cause-and-effect drama leading to the Theory of Himalayan Degradation. We discussed how Himalayan Degradation has affected over 350 million people living downstream along the Indo-Gangetic Plain and how their suffering has further accelerated the degradation of the Himalayan ecosystem through the monsoonal cyclical processes. The existing literature reveals that land use, natural resource management, and environmental conditions are directly linked and that negligence in one sector has ramifications in the others. For example, the loss of forest cover leads to soil erosion in the upper catchment. Eroded soil flowing through rivers passing along the steep gradients clogs rivers and canals downstream in the plain areas. As the river currents subside and its bed are filled with debris, unprecedented floods occur, leading to loss of lives properties, and development infrastructures. These environmental problems in turn have effects on the monsoon patterns originating from the Bay of Bengal, as the quality of sea water changes with
zooplanktons which is associated with never-ending spiral effects of Himalayan Degradation. After reviewing theoretical discussions, we looked at the spatial patterns of land use and cover in Nepal by six elevation classes (e.g., below 999.99 m; between 1000–1999.99 m; 2000–2999.99 m; 3000–3999.99 m; and 4000–4450 m; and above 4500 m). Our analyses of classified images from the 1980s, 1990, 2000, and 2010, by elevation classes, revealed that deforestation is increasing in lower elevations, whereas overall forest areas above 2000 meters (above the slope of 15°) are increasing in all seven provinces (Bhattarai et al. 2020). However, such increase at higher elevation is fluctuating, i.e., increasing in some years and decreasing for other years. These fluctuations were associated with natural calamities such as landslides, development activities especially the construction of roads, and river meandering. Areas under agriculture have increased in lower elevations, but agricultural areas are fluctuating at higher elevations, with an overall decrease in cultivated lands due to out-migration of the working-age population (Chap. 2). There has been a massive amount of conversion of forests into agricultural lands and settlements at lower elevations. Many forest areas have been degraded into shrublands and barelands, particularly in lower elevations.

We reviewed the existing literature on the role of forests and their products in mitigating harmful effects of greenhouse gas emissions. Researchers are largely in consensus that vegetation, as a “sink,” absorbs emissions and stores large quantities of carbon for extended periods of time. Well-managed young forests become good “sinks” of carbon, whereas old-growth forests may act as emitters of carbon especially at older ages and when trees decompose. Sustainable forest management is a critical component for climate mitigation, with benefits for subsistence farmers, urban communities, and a large number of business enterprises vis-à-vis the amelioration of the environment.

We reviewed the evolution of forest policy of Nepal and discussed how policy developments have impacted natural resource management. A comprehensive review of available documents clearly suggested that forest policies of Nepal have changed in line with the political systems. The decentralization drive of the late 1970s led to the development of the concept of “community forestry.” Under community forestry, a group-based decision-making process has been institutionalized. Many of the community forests began, and are continuing, to perform better than the government forests. However, this is true only in less accessible areas where the value of forest production remains low. Well-managed forests have contributed to biodiversity conservation, carbon sequestration, timber production, and soil and water conservation, while continuing to meet the forestry needs of local communities. Tropical forests are doing better in carbon sequestration than the forests of subtropical, temperate and alpine zones.

Based on our review of the biodiversity literature, we conclude that rich biodiversity is vital for climate mitigation. We surveyed the land use scenarios inside the protected areas—the national parks, wildlife reserves, and conservation area, which have been very rich in biodiversity—for the past four decades. From our analyses of land use and cover scenarios and from available government records for the protected areas, it revealed that these areas are very rich in biodiversity and there
is minimal or no deforestation in such areas. The buffer zone concepts in and around
the protected areas that have been practiced in Nepal have supported the develop-
ment of synergies between wildlife and human beings living in the vicinities of the
protected areas, which also act as good carbon sinks more so with tropical species.

We analyzed the effect of rivers and roads on land use and cover. Spatial analyses
of rivers and roads passing through various gradients in Nepal revealed that in steep
to very steep slopes, rivers and roads have been the major drivers of deforestation.
We also examined the effects of slope and aspects on land use and cover from 1990
to 2010. There is a loss of forest in the plain and moderately (below 10°) sloped
areas. In areas defined by steep slopes, human activities on land use and cover have
had minimal effects. However, natural erosion and erosion due to development
activities have been common occurrences in steep and very steep slopes. Soil erosion
and landslides have occurred in an unprecedented manner once unregulated bull-
dozer engineering work started after the 1995 in the Hills and Mountainous regions.
Added to that, vibrations of fragile ground from earthquakes have accelerated
landslides and soil erosion, especially, in the higher slope areas above 15° more so
in higher elevation regions of Nepal (Bhattarai et al. 2020). These factors have been
the major drivers of deforestation in slope areas. We also investigated the types of
soil and land use/cover by slope classes, but did not see any specific trends between
soils and vegetation cover by slope classes. It is possible that this inconclusive
finding may be due to the use of the soil information developed from 1:50,000
scale maps prepared by the Land Resource Mapping Project (LRMP 1986). Many
types of soils are lumped into a few soil classes, making it difficult to generalize the
effects of certain types of soils on vegetation covers at varying degrees of slopes.
Field visitations and soil samples testing at various locations are needed in order to
determine the type of relationship that exists between vegetation and soil types.

There is no doubt that forests have tremendous potential to serve as a tool in
combating climate change, protecting livelihoods, and creating a foundation for
more sustainable economic and social development by increasing the net production
of an ecosystem. We reviewed the literature on REDD+’s incentives and the activities
of community forestry user groups. Incentives from REDD+ have benefitted forest-
dependent communities, while these communities have assisted in addressing REDD
+’s national and global interests to reduce carbon emissions by conserving forests.

Having seen the responses of local communities to REDD+’s incentives, we proposed
the concept of “participatory natural resource management” and “ecosystem services.”
We have described how ecosystem services can influence policy and management
decision-making by involving individual households located within each service
providing unit. In the literature, we consistently found that woodlots and vegetated
areas rich in biodiversity provide a wide range of ecosystem services, but these services
vary depending on the location and management of watersheds. Properly identifying,
assessing, valuing natural resources and ecosystem services by watersheds, and prior-
itizing their management by articulating forest management outcomes as trade-offs in
ecosystem services are essential for the active involvement of individual households in
overall watershed management. Potential changes in the management regime of
woodlots and ecosystems would also be advantageous for the development of resilient
communities that contribute to the mitigation of climate change.
The recent shift from conventional forestry management to ecosystem services has changed peoples’ attitudes regarding the environmental significance of vegetation. Currently, policy makers are concerned with issues related to sustainability and the multifunctional roles of forests in safeguarding people from natural disasters to improving the global climate. We proposed the concept of “ecosystem services” to aid in the management of the much debated Churia and Tarai-Madhesh watersheds of Nepal. Ecosystem services can champion the efforts aimed at alternative management and policy options that are available for upstream and downstream communities by helping leaders base their decisions on evidence regarding the cause of ecosystem change and the consequences it brings to human well-being. We also discussed how woodlands and forests enhance the cycling of nutrients between the leaf litter and soil, as well as the interception of atmospheric carbon by various parts of plants. We argue that the proposed ecosystem services concept provides a valuable framework for analyzing and acting on the linkages between individual persons to their environments.

References

Acharya KP (2002) Twenty-four years of community forestry in Nepal. Int For Rev 4:149–156
Acharya AK, Kafle N (2009) Land degradation issues in Nepal and its management through agroforestry. J Agric Environ 10(1):115–123
Adhikari S (2016) Growing money from carbon. Kathmandu. http://communityredd.net. Accessed 16 Feb 2016
Agrawal A, Angelsen A (2009) Using community forest management to achieve REDD+ goals. In: Angelsen A, Brockhaus M (eds) Realising REDD+: national strategy and policy options. CIFOR, Bogor
Ajtay GL, Ketner P, Duvigneau P (1979) Terrestrial primary production and phytomass. In: Bolin B, Degens ET, Kempe S, Ketner P (eds) The global carbon cycle. Wiley, Chichester
Amatya SM, Shrestha KR (2010) Nepal forestry handbook. Nepal Foresters’ Association, Kathmandu
Angelsen A, Brockhaus M, Sunderlin WD, Verchot LV (2012) Analysing REDD+: challenges and choices. CIFOR, Bogor
Anonymous (2004) Forest carbon sequestration. CATALYST, the magazine of the union of concerned scientist 3:1–4
ANSAB/ICIMOD/FECOFUN (2013) Design and setting up of a governance and payment system for Nepal’s community forest management under reduced emission from deforestation and degradation (REDD), Project report: ANSAB/ICIMOD/FECOFUN. Kathmandu.
Aryal K, Berg A, Ogle B (2009) Uncultivated plants and livelihood support–a case study from the Chepang people of Nepal. Ethnobot Res Appl 7:409–422
Aryal K, Kotru R, Phuntsho K (2013) Unlocking uncultivated food for mountain livelihood: case from Hindu Kush Himalayas. J Agric Environ 14:160–170
Awasthi KD, Sitaula BK, Singh BR, Bajracharya RM (2002) Land use changes and morphometric analysis using GIS for two mountain watersheds of western Nepal. Land Degrad Dev 13:1–19
Baccini A, Walker W, Carvalho L, Farina M, Sulla-Menashe D, Houghton RA (2017) Tropical forests are a net carbon source based on aboveground measurements of gain and loss. Science. 28 Sep 2017. https://doi.org/10.1126/science.aam5962. https://science.sciencemag.org/content/early/2017/09/27/science.aam5962?versioned=true. Accessed 20 Jan 2019
Baker TR, Phillips OL, Malhi Y, Almeida S, Arroyo L, Di Fiore A, Erwin T, Killeen TJ, Laurance SG, Laurance WF (2004) Variation in wood density determines spatial patterns in Amazonian forest biomass. Glob Change Biol 10:545–562
Bampton JFR, Ebregt A, Bangade MR (2007) Collaborative forest management in Nepal’s Terai: policy, practice and contestation. J For Livelihood 6:30–43
Baral S, Malla R, Ranabhat S (2009) Above-ground carbon stock assessment in different forest types of Nepal. Banko Janakari 19:10–14

Bardgett RD, Wardle DA (2010) Above ground-belowground linkages: biotic interactions, ecosystem processes, and global change. Oxford series in ecology and evolution. Oxford University Press, Oxford, UK

Bartlett AG (1992) A review of community forestry advances in Nepal. Commonw For Rev 71(2):95–100

Bhatt BP, Tomar JMS (2002) Firewood properties of some Indian mountain tree and shrub species. Biomass Bioenergy 23:257–260

Bhatta B, Karna AL, Dev OP, Springate-Baginski O (eds) (2007) Participatory forest management in the Nepalese Tarai: policy, practice and impacts. Earthscan, Sterling

Bhattarai KR, Vetaas OR (2003) Variation in plant species richness of different life forms along a subtropical elevation gradient in the Himalayas, East Nepal. Glob Ecol Biogeogr 12(4):327–340

Bhattarai K, Conway D, Shrestha NR (2002) The vacillating evolution of forestry policy in Nepal: historically manipulated, internally mismanaged. Int Dev Plan Rev 24(3):315–338. https://doi.org/10.3828/idpr.24.3.5

Bhattarai K, Conway D, Youssef M (2009) Determinants of deforestation in Nepal’s central development region. J Environ Manag 91(2) November-December:471–488. https://doi.org/10.1016/j.jenvman.2009.09.016

Blaikie P, Greife A, Naraharisetty SCS (2020) Influence of topography on sustainable land management: an analysis of socioeconomic and Ecodemographic conditions of Nepal. Agriculture 2020 10:224. https://doi.org/10.3390/agriculture10060224www.mdpi.com/journal/agriculture

Bisgrove R, Hadley P (2002) Gardening in the global greenhouse: the impacts of climate change on gardens in the UK. UKCIP, Oxford

BJ (2016) Banko Janakari. J For Inf Nepal 26(1). http://www.dfrs.gov.np . Accessed 9 June 2016

Blaikie P, Brookfield H (1987) Land degradation and society. Routledge Kegan & Paul, New York

Blaikie PM, Muldavin JSS (2004) Upstream, downstream, China, India: the politics of environment in the Himalayan region. Ann Assoc Am Geogr 94(3):520–548. https://doi.org/10.1111/j.1467-8306.2004.00412.x

Brack, D. 2019. Forest and Climate Change. Background study prepared for the fourteenth session of the United Nations Forum on Forests. March 2019. Accessed 05 Jan 2020. https://www.un.org/esa/forests/wp-content/uploads/2019/03/UNFF14-BkgdStudy-SDG13-March2019.pdf

Brown S, Olsson L (2011) The political ecology of land degradation. Ann Rev Environ Resourc. Nov. 2011

Brown K, Pearce D (1994) The economic value of non market benefits of tropical forests; carbon storage. In: Weiss J (ed) The economics of project appraisal and the environment. New horizons in environmental economics. Edward Elgar, Aldershot Publishing, Cheltenham

Brown S, Sathaye J, Cannell M, Kauppi PE (1996) Mitigation of carbon emissions to the atmosphere by forest management. Commonw For Rev 75(1):80–91

Burgess ND, Bahane B, Clairs T, Danielsen F, Dalsgaard S, Funder M, Hagelberg N, Harrison P, Haule C, Kabalimu K, Kilahama F, Kilawe E, Lewis SL, Lovett JC, Lyattu G, Marshall AR, Meshack C, Miles L, Milledge SAH, Munishi PKT, Nashanda E, Shirima D, Swetnam RD, Willcock S, Williams A, Zahabu E (2010) Getting ready for REDD plus in Tanzania: a case study of progress and challenges. Oryx 44:339–351

Busch J, Strassburg B, Cattaneo A, Lubowski RN, Boltz F, Ashton R, Bruner A, Creed A, Obersteiner M, Rice R (2009) Collaborative modeling initiative on REDD economics. IOP Conf Ser Earth Environ Sci 6(25):252019

Caplow S, Jagger P, Lawlor K, Sills E (2011) Evaluating land use and livelihood impacts of early forest carbon projects: lessons for learning about REDD+. Environ Sci Pol 14:152–167

Carpenter C (2005) The environmental control of plant species density on a Himalayan elevation gradient. J Biogeogr 32(6):999–1018
References

Carson R (1962/2011) Silent Spring. Houghton Mifflin Harcourt, Boston/New York
Cescatti A (2016) An ecologist at the European Commission’s Joint Research Centre in Ispra, Italy
Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D (2005) Tree allometry and improved estimation of carbon stocks. Oecologia 145(1):87–99
Ciais P, Reichstein M, Viovy N, Granier A, Oge J, Allard V, Aubinet M, Buchmann N, Bernhofer C, Carrara A, Chevallier F, De Noblet N, Friend A, Friedlingstein A, Grünwald P, Heinesch B, Keronen P, Knolh A, Krinner A, Loustau D, Manca G, Matteucci G, Miglietta F, Ourcival J, Papale D, Pilegaard K, Rambal S, Seufert G, Soussan J, Sanz E, Schulze E, Vesala T, Valentini R (2003) Europe-wide reduction in primary productivity caused by the heat and drought in 2003. Nature 437(22)
Colwell RK, Rahbek C, Gotelli NJ (2004) The mid-domain effect and species richness patterns: what have we learned so far? Am Nat 163(3):E1–E23
Cong R-G, Smitha HG, Olsson O, Bradya M (2014) Managing ecosystem services for agriculture: will landscape-scale management pay? Ecol Econ 99:53–62
Constitution of Nepal (2015) September 20, 2015. Constitutional Assembly Secretariat, Singh Durbar, Kathmandu, Nepal
Costanza R et al (12 authors) (1997) The value of the world’s ecosystem services and natural capital. Nature 387:253–260
Crowther T (2015) The scale of human impact is astonishing. An ecologist now at the Netherlands Institute of Ecology in Wageningen who led the study while at Yale University in New Haven, Connecticut
Daily G (1997) Nature’s services: societal dependence on natural ecosystems. Island Press, Washington, DC
Dangi R (2012) REDD+: issues and challenges from a Nepalese perspective. In: Devkota DC, Upret BK, Bhattarai TN (eds) Climate change and UNFCC negotiation process. MoEST Publications, Kathmandu
Danovaro R, Gambi C, Dell’ Anno A, Corinaldesi C, Fraschetti S, Vanreusel A, Vinck M, Goody AJ (2008) Exponential decline of deep-sea ecosystem functioning linked to benthic biodiversity loss. Curr Biol 18(1):1–8
De Groot RS (1987) Environmental functions as a unifying concept for ecology and economics. Environmentalist 7(2):105–109
DFRS (1999) Forest Resources of Nepal (1987–1998). Department of Forest Research and Survey (DFRS), Kathmandu, Nepal
DFRS (2015) State of Nepal’s Forests. Forest Resource Assessment (FRA) Nepal. Department of Forest Research and Survey (DFRS), Kathmandu
Dhiaulhaq A (2011) How will climate change influence plant productivity and the carbon cycle? Dhiaulhaq Review: On Climate change, sustainability and environment. https://dhiaulhaqreview.wordpress.com/2011/09/27/how-will-climate-change-influence-plant-productivity-and-the-carbon-cycle/. Accessed 18 June 2016
Dixit KM (2014) Rescue of the Chure: thirty-four million years of geological heritage is being destroyed in a bout of rapaciousness, MyRepublica. http://www.ekantipur.com/2014/06/20/opinion/rescue-of-the-chure/391083.html. Posted on: 2014-06-20 10:43. Accessed 29 June 2014
DNWLC (2014) Department of national park and wildlife conservation. Ministry of Forest and Soil Conservation, Government of Nepal, Kathmandu
DOF (2015) Status of Community Forest Users’ Groups. Department of Forests (DoF), Kathmandu. http://dof.gov.np/dof_community_forest_division/community_forestry_dof. Accessed 2 Feb 2016
DoF (2016) Department of Forest. Government of Nepal. Kathmandu, Nepal. Ministry of Forest and Soil Conservation
DoFRS (2014) Tarai forests of Nepal. forests resource assessment Nepal project. Department of Forest Research and Survey, Babarmahal/Kathmandu
DOR (2010) Statistics of strategic road networks (2009/10). Department of Roads (DOR), Kathmandu
Dugan S (1993) Reflections on helping: sustainable development, capacity building and participation. Int J Public Adm 16(11):1705–1713. https://doi.org/10.1080/01900699308524869
Eckholm EP (1976) Losing ground: environmental stress and world food prospects. W. W. Norton, New York, p 223
Egoh B, Reyers B, Rouget M, Richardson DM, Le Maître DC, van Jaarsveld AS (2008) Mapping ecosystem services for planning and management. Agric Ecosyst Environ 127:135–140
Egoh BN, Reyers B, Rouget M, Richardson DM (2011) Identifying priority areas for ecosystem service management in South African grasslands. J Environ Manag 92:1642–1650
Ehrenberg R (2015) Global count reaches 3 trillion trees: approach combines ground-based surveys with satellite imaging to find higher density than anticipated. Nature 02 September 2015. https://doi.org/10.1038/nature.2015.18287
Ehrlich PR, Ehrlich AH (1981) Extinction: the causes and consequences of the disappearance of species, 1st edn. Random House, New York
Ehrlich PR, Mooney HA (1983) Extinction, substitution, and ecosystem services. Bioscience 33:248–254
FAO et al (2008) REDD+ reducing emissions from deforestation and forest degradation. http://www.fao.org/redd/en/
FECOFUN (2020) Federation of Community Forestry Users, Nepal. http://www.fecofun.org.np/introduction.php. Accessed 10 Feb 2020
Folke C, Hammer M, Jansson AM (1991) Life support value of ecosystems: a case study of the Baltic region. Ecol Econ 3(2):123–137
Folke C, Carpenter S, Walker B, Scheffer M, Elmqvist T, Gunderson L, Holling CS (2004) Regime shifts, resilience, and biodiversity in ecosystem management. Annu Rev Ecol Evol Syst 35:557–581
Forestry Nepal (1993) Forestry act. Retrieved from http://www.forestrynepal.org/publications
Forestry Nepal (1995) Forestry regulation. Retrieved from http://www.forestrynepal.org/publications
FRA (Forest Resource Assessment) (2000, 2013, 2014) Standard guidelines for forest cover and forest types mapping. Department of forest Research and Survey, Ministry of Forest and Soil Conservation, Government of Nepal.
FRA (Forest Resource Assessment). 2013, 2014. Standard guidelines for Forest cover and Forest types mapping. Department of forest Research and Survey, Ministry of Forest and Soil Conservation, Government of Nepal
Freitas SR, Hawbaker TJ, Metgen JP (2010) Effects of roads, topography, and land use on forest cover dynamics in the Brazilian Atlantic Forest. For Ecol Manag 259(3):410–417
Garnaut R (2008) The Garnaut climate change review: the final report. Cambridge University Press, Port Melbourne
Gassman PW, Reyes MR, Green CH, Arnold JG (2007) The soil and water assessment tool: historical development applications and future research directions. Transaction of the American Society of Agricultural and Biological Engineers., ISSN 0001-2351 50(4):1211–1250
Gautam KR (2002) Carbon sequestration in agroforestry and annual cropping system in inner Terai, Central Nepal. M.Sc. thesis. Agricultural University of Norway, Aas, Norway
Gautam A, Shivakoti G, Webb E (2004) A review of forest policies, institutions, and changes in the resource condition in Nepal. Int For Rev 6(2):136–148. https://doi.org/10.1505/ifor.2004.6.issue-2
Geneletti D (2003) Biodiversity Impact Assessment of roads: an approach based on ecosystem rarity. Environ Impact Assess Rev 23(2003):343–365
Ghimire BK, Mainali KP, Chadhary RP, Ghimeray AK (2010) Regeneration of Pinus wallichiana AB Jackson in a trans-Himalayan dry valley of north-central Nepal Himal. J Sci 6:19–26
Gilmour DA, Fisher RJ (1991) Villagers, forests, and foresters: the philosophy, process, and practice of community forestry in Nepal. Sahayogi Press, Kathmandu
Grace J, Zhang R (2006) Predicting the effect of climate change on global plant productivity and the carbon cycle. In: Morison JIL, Morecroft MD (eds) Plant growth and climate change. Blackwell, Oxford
Guisan A, Zimmermann NE (2000) Predictive habitat distribution models in ecology. Ecol Model 135(2–3):147–186
Gutman P, Aguilar-Amuchastegui N (2012) Reference levels and payments for REDD+ lessons from the recent Guyana Norway agreement, Technical report. World Wildlife Fund (WWF), Washington, DC
Gyawali K (2012) Pers. Com. Secretary of the Ministry of Environment, Government of Nepal, Kathmandu
Hagen R (2014) Lessons Learned From Community Forestry and Their Relevance for REDD+. USAID-supported Forest Carbon, Markets and Communities (FCMC) Program, Washington, DC.

Hamburg SP (2000) Simple rules for measuring changes in ecosystem carbon in forestry offset projects. Mitig Adapt Strateg Glob Chang 5(1):25–37

Hall CAS, Stanford JA, Hauer R (1992) The distribution and abundance of organisms as consequence of energy balances along multiple environmental gradients. Oikos 65:377–390

Hanson PJ, Wetzin JF (2000) Drought disturbance from climate change: response of United States forests. Sci Total Environ 262:205–220

Hawkins B, Sharrock S, Havens K (2008) Plants and climate change: which future? Botanic Gardens Conservation International, Richmond

HMG (1976) His Majesty’s Government of Nepal

Hobley M, Malla YB (1996) From the forests to forestry- the three ages of forestry in Nepal: privatization, nationalization, and populism. In: Hobley M (ed) Participatory forestry: the process of change in India and Nepal. ODI, London, pp 65–82

Hof G, Wagner HH, Herzog F, Edwards PJ (2008) Effects of topographic variability on the scaling of plant species richness in gradient dominated landscapes. Ecography 31:131–139

Hol WHG et al (2010) Reduction of rare soil microbes modifies plant-herbivore interactions. Ecol Lett 13:292–301

Holland PG, Steyn DG (1975) Vegetation responses to latitudinal variations in slope angle and aspect. J Biogeogr 2:179–183

Houghton J (2004) Global warming: the complete briefing. Cambridge University Press, Cambridge, UK

Houghton R (2016) An ecologist at the Woods Hole Research Center in Falmouth, Massachusetts. Quoted in Nature, February 04, 2016

Houghton R, Skole D, Nobre CA, Hackler J, Lawrence K, Chomentowski WH (2000) Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. Nature 403:301–304

Hueting R (1980) New scarcity and economic growth: more welfare through less production? North Holland Publication Co, Amsterdam/New York, Oxford

ICIMOD (2011) Operating guidelines of Forest Carbon Trust Fund 2011. ICIMOD, Kathmandu

ICIMOD, ANSAB, FECOFUN (2011) Operating Guidelines of Forest Carbon Trust Fund 2011. ICIMOD, Kathmandu

IPCC (2000) The intergovernmental panel on climate change, special report on land use, land-use change and forestry. Cambridge University Press, Cambridge, UK

IPCC (2006) Good practice guidelines for national greenhouse gas inventories. Intergovernmental Panel on Climate Change, Geneva

IPCC (2007) Climate change 2007: the physical science basis – summary for policymakers. Intergovernmental Panel on Climate Change, Geneva

IPCC (2014) Climate Change 2014 Synthesis Report: Summary for Policymakers

Ives JD (2011) Environmental changes and challenge in the Himalaya: a historic perspective. Pirineos Revista de Ecologia de Montaña 167:29–68. https://doi.org/10.3989/Pirineos.2012.167003

Ives AR, Carpenter SR (2007) Stability and diversity of ecosystems. Science 317:58–62

Ives JD, Ives P (eds) (1987) The Himalaya-Ganges problem. Proceedings of the Mohonk Mountain conference. Mt Res Dev 7(3):181–344

Ives JD, Messerli B (1989) The Himalayan dilemma: reconciling development and conservation. Routledge, London and New York, p 295

Jackson J (1994) Manual of afforestation in Nepal, 2nd edn. Forest Research and Survey Centre, Kathmandu

Jain RK, Singh B (1999) Fuelwood characteristics of selected indigenous tree species from Central India. Bioresour Technol 68:305–308

Jina BS, Sah P, Bhatt MD, Rawat YS (2008) Estimating carbon sequestration rates and total carbon stockpile in degraded and non-degraded sites of Oak and Pine forest of Kumaun Central Himalaya. Ecological Society, Nepal Ecolprint 15:75–81

Joshi AL (1993) Effects on administration of changed forest policies in Nepal. In: Proceedings of a Workshop on Policy and Legislation in Community Forestry, January 27–29, 1993. Bangkok, RECOFTC
Joshi NM, Maharjan KL (2007) Institutional changes in forest resource management and change in forest coverage in Nepal. J Int Dev Coop 13(1):231
Kanel KR (n.d.) Current status of community forestry in Nepal. A report submitted to Regional Community Forestry Training Center for Asia and the Pacific Bangkok, Thailand
Kanel KR, Poudyal RP, Baral JC (2005) Current status of community forestry in Nepal. Regional Community Forestry Training Center for Asia and the, Pacific Bangkok
Karky BS, Skutsch M (2010) The cost of carbon abatement through community forest management in Nepal Himalaya. Ecol Eon 69:666–672
Katari R, Konwer D (2002) Fuelwood characteristics of indigenous tree species of north-east India. Biomass Bioenergy 22:433–437
KC JK, Gautam AP (2016) Impact of roads on biodiversity: a case study from Karekhola rural road in Surkhet district of Nepal. Banko Janakari 26(1)
Keenan RJ (2015) Climate change impacts and adaptation in forest management: a review. Ann Forest Sci 72:145–167
Kehlenbeck H, Schrader G (2007) Climate Change, Happy future for plant pests? In Secretariat of the Convention on Biological Diversity (Ed.). Emerging issues for biodiversity conservation in a changing climate. Technical series no. 29. CBD, Montreal
Khanal S, Poudel BS, Mathema P, Pokharel YP, Kharal DK (2016) Comparison of forest cover mapping results of two successive forest resource assessments of Nepal. Banko Janakari 26(1)
Kinzig AP, Pacala SW, Tilman D (eds) (2001) The functional consequences of biodiversity. Empirical progress and theoretical extensions. Princeton University Press, Princeton/Oxford
Klein RJ, Schipper ELF, Dessai S (2005) Integrating mitigation and adaptation into climate and development policy: three research questions. Environ Sci Pol 8:579–588
Körner C (2007) The use of “altitude” in ecological research. Trends Ecol Evol 22:569–574
Krutilla J, Fisher AC (1975) The economics of natural environments: resources for future. Johns Hopkins University Press, Washington, DC
Kulshrestha SN, Lac S, Johnston M, Kinar C (2000) Carbon sequestration in protected areas of Canada: an economic valuation. Economic Framework Project Report 549. December 2000. Canadian Parks Council, Parks
Kumar P (ed) (2010) The economics of ecosystems and biodiversity: ecological and economic foundations. Earthscan Publishing for a Sustainable Future, London/Washington, DC
Largent M (1999) Bionomics: Vernon Lyman Kellogg and the Defense of Darwinism. J Hist Biol 32(3):465–488
Lawton J (1997) The science and non-science of conservation biology. Oikos 79(1):3–5
Leopold A (1949/1989) A Sandy County Almanac and Sketches Here and There. Oxford University Press, Oxford
Leroy C, Carrias JF, Corbara B, Pélozuelo L, Dézerald O, Brouard O ... Céréghino R (2013) Mutualistic ants contribute to tank-bromeliad nutrition. Ann Bot 112(5):919–926. https://doi.org/10.1093/aob/mct147
Lewis SL, Malhi Y, Philips OL (2005) Predicting the impacts of global environmental changes on tropical forests. In: Malhi Y, Philips OL (eds) Tropical forests and global atmospheric change. Oxford University Press, Oxford
Li Y, Xie D, Wang S (2006) Impact of land cover types on the soil characteristics in karst area of Chongqing. J Geogr Sci 16(2):143–154
Lloyd J, Farquhar GD (1996) The CO₂ dependence of photosynthesis, plant growth responses to elevated atmospheric CO₂ concentrations, and their interaction with soil nutrient status. I. General principles and forest ecosystems. Funct Ecol 10:4–32
Lomolino MV (2001) Elevation gradients of species-density: historical and prospective views. Glob Ecol Biogeogr 10:3–13
Losey JE, Vaughan M (2006) The economic value of ecological services provided by insects. Bioscience 56:331–323
LRMP (1986) Land Resource Mapping Project, Survey Department, HMGN and Kenting Earth Sciences, Kathmandu, Nepal
Luck GW, Harrington R, Harrison PA, Kremen C, Berry PM, Bugter R et al (2009) Quantifying the contribution of organisms to the provision of ecosystem services. Bioscience 59:223–235
References

Lugo AE, Gucinski H (2000) Function, effects, and Management of Forest Roads. August 2000. For Ecol Manag 133(3):249–262. https://doi.org/10.1016/S0378-1127(99)00237-6

Lund JF, Balooni K, Casse T (2009) Change we can believe in?. Reviewing studies on the conserv

MacDicken KG (1997) A guide to monitoring carbon storage in forestry and agroforestry projects. Forest Carbon Monitoring Programme, Winrock International Institute for Agricultural Development, Litterock

Maitima JM, Mugatha SM, Redi SR, Gachimbi LN, Majule A, Lyaruu H, Pomery D, Mathai S, Mugisha S (2009) The linkages between land use changes, land degradation and biodiversity across East Africa. Afr J Environ Sci Technol 3(10):310–325

Malhi Y (2015) A forest ecologist at the University of Oxford, UK.

Malhi Y, Meir P, Brown S (2002) Forests, carbon and global climate. Phil Trans R Soc Lond A 360:1567–1591

Malla Y (2001) Changing policies and the persistence of patron-client relations in Nepal: stakeholders’ responses to changes in forest policies. Environ Hist 6:287–307. https://doi.org/10.2307/3985088

Mallapaty S (2016) Nepal assesses forests for maximum carbon credits. SciDevNet: Bringing Science and Development together through news and analysis. https://www.scidev.net/south-asia/forestry/news/nepal-forests-carbon-credits.html. Accessed 24 Apr 2019

Maren IG, Karki S, Prajapati C, Yadav RK, Shreshta BB (2015) Facing north or south: does slope aspect impact forest stand characteristics and soil properties in a semiarid trans Himalayan valley. J Arid Environ 121:112–123

Marsh GF (1874) The earth as modified by human action. Arno, New York

McCain CM, Grytnes JA (2010) Elevation gradients in species richness. Wiley, Chichester

McGuire AD, Joyce LA (2005) Responses of net primary production to changes in CO2 and climate. In: Joyce LA (ed) Productivity of America’s forest and climate change. US Department of Agriculture (USDA), Washington, DC

Melillo JM, Callaghan TV, Woodward FI, Salati E, Sinha SK (1990) Effects on ecosystems. In: Tea Houghton J (ed) Climate change: the IPCC scientific assessment. Cambridge University Press, Cambridge, pp 283–310

Melillo JM, McGuire AD, Kicklighter DW, Moore BIII, Vorosmarty CJ, Schloss AL (1993) Global climate change and terrestrial net primary production. Nature 363:234–240

MFSC (2014) Ministry of Forest and Soil Conservation. Government of Nepal

MoFSC (2011) Study on REDD plus piloting in Nepal. Ministry of Forests and Soil Conservation, Kathmandu

MoFSC (2014), National Biodiversity Strategy and Action Plan. Ministry of Forests and Soil Conservation (MFSC), Kathmandu, Nepal, 20–28

MoFSC (2016) Ministry of Forest and Soil Conservation. Government of Nepal

Mokany K, Raison R, Prokushkin AS (2006) Critical analysis of root: shoot ratios in terrestrial biomes. Glob Chang Biol 12:84–96

MPFS (1988) Master Plan for Forestry Sector Nepal (Appendix Table 2.2 Forest Types, Representative Species, Uses and Wood Density). Ministry of forest and soil conservation, Government of Nepal

MPFS (1989) Analysis of policies and legislation. Master Plan for Forestry Sector. His Majesty's Government of Nepal

Mugnier JL, Leturmy P, Mascle G, Huyghe P, Chalaron E, Vidal G, Husson L, Delcaillau B (1999) The Siwaliks of western Nepal I. Geometry and kinematics. J Asian Earth Sci 17:629–642

Naudts K (2016) A postdoctoral ecologist at the Max Planck Institute for Meteorology in Hamburg, Germany. A team of scientists at the Laboratory of Climate Science and Environment in Gif-sur-Yvette

Negi JDS, Manhas RK, Chauhan PS (2003) Carbon allocation in different components of some tree species of India: a new approach for carbon estimation. Curr Sci 85(11):1528–1531

Nemani RR, Keeling CD, Hashimoto H, Jolly WM, Piper SC, Tucker CJ, Myneni RB, Running SW (2003) Climate-driven increases in global terrestrial net primary production from 1982 to 1999. Science 300(5625):1560–1563

Nepal S (2006) A comparative study on carbon sequestration from two forest types in community forestry system (A case study from coniferous and broad-leaved forests in Palpa District). B.Sc. thesis, Tribhuvan University, Institute of Forestry, Nepal
Newton P, Nichols ES, Endo W, Peres CA (2012) Consequences of actor level livelihood heterogeneity for additionality in a tropical forest payment for environmental services programme with an undifferentiated reward structure. Glob Environ Chang 22:127–136

Newton P, Schaap B, Fournier M, Cornwall M, Rosenbach DW, DeBoer J, Whittemore J, Stock R, Yoders M, Brodnic G, Agrawal A (2015) Community forest management and REDD+. Forest Policy Econ 56:27–37

Ngugi MR, Johnson RW, McDonald WJF (2011) Restoration of ecosystems for biodiversity and carbon sequestration: simulating growth dynamics of brigalow vegetation communities in Australia. Ecol Model 222:785–794

Nichols S (1982) Fragile Mountain: A film by Sandra Nichols. First published: December 1984. https://doi.org/10.1525/aa.1984.86.4.02a00840. https://anthrosource.onlinelibrary.wiley.com/doi/10.1525/aa.1984.86.4.02a00840

Nightingale AJ (2003) A feminist in the forest: situated knowledges and mixing methods in natural resource management

Nightingale A (2005) The expert taught us all we know’: professionalization and knowledge in Nepalese community forestry. Antipode 37(3):581–604

Oberholzen E, Fonzen PF (1984) Use of multipurpose trees in hill farming systems in Western Nepal. Agrofor Syst 2:187–197

Odum (1968) Energy flow in ecosystems: a historic review. In: American zoologist, vol 8. Oxford University Press, pp 11–18

Odum EP (1989) Ecology and our endangered life-support systems. Sinauer Assoc., North Scituate

Oli BN (2009) Carbon status in forests of Nepal: an overview. Forests Trees and Livelihoods 8 (1):62–66. June 2009. https://www.researchgate.net/publication/283986436_Carbon_status_in_forests_of_Nepal_an_overview. Accessed April 24, 2019

Pandey HP, Bhusal M (2016) A comparative study on carbon stock in Sal (Shorea robusta) forest in two different ecological regions of Nepal. Banko Janakari 26(1):24–31

Pandey SS, Maraseni TN, Cockfield G (2014a) Carbon stock dynamics in different vegetation dominated community forests under REDD+: a case from Nepal. For Ecol Manag 327:40–47

Pandey SS, Cockfield G, Maraseni TN (2014b) Dynamics of carbon and biodiversity under REDD+ regime: a case from Nepal. Environ Sci Pol 38:272–281

Pandey SS, Cockfield G, Maraseni TN (2016) Assessing the roles of community forestry in climate change mitigation and adaptation: a case study from Nepal. For Ecol Manag 360 (2016):400–407

Paudel D (2012) In search of alternatives: pro-poor entrepreneurship in community forestry. J Dev Stud 48(11):1649–1664

Paudel D (2016a) Re-inventing the commons: community forestry as accumulation without dispossession in Nepal. J Peasant Stud 2016. https://doi.org/10.1080/03066150.2015.1130700

Paudel D (2016b) Re-inventing the commons: community forestry as accumulation without dispossession in Nepal. J Peasant Stud. To link to this article: https://doi.org/10.1080/03066150.2015.1130700

Paudel S, Vetaas OR (2014) Effects of topography and land use on woody plant species composition and beta diversity in an arid trans-Himalayan landscape, Nepal. J Mt Sci 11(5):1112–1122

Pearson TR, Brown S, Ravindranath NH (2005) Integrating carbon benefit estimates into GEF projects: guidelines. Capacity development and adaptation group. Global Environment Facility, United Nations Development Programme, New York

Phelps J, Webb EL, Agrawal A (2010) Does REDD+ threaten to recentralize forest governance? Science 328:312–313

Philips OL, Aragão L, Lewis SL, Fisher JB, Lloyd J, Gonzales GL, Malhi Y, Monteagudo A, Peacock J, Quesada CA, Heijden G (2009) Drought sensitivity of the Amazon rainforest. Science 323(5919):1344–1347

Popkin G (2019) How much can forests fight climate change? Nature (News Feature). https://www.nature.com/articles/d41586-019-00122-2. Accessed Jan 15 2019

Puliti S (2012) Analyses of the Feasibility of Participatory REDD+ MRV Approaches to Lidar RECOFTC, IIED, REDD-NET (2011) REDD+, governance, and community forestry: highlights from the Forest Governance Learning Group Asia Experts’ Meeting. RECOFTC, IIED, REDD-Net, Bangkok
Regmi MC (1976) Landownership in Nepal. University of California Press, Los Angeles
Ribot JC, Agrawal A, Larson AM (2006) Recentralizing while decentralizing: how national
governments reappropriate forest resources. World Dev 34:1864–1886
Rio Earth Summit (1992) Earth Summit in Rio de Janeiro. Environmental and Society Portal. http://www.environmentandsociety.org/tools/keywords/earth-summit-rio-de-janeiro. Accessed 15 Dec 2015
Sandbrook C, Nelson F, Adams WM, Agrawal A (2010) Carbon, forests and the REDD paradox. Oryx 44(03):330–334
Sanders NJ, Rahbek C (2012) The patterns and causes of elevation diversity gradients. Ecography 35(1):1–3
Schneiders A, Daele TV, Landuyt WV, Reeth WV (2012) Biodiversity and ecosystem services:
complementary approaches for ecosystem management. Ecol Indic 21:123–133
Seiler A (2001) Ecological effects of roads: a review. Introductory research essay no. 9. Department
of Conservation Biology, Swedish University of Agricultural Science, Upsalla
Sharma S, Bajracharya RM, Sitaula BK, Merz J (2005) Water quality in the Central Himalaya:
review articles. Curr Sci 89(5). September
Shrestha NR (1990) Landlessness and migration in Nepal. Westview Press, Boulder
Shrestha BP, Devkota BP (2016) Carbon stocks in the oak and pine forests in Salyan district, Nepal.
Banko Janakari 23(2)
Shrestha PM, Dhillion SS (2006) Diversity and traditional knowledge concerning wild food species
in a locally managed forest in Nepal. Agrofor Syst 66:55–63
Shrestha BM, Singh BR (2008) Soil and vegetation carbon pools in a mountainous watershed of
Nepal. Nutr Cycl Agroecosyst 81:179–191
Shrestha BM, Sitaula BK, Singh BR, Bajracharya RM (2004) Soil organic carbon stocks in soil
aggregates under different land use systems in Nepal. Nutr Cycling Agroecosyst 70(2):201–213
Shrestha BB, Uprey Y, Jha PK (2006) Wood properties in relation to foliar phenology of some
planted tree species at Kirtipur, Central Nepal. Trop Ecol 47:201–209
Shrestha BM, Williams S, Easter M, Paustian K, Singh BR (2009) Modeling soil organic carbon
stocks and changes in a Nepalese watershed. Agric Ecosyst Environ 132(1–2):91–97. https://doi.org/10.1016/j.agee.2009.03.003
Singh BK, Smith P (2009) An assessment of climate change, forests, and biodiversity in Nepal. [Report
prepared by the United States Agency for International Development. USAID/EGAT/Global
Climate Change Team]. http://pdf.usaid.gov/pdf_docs/pnaeb826.pdf. Accessed 8 June 2016
Sitaula BK, Bajracharya RM, Singh BR, Solberg B (2004) Factors affecting organic carbon
dynamics in soils of Nepal/Himalayan region- a review and analysis. Nutr Cycl Agroecosyst
70:215–229
Skutsch MM, van Laake PE, Zahabu EM, Karky BS, Phartiyal P (2009) Community monitoring in
REDD+. In: Angelsen A, Brockhaus M (eds) Realising REDD+: national strategy and policy
options. CIFOR, Bogor
Springate-Baginski O, Blaikie PM (2007) Forests, people and power: the political ecology of
reform in South Asia. Earthscan, Padstow
Stainton JDA (1972) Forests of Nepal. John Murray, London
Stankey GH, Clark RN, Bormann BT (2005) Adaptive management of natural resources: Theory,
concepts, and management institutions. Gen. Tech. Rep. PNW-GTR-654. U.S. Department of
Agriculture, Forest Service, Pacific Northwest Research Station, Portland, 73p
Stern N (2007) The economics of climate change: the stern review. Cambridge University Press, Cambridge
Stitt M, Krapp A (1999) The interaction between elevated carbon dioxide and nitrogen nutrition: the
physiological and molecular background. Plant Cell Environ 22:583–621
Streck C, O’Sullivan R, Smith T, Tarasofsky R (2008) Climate change and forestry: an introduc-
tion. In: Streck C, O’Sullivan R, Smith T, Tarasofsky R (eds) Climate change and forest:
emerging policy and market opportunities. The Royal Institute of International Affairs, London
Subedi BP (2006) Linking plant-based enterprises and local communities to biodiversity conserv-
vation. Adroit Publishers, New Delhi
Survey Department (2001) Department of Survey, Government of Nepal
